# BESS-SB13

2013 PROCEEDINGS

JUNE 24-25

Hosted by Simpson Gumpertz & Heger + Cal Poly Pomona

EDITED BY PABLO LA ROCHE AND JUDSON TAYLOR

# BUILDING ENCLOSURE SUSTAINABILITY SYMPOSIUM
# SUSTAINABLE BUILDINGS CONFERENCE 2013
# ADVANCING TOWARD NET ZERO

Proceedings of the 3rd Symposium, hosted by Simpson Gumpertz & Heger Inc. and California State Polytechnic University, Pomona.



Edited by Pablo La Roche and Judson Taylor

CAL POLY POMONA

SIMPSON GUMPERTZ & HEGER

Engineering of Structures
and Building Enclosures

**Proceedings Building Enclosure Sustainability Symposium and Sustainable Building Conference 2013. Towards Net Zero.**

**California State Polytechnic University, Pomona – Department of Architecture**
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# PREFACE

The Building Enclosure Sustainability Symposium (BESS) was initiated in 2009 through a partnership of the Department of Architecture at California State Polytechnic University Pomona and Simpson Gumpertz & Heger Inc. The symposium was designed to bring together professionals from academia, architecture, engineering and construction, as well as students, to discuss state-of-the-art sustainable building enclosure design.

In 2013, BESS partnered with the Sustainable Building Conference Series to become BESS-SB13 CALIFORNIA. The Sustainable Building Conference Series is supported by CIB, iiSBE, UNEP-SBCI and FIDIC and includes a series of events all over the world, to discuss different aspects of Sustainable Buildings. The SB conference series, now on a three-year cycle, is recognized as the world's preeminent meeting in this important field. The three-year conference cycle begins with a year of planning in 2012, followed by regional conferences in 2013, and will culminate in an international event in 2014. BESS-SB13 CALIFORNIA is one of the sixteen regional SB conferences; the global conference will be held in the city of Barcelona, Spain, in the Palau de Congressos de Catalunya on 28,29,30 October 2014. The SB14 Conference intends to truly be a critical revision regarding building construction and urban development in the world, and propose best practices that can be disseminated worldwide.

This book of proceedings represents a collection of papers that have been rigorously reviewed by an international panel of leading experts, and will be included in the ICONDA®CIBlibrary, where the full proceedings will be available to all as free downloadable pdf documents and searchable by individual papers. These papers are a compilation of state of the art research and have been organized in the areas of Innovative Design, Improving Existing Building Stock Performance, Building Performance Validation, Affordable Sustainability & Empowering the User, and Education. In addition, the top papers from this conference will be fast-tracked for inclusion at SB14 in Barcelona and the "Informes de la Construccion" award will be given to a paper to be published in this prestigious Spanish journal indexed in the Science Citation Index.

Pablo La Roche and Judson Taylor
Conference Co-Chairs

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Thank you also to all the sponsors for making this symposium possible.
To the paper reviewers from all continents that did a remarkable job and a very special thanks to our Planning Committee, The Sustainable Buildings Conference Series Staff, CalPoly Pomona and all of our Cal Poly Pomona student helpers.

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These events attract researchers, practitioners, stakeholders, policy makers, investors, users… everybody; we are all building users, aren't we?

SB Conferences happen on a three year cycle pattern: a first preparation year to launch the SB Regional Conferences, a second year for these to take place, and the third year devoted to the World SB Conference, which is the conclusion of the SB Regional Conferences, and the starting point of the following cycle.

On this occasion, the SB Regional Conferences will take place in year 2013, and the World Conference will happen in year 2014, in Barcelona."

And on describing World SB14 Barcelona:

"In this severe economic, financial, energetic, and environmental crisis situation, a historic cycle shift appears as indispensable. And, in front of this necessity, the question is: are we adapting buildings and cities to the new reality and new challenges at the necessary pace?

The SB14BCN Conference intends to truly be a critical revision of the many country/regional situations regarding building construction and urban development in the world, so that best practices can be widespread and other integrative, collaborative global level proposals can arise.

There are three common challenges that affect building construction in a variety of manners in the different parts of the world:

- The world's population need for decent housing
- Satisfying that need in very different socio-economic conditions in several countries and regions in the world
- Reduction of the ecological footprint and impact associated to building

These challenges are global but have a peculiar reality throughout the regions of the world, in response to the actual local needs of housing and its future evolution, the ecological footprint generated by the development circumstances, and the role played by the building sector in the regional economy. Different situations will generate different models, with specificities and similarities. Presenting, sharing, discussing them, and generating common visions and solutions is the objective of the process that leads to World SB14 Barcelona. Presenting, sharing, discussing global challenges, and generating common visions and solutions is the objective of the process that leads to World SB14 Barcelona.

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# SECTION 1

## INNOVATIVE DESIGN

# Climate Response for the Tropics:

## Three houses as guidelines for contemporary design in San Juan, PR

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*ABSTRACT: The island of Puerto Rico is located in the Caribbean at 18°15"N and 66°30"W within the Tropic of Cancer. It enjoys a stable climate with an average climate of 27°C (80°F) throughout the year. Although it also benefits of cool breezes from the Atlantic Ocean, most of the structures are not designed considering the climate. To better understand the behavior of structures on the Island, three houses from three architectural periods were selected: Spanish Colonial, Turn-of-the-Century, and Tropical Modern. The natural lighting conditions, thermal properties and natural ventilation of these residences were analyzed with the aid of Ecotect and Fluent. Once the results for each of the structures was analyzed and compared, a set of design guidelines were produced, based on the individual results, to aid in the design of climate-conscious structures in San Juan, Puerto Rico.*

*Keywords: design, natural ventilation, tropics*

### 1. INTRODUCTION

Although Puerto Rico's architecture has been influenced by various cultures throughout its development, few scientific studies have been conducted on the structures, technologies, and their efficiency. Most of the Islands contemporary architecture is not climatically responsive, forcing users to invest in alternate cooling methods. This research intends to provide a better insight into the historical constructions in Puerto Rico, and provide architectural solutions to show how contemporary structures could be adapted to make them more climatically conscious. Ideally, this research will promote interest on the Island to create better designed structures that deal with the local climate using traditional methods and construction with a new perspective.

*How can the traditional design solutions, including natural ventilation and materials, be adapted for contemporary use? Which of the selected houses has the best climatic performance?* The answer to these questions should provide a better understanding of the design approaches that will be necessary to create climate conscious buildings in Puerto Rico.

The results obtained from this research have the possibility to affect the way architecture is perceived in Puerto Rico. The insight provided could clear speculations on building design efficiency and material performance. Additionally, the results could pose new questions and provide an impulse into further researches on the Island. On the long run, this investigation can lead to new design approaches in construction in Puerto Rico by using local materials to help control the energy demands of the homes. When the results and guidelines are used by willing architects, the ensuing designs could even prove to have a lower cost than current housing, making it affordable to a wider range of families.

### 2. SCOPE AND PARAMETERS

Before the subject of architecture in Puerto Rico can be approached, there are certain terms and parameters that must be clarified. Vernacular architecture is that which is shaped and improved upon by the users throughout generations. (Carimos, 2000) In contrast, traditional architecture is that which is planned and emulated through a period of time. It contains elements that are part of an aesthetic-oriented interpretation rather than a functional one. [i]Vernacular architecture can be transformed into traditional once the designs are interpreted through an aesthetic lens. For this study, three periods representing mainly traditional examples were selected.

The island of Puerto Rico boasts an expansive array of micro climates and geological features that favored some solutions and discarded others. Geographical determinism has provided the Island's inhabitants with a broad spectrum of conditions to which to adapt. From coast lines to mountain ranges; from mangroves to rivers; from rain forests to dry forests, Puerto Rico offered variations and the residents reacted, in the majority of cases, accordingly.

## 3. METHODOLOGY

For this study, three periods representing traditional construction examples were selected. These are the Spanish Colonial[ii] (from the end of the sixteenth century to the end of the nineteenth), Turn-of-the-Century[iii] (from the end of the nineteenth century to the 1930s), and the Tropical Modernism[iv] (from the 1940s to the 1970s). These periods were selected as they marked a clear break from the architecture styles of previous years and introduced new vocabularies. In order to focus the research, representative single-family residences, of one level, located in an urban context and in San Juan, PR were selected. Due to their construction, the structures have a level of permanence that has allowed them to remain relevant in contemporary society. These structures were easily accessible for the on site assessment and photographic documentation.

In order to complete the experimentations within the time restrictions, computers were used to simulate the air flow and environmental conditions. The programs analyzed the use of materials, layout and orientation of the structure. The results were then assessed individually and compared to establish the performance of the houses. The two computer programs selected for the simulations were Ecotect and Fluent. Each one of these programs provides different analysis perspectives that, when compared and studied, provide an overall condition survey. This poses restrictions as the data collected from these computer simulations will be based on average meteorological data and ideal conditions that would be difficult to obtain in real-life scenarios. This leaves, however, the possibility for this research to be carried out further and in more detail in the future.

## 4. ECOTECT

A computer model was created for each of the structures that specified the orientation, climatic conditions and construction materials. Ecotect experiments were run on several aspects of the design solutions for each of the houses analyzed and the results from these experimentations are as follows:

### 4.1. Daylighting Analysis

The most efficient design for optimum daylighting is the Tropical Modern house. The attention to orientation, and the ability of the architect to separate public from private areas using light, separates this design from the others. Care was taken to design an open house where every room was accessible to natural lighting conditions. It is remarkable that by studying the lighting analysis plans the living spaces and the service or support spaces can be clearly differentiated from each other.

### 4.2. Thermal Comfort Analysis

Out of the three structures, the one with the best performance is the Colonial house. The analysis for this structure shows that the temperature close to the interior walls can be as low as 15°C (59°F) making this area the coolest of the examples. It can be argued that due to the great thickness of the walls, 50 cm (20 inches), it has great thermal storage. It can then be concluded that since the interior partition walls never receive direct sunlight they are always maintained at a lower temperature than the surrounding spaces. Additionally, the structure only has three exterior surfaces that are exposed to the sun, the north and south walls and the roof, allowing it to maintain comfortable interior temperatures.

### 4.3. Temperature Distribution

The analysis was performed in three primary zones, the roof, living space and floor. The living space that spends the most amount of time within the comfort zone is that of the Colonial building. For the floor, the Colonial and the Tropical Modern houses spend the same amount of time within the comfort zone, 97%, while the Turn-of-the-Century structure only spends 59.1% of the time. An elevated floor has been commonly considered ideal for hygienic as well as ventilation reasons, but this study suggests that while the elevated floors can provide protection from vermin, it is inefficient to help maintain comfortable temperatures at the floor level.

4.4. Conclusions

Ecotect proves to be a very useful tool for the analysis of buildings, especially under the scope and time constraints involved with this research. Since this investigation focuses mostly on the efficiency of design parameters for natural ventilation, user variables were not taken into consideration. These could be incorporated in future research to gain a better understanding on how the buildings can be adapted and the impact of those adaptations.

The results presented indicate that although at first instance the thermal mass of the Colonial structure could be considered detrimental to the comfort of the house, it seems to be quite the opposite. Although this example is only exposed to the elements on three of its surfaces it is a combination of the height and thickness of the interior walls that act together in conditioning the space and making it comfortable for the most amount of time. As a result of the massive wall construction, the lighting levels in the interior are less than ideal indicating that supplemental lighting would occasionally be needed adding a heating load.

For the Turn-of-the-Century house most of the analysis parameters seem to conclude that this is the poorest design for the climate, although some construction details such as the roof prove to be very efficient in keeping exterior heat gains away from the interior. Historically, courtyards were integrated into the structures and said to help bring fresh cool air into the interior of the homes, but this is proven otherwise by the results obtained in the thermal impact of the courtyard. It is necessary to clarify that these conclusions are based on the interpretation of the results here discussed, but would need further study and research.

Since reinforced concrete is widely used for construction in Puerto Rico, the reactions to the environment of the Tropical Modern house have been studied and experienced by most of the population. In this example it is interesting to note the care that the architect took in bending the perception of “inside” and “outside” by creating spaces that were open to the surrounding gardens and only making the necessary areas private. The use of natural lighting in the creation of spaces is truly remarkable when compared to the other two examples, showing that this was also taken into consideration by the architect.

## 5. FLUENT

Fluent was used to carry out the Computational Fluid Dynamics (CFD) simulation for the three selected structures. The results obtained are supplemental to those of Ecotect and provide a better understanding of the buildings’ operation. The CFD analysis simulated the air movement through and around the structures in plan and section. The orientation and wind velocity were obtained from the data available in Ecotect’s Weather Tool.

Once the mesh had been adapted, the wind speed (6.9m/s or 15 mph) and direction (x=-1, y=-0.5) were entered for the inlet. The Residual monitors of continuity, x-velocity, and y-velocity were setup and the analysis was initialized. For the plans, a minimum of 115,000 iterations were completed and 100,000 iterations for the sections in order to get the most accurate air flow results. Once the iterations were complete, the results were gathered by graphing the velocity vectors and the static pressure.

It is expected that all of the structures have sufficient natural air movement to properly ventilate the spaces. Because of the urban design of the Colonial Old San Juan, the streets should serve as funnels for the wind where it would have higher speeds than in plazas or open areas. Ventilation for the Colonial structure is expected to enter from the north, cross the spaces, and exit from the south façade. The air-flow for the Turn-of-the-Century house would primarily differ from that of the Colonial structure because this example can be opened completely in all the orientations to allow the maximum amount of air in. It is expected that the air movement will be from the east to the west and will ventilate all the spaces. The courtyard should provide additional ventilation, making all the spaces comfortable. The ventilation for the Tropical Modern structure is expected to be similar to that of the Turn-of-the-Century house. Because this house was designed taking natural ventilation into consideration, all the spaces should have adequate circulation.

5.1. Colonial Structure House

As a result of the strong and compact air movement through the streets, with a magnitude of 3 m/s (7 mph), enough air to provide proper ventilation at a speed of 0.75 m/s (2 mph) is diverted into the building. Because the selected house opens to an interior courtyard, it has cross ventilation that mainly enters the structure on the north façade and sweeps through before exiting on the south. Also complemented by some of the ventilation coming from the interior courtyard from a southern direction. This makes a figure eight pattern within the three main spaces of the structure giving sufficient air circulation for proper ventilation of the interior spaces.

5.2. Turn-of-the-Century House

The air circulation patterns for the Turn-of-the-Century house are complex compared to those of the Colonial structure. This is mostly due to all of the façades being exposed to air movement. Because of a lack of structures on the east of Del Parque Street, the trade winds had a direct approach. After hitting the structures, the wind would then be funneled in a northwest direction only to return to a west direction after passing the buildings. As expected, most of the rooms receive good ventilation with the exception of the rooms on the southwest of the structure that seem to receive poor or no circulation.

Study of the three analyzed sections for this example reveals that there is a great amount of air movement over the house and surrounding structures. It is this air draft that helps the circulation of the air through the interior courtyard. The impact and air movement on the east façades shows that, once the air flow hits the building, it moves upward and eventually over the roof creating an updraft.

5.3. Tropical Modern House

Out of the three structures that were selected for this investigation, the Tropical Modern house was the only one that was designed taking the prevailing wind direction into account. It was then expected that this house should respond very favorably in the simulations. The architect’s approach when designing created a building where the interior and exterior spaces could be mixed and interchanged. The only areas of the residence that can be closed off are the rooms, kitchen and living room. The dining and recreation areas are all located outside.

At this location the primary wind direction is the northeast followed by the southeast. The air circulates through all the spaces in the house, with the bathroom having the least air movement. Though most of the house presents expected airflow patterns, it is interesting to note that some of the air flow in the rooms occurs from the southwest. This is probably due to the air being forced in this direction by the neighboring building. The wind patterns are another example of how the architect designed the house divided in two zones. The public areas of the residence are mainly oriented perpendicularly so they open and receive the air from the east, while the rooms have a parallel orientation. The varying wall and ceiling heights of the structure would also help the air circulate throughout the spaces.

5.4. Conclusion

Overall, the CFD results presented no major unexpected outcomes. The three structures received enough natural ventilation to make them comfortable. Since all the windows and doors were considered to be open at the time of simulation, poor air movement in these results could present bigger problems once the user controls and adapts the air circulation. In all three cases the impact of surrounding structures on the direction and velocity of the wind was noticeable.

## 6. FINAL CONCLUSIONS

The design recommendations presented from the research are directly based on the results obtained from analyzing the three selected structures, and are therefore based on the local meteorological conditions. This is not enough to render the solutions unacceptable in other climates. All the recommendations should be considered and adapted to make better use of local weather resources.

As part of the building analysis, a series of design solutions were identified that could provide a basis for architectural decisions. The following recommendations do not intend to be a design formula for creating architecture, but more of a guideline to follow to produce buildings that relate better to their environment. User interference and general building use will also impact the climatic responses of the building, and they should be taken into consideration with each case individually.

6.1. Double Layered or Pitched Roof

*Fig. 1: Roof exposure*

When the results for the roof/ ceiling combination for the houses were compared it showed that the best performance was the Turn-of-the-Century structure. The roof system consists of a pitched corrugated metal surface on the outside and a suspended wood ceiling on the inside. This system not only allows the rain to stream away from the roof surface lowering the risk of filtrations, but also provides a space of air insulation from the exterior temperatures to the interior temperatures. The heat that is absorbed by the pitched roofs is also lower than that of a flat roof since the amount of time that the surfaces are exposed to direct sunlight differs greatly. (Fig. 1)

6.2. Tall Ceilings with Adequate Ventilation

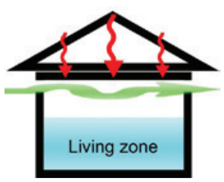


*Fig. 2: Roof ventilation*

All of the structures analyzed had tall ceilings and the analysis results indicated that, because of their height, the heat that radiated into the living spaces did not reach the living zone. The high ceilings have to be accompanied by adequate ventilation that would not allow the storage of warm air near the surface. (Fig. 2)

6.3. Slab on Ground

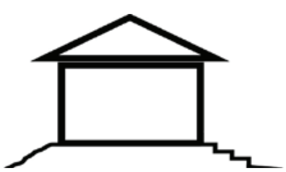

*Fig. 3: Elevated slab on ground*

Following the analysis of the results, the two structures with a slab on ground performed noticeably better than the house with a suspended floor. These results seem to indicate that by placing the floor surface directly on the ground helps keep it at a comfortable temperature. When designing a house, site contours and adequate rain water control strategies should be considered to avoid flooding. The structure should therefore be elevated by a berm, or by building the floor some steps over the ground level. (Fig. 3)

6.4. Thick or Insulated Walls

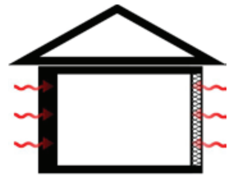

*Fig. 4: Thermal mass*

In this category, the Spanish Colonial house had the best performance. Here, the thickness of the walls provides the interior spaces with a thermal stability not perceived in the other two structures. The half-meter (1.5 feet) thick *mampostería* walls of this house prove costly and difficult to build in the current construction market; therefore, insulation should provide an adequate alternative solution. The selected insulation should allow the chosen construction material to have a thermal mass similar to that of the *mampostería* walls. (Fig. 4)

6.5. Deep Shading Devices

*Fig. 5: Long shading devices*

When the Ecotect results were analyzed, the Turn-of-the-Century structure presented a peak in temperatures in the hours before midday for the brightest day. Further research into this “peak” showed that the lack of shading for the east surface of the house allowed the sun to heat the walls and radiate the heat into the interior spaces. In contrast, the west façade, that has a covered porch, seems to not experience the same temperature rise. The South-facing walls should also have shading devices that work throughout the year. These should be primarily horizontal, while the devices used for the east and west façades can be vertical, horizontal, or a combination of both. (Fig. 5)

6.6. Louvered Windows

*Fig. 6: Louvers*

The three houses that were analyzed all had versions of wooden louvered windows. This alternative provides the users with the ability to control the amount of privacy and ventilation. Although they are not ideal for views, they help control direct solar radiation from entering and heating the spaces. If adequately sized, louvered windows could provide the best protection against climatic conditions and radiation, while still allowing sunlight and ventilation to enter. (Fig. 6)

### 6.7. Perpendicular Ventilation Openings

*Fig. 7: Openings*

One of the most interesting comparisons between the structures is the performance of ventilation openings. The best performer was the Tropical Modern structure where the orientation of wide perforations perpendicular to the primary wind direction seem to permit proper ventilation to occur. As a contrast, the Colonial house, with openings parallel to the wind direction, seemed to receive the least amount of air circulation entering the structure. The Tropical Modern house was also designed with large openings for ventilation when compared to those in the Turn-of-the-Century structure, which seemed to have the least amount of air flow. This structure has tall but narrow openings that, in conjunction to the internal walls, do not seem to provide the ideal conditions for natural ventilation. (Fig. 7)

### 6.8. Open Structures

*Fig. 8: Open structure*

This category is closely linked to the previous recommendation. A floor plan with many interior walls and divisions greatly impacts the ability of air to circulate freely and ventilate all the rooms in the building, such as in the Turn-of-the-Century example. When compared to the open space design achieved in the Tropical Modern house, the Turn-of-the-Century structure seems closed and compacted. Apart from the benefits in air circulation, an open design allows for natural lighting levels to enter the spaces reducing the need for supplemental lighting. (Fig. 8)

### 6.9. Appropriately Designed Courtyards

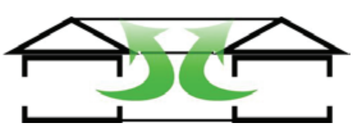

*Fig. 9: Courtyard as chimney*

The only structure analyzed that had a courtyard as part of the space design was the Turn-of-the-Century house. The results showed that the courtyard allows air to enter the adjoining spaces instead of working as a chimney to remove the hot air. In order for it to not be detrimental to indoor temperatures, the design of the courtyard should focus on removing warm air from inside and discharging it into the sky as opposed to suctioning air from the outside into the structure. Additional analyses were performed on this structure showing that the removal of the open courtyard would lower the interior temperatures. (Fig. 9)

### 6.10. Final Conclusions

By taking these factors into consideration, a designer could produce buildings that relate to their local climate and exploit the possibilities of natural lighting and ventilation. All three structures seem to offer favorable and unfavorable conditions. When space design and quality are taken into consideration, the Tropical Modern house provides the best solutions. This residence considers lighting levels, ceiling heights, ventilation patterns, site conditions, and materials in creating spaces that relate to their context. This can be deemed an unfair conclusion since, out of the three analyzed structures, this was the only that was purposely designed to relate to the environment. In reality it indicates that if care is taken in studying the site and weather conditions for the house, architects can produce climate conscious designs that are accessible and efficient. Although some modern materials and technologies prove to be efficient they are not necessary to produce climate conscious designs. Before learning about new external technologies, architects in Puerto Rico should first learn about efficient design with the available resources. Once this is achieved, technological advances can then be used to improve the designs.

## 7. AKNOWLEDGEMENTS

Thanks to Dr. Mohamed B Gadi for supervising and providing advice on the development of this dissertation. Special thanks to Arq. Beatriz Del Cueto, FAIA and Arq. Jorge Rigau, FAIA for providing guidance and historic background information. The Colegio de Arquitectos y Arquitectos Paisajistas de Puerto Rico and the Haeussler and Orraca families for providing access to their homes.

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## Notes

[i] To define vernacular architecture, the *Plan Carimos* provides a good definition; it states that, "It is the product of the tropics that does not require master builders, but rather, unschooled architects formed in the school of tradition." It also states that it is a "resultant of the habitat" and is defined by the climatic conditions. It is the architecture that is shaped and improved upon by the users throughout generations, based on the geographical determinism. On the other hand, traditional architecture is copied from a particular style that contains functional as well as aesthetic elements and becomes an accepted vocabulary that is repeated as part of a cultural tradition.

[ii] These more permanent structures were similar to the ones constructed in Spain in Estremadura and Andalucía, where most of the first colonists originated form. These buildings would integrate local materials into the construction such as stones, *tapia*, clay tiles, *ausubo*, and *mampostería*. At first, these structures changed very little, but as the time passed they were progressively adapted to the climatic conditions of the Island, thus creating the Spanish Colonial Architecture style.

In his book Puerto Rico 1900: Turn-of-the-Century Architecture in the Hispanic Caribbean, Jorge Rigau mentions, "The Colonial period produced an architecture of great cultural significance, pregnant with meaning, but- value judgements aside- in many ways removed from contemporary building concerns. In the best examples, thick walls, tall spaces, and large openings constitute direct climatic solutions which seem of limited importance today." (Rigau, 1992, p.14.) As the time passed, the spanish colonizers continued to establish a clear difference between them and the Taino and the African slaves that were introduced early in the sixteenth century. The Spaniards considered themselves *gente de razón* (people of reason) and insisted in maintaining close ties with Spain which was reflected in their architecture. The construction of these houses was a clear sign of social standing and descent. By the end of the eighteenth century, the Spanish Colonial houses revealed a Puerto Rican identity, and a broader sense of security and wealth. (Jopling, 1992, p.26.)

The construction materials for these buildings were readily available in Puerto Rico and therefore less costly than the use of brick which was imported. Stone masonry was not common on the Island since stone masons were not readily available for construction works. These conditions led to the subsistence of the *tapia* construction method for buildings. Apart from using locally ready materials, these walls would sustain hurricanes and earthquakes while aiding in the climatic control of the interior spaces. The walls have an average thickness around half a meter and have an average hight from 3.5 to 5 meters. The roof of the structures was integrated into the wall construction since the *ausubo* beams were placed during the construction of the parapet. These were mainly flat and consisted of "*ausubo* beams, crossed by fine wood slats and two to three alternate layers of thin flat roofing brick". (Del Cueto, 1997, page 9.) This technique allowed for an aesthetic finish in the inside and a strong exterior surface that could withstand the onslaught of the local climate. To aid with the air circulation in the spaces, the openings were fitted with movable louvers that also provided a certain level of privacy.


*Fig. 10 Architectural details of a typical Spanish Colonial house in San Juan, Puerto Rico: a. Wall thickness and spatial relationship, b. main façade, c. doors with movable louvers, d. ceiling detail.*

[iii] The advancements of technology and the growing population in San Juan made it necessary for certain design guidelines to be followed in order to maintain healthy living

conditions. In his book Puerto Rico 1900: Turn-of-the-Century Architecture in the Hispanic Caribbean 1890-1930, Rigau explains: “By 1889 residences in San Juan were required to have a “convenient distribution of light and air”, “access to the sun’s rays”, and “vents or shafts which would allow communication with outside air”.” (Rigau, 1992, p.37.) The structures that were being built, as well as the existing, continued to apply these concepts to the Colonial style homes of the period.

It was not until the Spanish-American War in 1898 that a change became evident in Puerto Rico. As part of the Treaty of Paris, Puerto Rico was to become a territory of the United States. All direct ties with Spain were ended and a new culture was to be assimilated into the Island. The residents of Puerto Rico were forced to adopt English as an official language, the social classes were shaken as the economy of Puerto Rico became part of the North American process of production and consumption.( Jopling, 1992, p.41.) Apart from a change in sovereignty, Puerto Rico also felt the changes that where happening worldwide. The Industrial Revolution, with its capacity for mass production, the specification of reinforced concrete and the introduction of the balloon-frame construction presented the first major change in the way architecture in the island was approached since the arrival of the Spaniards. (Jopling, 1992, p.41.)

With all these new technologies a new type of residential architecture was being produced. As a response, new construction guidelines were established to assure the maximum safety and wellness. Rigau states that among these recommendations for healthy living were:
“Structures had to be raised from the ground by a minimum of about sixty centimetres, either on stilts or over a perforated masonry wall to allow for the free flow of air. Rooms were deliberately tall and the roof and ceiling could not share the same surface, for the space sandwiched between them protected the dwelling from high temperatures. In many cases, walls were required to be of wood sheathing on both sides with an insulation pocket between the inside and outside surfaces. Over each door and window a transom for permanent ventilation had to be provided. Although their shapes could vary from rectangular to semicircular, transoms were sized in terms of a specific percentage of the total opening below, and detailed to allow air to pass through them.” (Rigau, 1992, p.37.)

Although these guidelines where in tune with the “period’s obsession with salubrity and hygiene”( Rigau, 1992, p.37.) they were based on the local climate and therefore allowed the houses to ventilate and maintain comfortable temperatures. Nevertheless, these were guidelines for design and in some cases residences were being built with concrete blocks with ornamental surfaces instead of wood. Del Cueto states that during the twentieth century some architects on the Island were specifying the use of ornamental concrete blocks for the construction of the exterior walls. It is not certain whether the blocks were produced in the west coast of Puerto Rico, or if they were brought from the U.S., but it is clear that they were preferred over brick and quarry stone since they were mass produced. This meant that there was a broader availability of factory-produced components that gave an ornate appearance to the surface. (Del Cueto, 1997, page 14.) It should be noted that, although the walls were built with concrete, these structures continued to have a wooden trussed roof with an exterior corrugated zinc roof and a separate ceiling surface.

*Fig. 2 Details of the González-Cuyar residence, an example of Turn-of- the-Century architecture in San Juan: a. main façade, b. wood and zinc roof detail, c. louvered doors, d. back façade.*

[iv] The Turn-of-the-Century architecture style was maintained, mostly unchallenged, until the arrival of Modernism to Puerto Rico. Meanwhile, in the 1930's, a period economic depression struck the Island and poverty became widespread. It was not until after the effects of the wars and the depression started to lift that Puerto Rico started to see changes. The appointment of Rexford Tugwell as governor of Puerto Rico in 1941 brought a sense of change and progress, the basis for the modernist movement in the Island.

During this time of transition into Modernism, the population in San Juan grew exponentially in the 1930s as the rural workers moved into the city in search of jobs and a better life for their families.(Jopling, 1992, p.57.) Vivoni explains this transition period: "Puerto Rican history tells us that in 1941 Puerto Rico experienced a "peaceful revolution". The revolution occurred within the establishment, and it used models of administration different from before, but was unable to alter, fundamentally, the true problems inherent to the relationship between the United States and Puerto Rico. In 1941, after centuries of colonialism, the Puerto Rican situation was desperate.... The effect of the peaceful revolution was felt in several aspects of Puerto Rican life. Puerto Rico engaged in a process of homogenization in which cultural, economic, and social differences were leveled out by industrialization and internationalism. The practice of architecture in Puerto Rico also reflected the search for an image of international equality. Through the Committee on Design of Public Works, the government set out to modernize architecture in Puerto Rico."(Vivoni, 2006, p.20.)
During this time many foreign architects arrived in Puerto Rico to work in modernizing the Island. Among these architects was Henry Klumb, a German who, after being an apprentice to Frank Lloyd Wright, went on to become one of the best known architects of the mid twentieth century in Puerto Rico.

The modernist movement on the Island was "belated, unequal, and out-of synch" and was therefore received with "disillusionment and criticism".( Vivoni, 2006, p.20.) Following the definition offered by Bruno Latour, "The adjective "modern" designates a new regime, an acceleration, a rupture, revolution in time. When the word "modern", "modernization", or "modernity" appears, we are defining, by contrast, an archaic and stable past." (Latour, 1993, p.10.); Klumb is the perfect example of the "modern" architect in the island. He stated that the Spanish Revival, which was the official architectural vocabulary chosen by the government, was "the most wretched [architecture] imaginable". (Bameneche, 2003, p.17.) He then proposed an architecture that was his own interpretation of the Prairie Style, developed by Wright, that would take into consideration the climatic conditions of the Island. Additionally, Klumb found himself in constant struggle against the new technologies, such as the air conditioner, that, for him, were unsustainable in the economy of the time.( Vivoni, 2006, p.39.)

In 1945 Klumb designed one of his first particular dwelling, the Haeussler Residence, on the Island after forming his private practice, The Office of Henry Klumb. As with his other designs, the house integrates the local climate and surrounding green spaces to form part of the dwelling. As part of his integration to nature, Klumb performed an analysis of the prevailing breeze in order to provide the house with an ideal orientation for natural ventilation.


*Fig. 6 Haeussler Residence, 1945: a. main façade, b. perspective of main façade and entrance, c. perspective of the west façade, d. living room detail.*

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# Integration of Environmental Sensors with BIM

## Seven Case Studies

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*ABSTRACT: This paper investigates the feasibility of connecting environmental sensors such as light, humidity, or CO2 receptors to a building information model (BIM). A base case was created in Rhino; using Grasshopper and Firefly, a simple digital model responded to lighting-levels detected by a photoresistor on an Arduino board. The case study was duplicated using Revit Architecture, a popular BIM software, and Dynamo, a visual programming environment, in an innovative application. Another case study followed a similar procedure by implementing the Revit API directly instead of using Dynamo. Then the process was reversed to demonstrate that not only could data could be sent from sensors to change the 3d model, but changes to parameters of a 3d model could effect a physical model through the use of actuators. It is intended that these virtual/physical prototypes could be used as the basis for testing intelligent façade systems before constructing full size mock-ups.*

*Keywords: environmental sensors, BIM, building information model, visual scripting, Dynamo, intelligent facades*

## 1. BACKGROUND

Designers have sought both passive methods and active systems to have their buildings respond to changing environmental conditions. Many historic examples exist that show the use of passive methods using natural features to manage daylight, as evidenced at Mesa Verde, or mitigating seasonal heat variation by the use of shade and thermal mass in the southwest United States at Acoma (Knowles 1981). Active systems have also been incorporated, ranging from those that require direct occupant participation to those that are completely automated building systems with embedded computation. Despite past problems in actuating full size components, the concept of kinetic architecture is flourishing as an exercise in combining aesthetics with energy conservation practices, including daylight harvesting and solar heat gain avoidance (Fox and Kemp 2009). This requires what Fox and Kemp refer to as “environmental cognizance,” the ability to not only measure values such as temperature, humidity, sun location, solar radiation, rain, etc., but to also have a building be aware of these conditions and respond to those inputs. Intelligent building facades rely on the ability to respond to climatic data.

In order to predict the future performance of building components, it is useful to initially create a virtual model and connect it to sensors to see if the responses of the components are appropriate. Visual scripting tools are one method for bridging the hardware/software gap between sensors and 3d modeling software. Some designers are effectively and enthusiastically using these tools to generate parametric, form-based solutions for buildings. At NBBJ, architects used Rhino and Grasshopper for the design of the Hangzhou Tennis Center. By defining the geometry of the structure in a visual scripting language, the architects could mathematically describe numerous formal variations in response to various tolerances (Miller 2011). Many comparable examples exist in the fields of architecture, construction, and academia due to the popularity of Grasshopper. This preference for Grasshopper could be attributed to the following: its direct relationship to Rhino, a popular 3d modeling program; a substantial group of independent developers who provide support and new components; its availability free of charge; and the development of tools such as DIVA used for performance evaluations (Rheinhart et. al. 2010). In one example, moveable light shelf angles were optimized for daylight availability. The designer used DIVA and Daysim for daylighting calculations with Rhino and Grasshopper including Galapagos, a genetic algorithm component used for optimization. This study demonstrated that a kinetic façade system can contribute to better illumination levels in a space through daylight harvesting, in turn reducing the reliance upon artificial lighting systems and saving energy energy. (El Sheikh and Kensek 2011).

However, Rhino itself is not a parametrically based modeling tool. Other researchers have experimented with using scripting or graphical algorithm editors to create a connection between parametric modeling and environmental simulation. One work in progress is the development of a parametric modeling based method for evaluating façade configurations for hot and humid climates (Velasco and Robles 2011).

"Daren Thomas of the Professur für Gebäudetechnik, Institut für Hochbautechnik at the technical university ETH Zürich has published a Python Shell for Revit. It was implemented using IronPython and is used to automate the running of daily tests of a building energy analysis package" (Tammik 2011). As building information models (BIM) are often used by architects, being able to use visual scripting with it would be an advantage.

## 2. METHODOLOGY

Seven case studies (six successful) were accomplished to demonstrate the feasibility of connecting environmental sensors to control a BIM and established that the process could go in both directions, from real models to virtual models and from digital models to physical models.

2.1 A simple model was created in Rhino and Grasshopper that reacted to values output by a photoresistor on an Arduino board. Arduino is a single chip microcomputer that executes programs created in the Processing programming language. One can use it to as a software interface, control system for robots, data recorder, kinetic responsive art installations, and other applications. Firefly was the interface between Grasshopper and the Arduino micro-controller.

2.2 The same simple model from the first case study was re-created in Autodesk Revit (a BIM software program). Dynamo was used as the link between Revit and the Arduino board. The photoresistor on the Arduino board output values that controlled parameters in Revit.

Dynamo is designed to extend Revit's parametric modeling capabilities by adding a level of associativity that does not exist in the off-the-shelf application including driving parameters based on external inputs, such as sensors, or by data taken from an analysis. One can map the appropriate parameters and dynamically change each value with a value derived from the input source. Dynamo was developed as a plugin to Autodesk Revit using the Revit API and built using the Windows Presentation Framework. Dynamo's look and feel is influenced by a number of visual programming interfaces that have come before including MaxMSP, the Maya Hypergraph, and LEGO MINDSTORMS NXT, which is based on National Instrument's LabVIEW. As a parametric modeling engine, Dynamo takes its inspiration from Bentley's Generative Components and McNeel's Grasshopper for Rhino.

This was the first time that Dynamo was used by someone besides its creator, Ian Keough. This prototype add-in for Revit was used to manipulate family parameters within the project environment; specialized code was being generated at the time to complete the case studies. Since then, applications of Dynamo have been demonstrated by other people.

2.3 A more complex 3d model was created in Revit that better portrayed the potential of controlling a 3d architecture model from the output of a photoresistor. Unchanged from case study 2, the photoresistor on the Arduino board output values that changed the parameters of components in Revit with Dynamo as the connective software.

2.4 Similar to the previous case, a photoresistor's changing values caused a response in a 3d digital model. In this case, there was also a simultaneous change in a 3d physical model.

2.5 Whereas the first three case studies used values from a photoresistor to control a Revit model, the fourth case study was designed so that changes in a parameter in a Revit model would move a physical model a specific distance through the use of Dynamo and Arduino actuators. Unfortunately, Dynamo does not have a functional Arduino write node, and the physical model/servo could not be actuated. Updates to Dynamo will allow this case study to be finished.

2.6 The fifth case study used the photoresistor on the Arduino to control a shading component in Revit. A Revit dll passed the data from the photoresistor to a Revit parameter to change the angle of the shading device.

2.7 The sixth case study allowed a user to change an angle parameter on a Revit family. The data was passed through the use of a Revit dll to the Arduino board to actuate a servo to control a physical model.

## 3. CASE STUDY RESULTS

3.1 Arduino Photoresistor, Firefly, Grasshopper, Rhino

A simple base case study was designed that consisted of three elements: a wall surface, a window opening, and a window shade that could move. Conceptually, the window shade dynamically responds to the presence of a sun by moving horizontally above the window opening to effectively shade the interior space. In reality, the initial models consisted of a box moving along the face of another box. The distance that the shading device moves is controlled by input from a photoresistor on the Arduino board (Fig. 1).

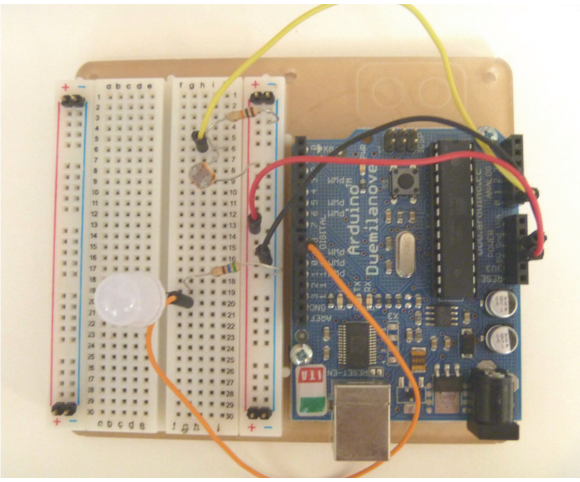


*Fig. 1: Completed circuit board (without USB cable). The LED was only used for testing purposes.*

The first model was constructed in Grasshopper with the 3d model appearing simultaneously in the Rhino view window (Fig. 2). The inter-relationship between the window shade and wall is explicitly defined and can be manipulated given a change to any particular dimension, specifically the amount of distance that the shading device would move (the parameter, "offset"). This offset distance is related to the measured light level value. To procure this input data, a Processing sketch is uploaded to Arduino to register analog values from a photoresistor and report them to Firefly. The Firefly component for Grasshopper receives these values and through simple mathematical operations in Grasshopper, translates them into displacement distances for the window shade. The response of the 3d Rhino model is practically real-time. As a user moves his hand off of the photoresistor and the lighting levels increase, the window shade moves. The next step was to do this same exercise using Revit and Dynamo.

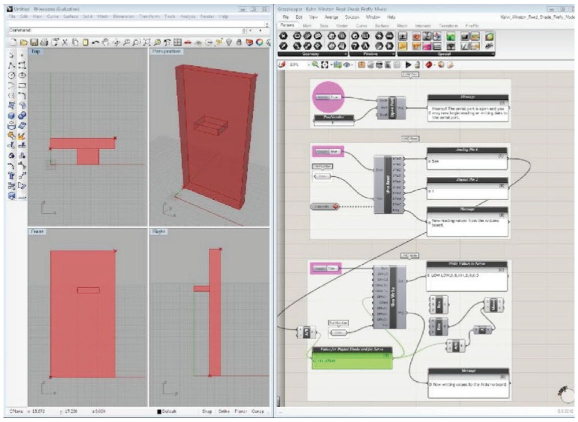

*Fig. 2: Rhino, Grasshopper, Firefly*

3.2 Arduino Photoresistor, Dynamo, Revit Simple Model

Parametric objects in Revit are called "families." They have "instance" parameters that refer to an individual object and "type parameters" that refer to a category of objects. Users can add new parameters to "loadable families" and to "conceptual masses." To modify forms in the Revit conceptual massing modeler, one can directly manipulate the model as in Rhino or change parameter values. Objects were adjusted by Dynamo through their parameters.

The model created in the Revit conceptual modeler visually matched the first Rhino model. First the window shade was created. It was given two instance parameters: Light Level is a value from 0 to 255 that is received from the Arduino board; Offset Shade sets the distance of the shading device from the edge of the window based on Light Level. In a second file, the wall was created. The shading device family was inserted into the wall model. It was verified that the shading device was on the correct location on the wall, that it behaved properly based on changing the parameters values manually (a bit of tweaking took place here to convert the 0-255 values to reasonable distances), and that Arduino was providing data that Dynamo was receiving correctly. Once these nodes were connected, the shade was moved by Dynamo in Revit directly in response to the Arduino light level readings, although more slowly than in the first case study (Fig. 3).

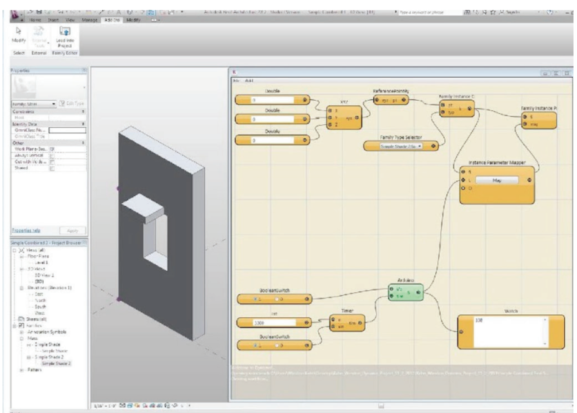

*Fig. 3: Revit, Dynamo*

3.3 Arduino Photoresistor, Dynamo, Revit Building Component Model

A third model was created that demonstrated the use of the lighting level to rotate louvers, change the size of openings, and increase the size of an overhang based on input from the photoresistor. As the user's hand passed over the photoresistor, the value changed from almost 0 to 255. Slowly, the Revit model updated the size of the holes in the dynamic panel, the rotation of the louvers, and the length of the overhang on the house (Fig. 4).

*Fig. 4: Light level is 255 (top). Light level is 75 (bottom). The original house was modeled in Revit by Andrea Martinez.*

3.4 Arduino Photoresistor, Dynamo, Revit Building Component Model, and Physical Model.

In this case, both a digital model and physical model responded to the changes in the photoresistor's value (Fig. 5). As the light level value approaches 255, all three vertices approach a maximum extension in the physical and digital models, likewise, when the value reading is at a lower threshold, only one or two of the actuators or vertices are raised (Fig. 6).

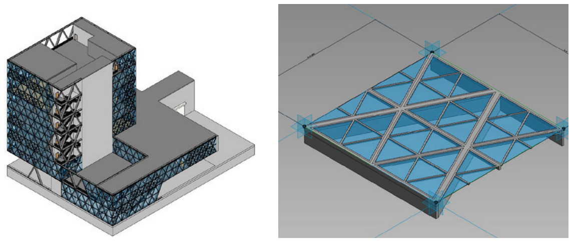

*Fig. 5: 3d model of building and façade component.*

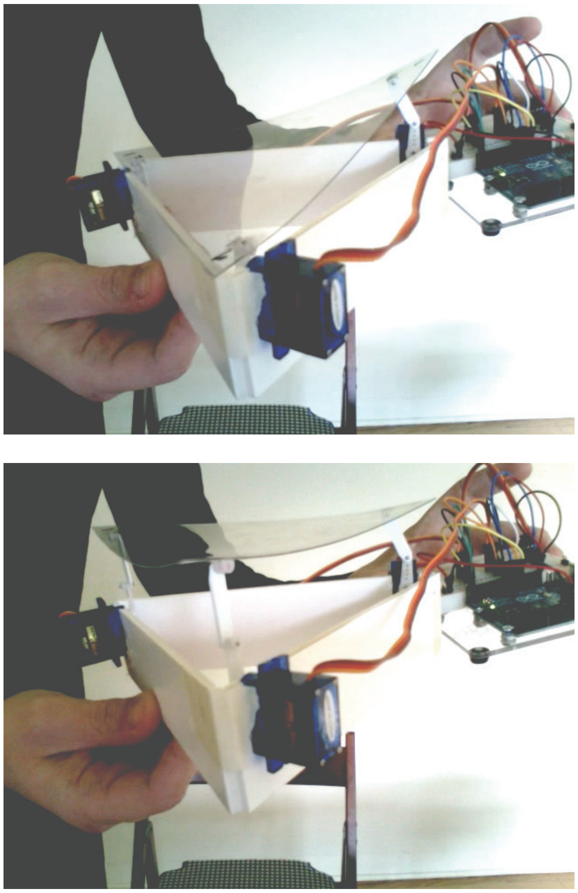

*Fig. 6: Physical model with one corner up (top) and all three corners up (bottom).*

3.5 Revit 3d Model, Dynamo, Arduino Servo, Physical Model
The setup is ready for this case study. However, as mentioned earlier, at present there is no supported functionality in Dynamo to output the Revit parameter values to the Arduino board.

3.6 Arduino Photoresistor Revit dll, Revit 3d Model
Although Dynamo worked, another method was tried using a custom dll written in the Revit API as the connection between the photoresistor on the Arduino board and the Revit model. This involved an extra step that involved writing out the light level values from the Arduino to a text file that was input to Revit. In addition, only one value at a time could be sent for each running of the Revit dll (Fig. 7 - 9). More clever coding in the future would directly link the output to Revit and provide for a serial stream of light level values.

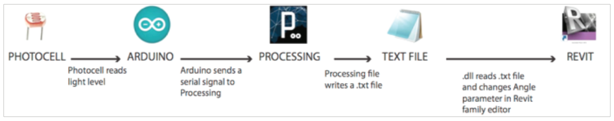


*Fig. 7: Diagram of process*

*Fig. 8: Step 1: sequence of running the dll in the Revit family editor, orginal value. Step 2: Revit acquiring the value from the photoresistor.*

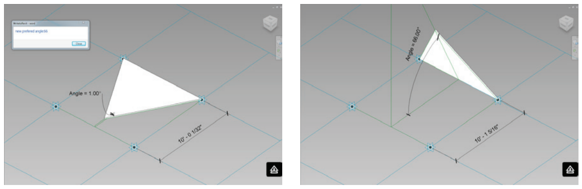

*Fig. 9: Step 3: the value is applied to the angle parameter. Step 4: the angle parameter updates the geometry.*

3.7 Revit 3d Model, Revit dll, Arduino Servo, Physical Model
In case study 7, a link from the Revit 3d model to a physical model was accomplished. Values can be changed in an angle parameter in Revit, and the physical model responds (Fig. 10 - 12).

An unfinished feature is to access the values in the sun component in Revit. Then as the sun "moves" in Revit, it would jointly change the shading device angle both in Revit and in the physical model.

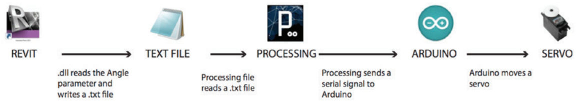


*Fig. 10: Diagram of process*

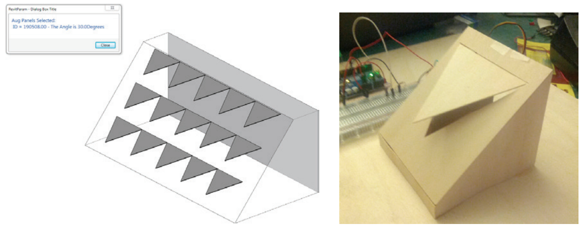

*Fig. 11: Parameter is 30 degrees in digital/physical models.*

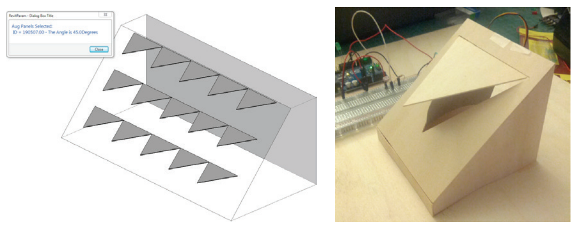

*Fig. 12: Parameter is 45 degrees in digital/physical models.*

## 4. DISCUSSION AND CONCLUSION

Although the examples shown are simple, they prove that both workflows are successful: using a light sensor to drive parameters in a building information model and changing parameters in a 3d model to provide input for servos to move a physical model. Some difficulties were encountered, and the entire topic area of optimization was not explored in this case study.

### 4.1 Difficulties

The interaction time in Dynamo/Revit is vastly slower than Grasshopper/Rhino. There were noticeable delays when the users moved their hands over the photoresistor. A primary challenge to overcome in the development of Dynamo is that of the speed of interactions with the database. Unlike Grasshopper, Dynamo has no concept of “volatile” geometry, that is, geometry that is visualized but does not get committed to the database until the user “bakes” it. For Grasshopper this provides a benefit in terms of the speed with which a workflow can be evaluated. In Dynamo, the evaluation speed of the workflow will always be tied to the speed with which its database transactions can be carried out. In addition, all geometry derived from a Dynamo workflow is “live,” having been already committed, which creates an inherent fragility as a user can then manipulate, or in the worst case, delete geometry directly in the Revit interface, subsequently breaking the workflow.

### 4.2 Optimization

The Revit / Dynamo models demonstrated a method of dynamically re-positioning a design element in response to an environmental stimulus. The method was not predicated upon approaching optimization with regard to solar radiation values. However, a starting point for conceptualizing a more complex shading device could begin with an analytic process was previously demonstrated by a team at Perkins + Will. They were able to export model geometry created in Revit, test it against solar radiation data from Ecotect, and ultimately import that Excel spreadsheet data back into Revit -- effectively translating said values into instance parameter changes (Aksamija, et. al. 2011).

Many projects have used Galapagos (an evolutionary optimization module) with Rhino, Grasshopper, and DIVA (simulation) for optimization of daylighting and energy savings. One recent example optimized window sizes for different climate zones and orientations by balancing daylight capture with increases in summer cooling loads (Geman, et. al. 2012).

Many fewer examples exist for Revit as a module similar to Galapagos does not currently exist for Dynamo. However, other methods have been used to find optimal configurations. Dynamo has been used with Vasari/Revit to create an interactive feedback loop where the amount of solar radiation on the roof of a massing model is optimized by rotating the building (Fig. 13).

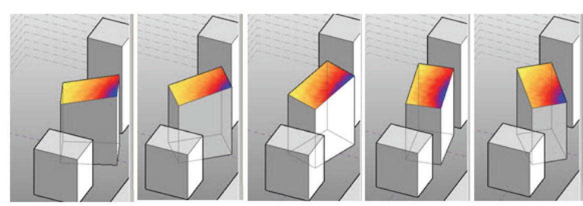

*Fig. 13: Progression of images showing radiation analysis until local maximum was reached. (image courtesy of Matt Jezyk, Autodesk) http://wikihelp.autodesk.com/Vasari/enu/Community/Work_in_Progress/Dynamo_for_Vasari (last accessed 1-25-12).*

The Dynamo setup in Fig. 14 followed a similar sequence as the solar radiation project shown in Fig. 13. The Reverse Optimizer node replaced the Optimizer node and the Incrementer node influenced the increment parameter of the shade. The shade depth continued to increase in size until the radiation value on the window no longer decreased, thus optimizing the shade length.

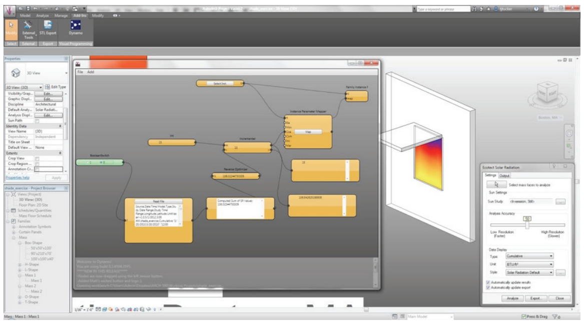

*Fig. 14: Progression of images showing radiation analysis until a local maximum was reached. (image courtesy of Tyler Tucker)*

4.4 Future Work

Although there is much to be done, we foresee two major next steps. One is focused on the interaction between environmental sensors and optimization algorithms to predict the changes that should be made to an interactive façade. An interesting subset of this would be to source data from real time weather feeds on the Internet such as Cosm. Another step is to construct a full size mock-up to see if it performs like the prototype hybrid virtual-real models. One known challenge to this is the up-scaling of power required to actuate larger servo drives, which in turn are moving significantly heavier construction materials. Micro servo-motors are powered through the Arduino board and operate with a maximum of five volts. In both cases, digital models would first be used to test the response of the systems.

The long-term goal is to create cognizant building facades that optimize their performance based on current, historical, and weather predictions in an effort to reduce energy consumption.

## 5. ACKNOWLEDGMENTS

Ian Keough, creator of Dynamo; Matt Jezyk, Autodesk; student researchers: Winston Kahn, Augustine Liu, Tyler Tucker

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# LCT ONE
## A Case Study of an Eight Story Wood Office Building

NABIH TAHAN, AIA

*ABSTRACT: The challenges for the global construction industry are enormous. More than 50% of the world's population today lives in cities with more than 1 million inhabitants* - and the trend is increasing. 40% of today's energy, $CO_2$ and resource consumption and 40% of waste production are accounted by the global construction industry. In the past, urban architecture has been based predominantly on conventionally produced prototypes with long, complex and resource-intensive construction work.

*LCT ONE is an eight story, timber based; sustainable building that* was developed in Austria in 2012, to reverse these trends. The goal of the project was to develop a flexible, high performance, prefabricated construction system as a new product, which meets all technical and economical requirements of modern real estate markets. The project is based predominantly on a renewable resource – wood, with additional emphasis placed on resource- and energy efficiency. The project is meant to demonstrate to the building industry that there are new timber technologies and industrial processes where a modern, system approach to construction can be applied. The aim is not only to improve the performance of buildings but also develop a modern process to guarantee it.

*Keywords: Performance, energy efficiency, resource efficiency, new building system, sustainability, Life Cycle, prefabrication*

### 1. INTRODUCTION

In order for buildings to perform better, the construction industry must change the way it designs and builds. LCT ONE, an eight story wood office building, is a prototype, a proof of concept that demonstrates an innovative process and product. LCT ONE focuses on reducing the negative impact of buildings on the environment, while improving the comfort and indoor air quality for the occupants.

LCT ONE began as a research and development project based on the Life Cycle Assessment of buildings. The motivation was to find a substitute for traditional construction which plays a major role in causing our climate crisis. Our population is growing and the trends are shifting. People are moving from rural to urban areas. Cities must find new ways to grow, around transit systems with sustainable developments that don't deplete our resources and harm our environment. Therefore cities must readapt to the current changes. We can no longer afford to build our cities using materials based on fossil fuels such as concrete and steel, using archaic methods resulting in long construction schedules and cost overruns. LCT ONE is a prototype solution that presents an alternative, a concept to introduce a Natural Change in Urban Architecture, which is based on a renewable resource, wood. The Life Cycle Tower (LCT) research project resulted in a *process*; a *system* and a *product* culminating in the design and construction of LCT ONE. The result was a sustainable wood / concrete hybrid system for mid-rise and tall buildings that can go up to 328 feet and 30 stories and meet local building code requirements. (see Fig. 1)

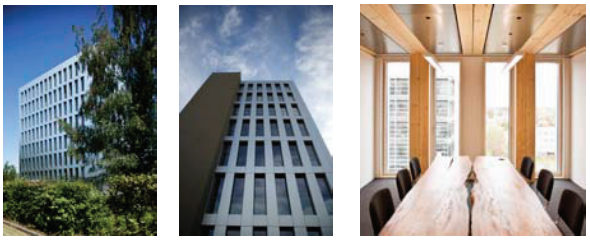

*Fig.1: LCT ONE- exterior and interior photos*

### 2. MOTIVATION FOR RESEARCH PROJECT

A sustainable building strategy considers the entire Life Cycle of buildings and their products. This includes resource extraction, material production, construction, operation, demolition and recycling. Since the industrial revolution, progress in developing cities translated into more concrete and steel produced with more oil and coal, to build tall and mid-rise buildings. The industry now realizes that this strategy is not sustainable and is looking for innovation. LCT ONE was developed to introduce alternatives by substituting renewable resources for fossil fuels and systems and processes that can guarantee better building performance. The following issues were considered in developing the concept:

2.1. Forestry Carbon Cycle
Wood is a renewable resource that grows from the sun. It is the ultimate solar product. Forests and their trees absorb carbon while giving us oxygen. Modern, timber based products, such as engineered lumber, are available worldwide. Heavy timber glulam members are stable, will not shrink and twist, and by using modern industrial methods, it is possible to pre-cut and prefabricate components to exact tolerances, which are air-tight, resulting in saved energy. At the end of a buildings' life, the wood can be reused for other purposes and later turned into fuel and energy. The use of wood is carbon neutral.

2.2. Ecological Backpack
The selection of building materials must be linked to the use of natural resources, including raw materials (renewable and non-renewable), energy, water and land. To specify products for the LCT system, data was collected and calculations performed to measure the total amount of natural resources required to produce a certain product or building. Because trees grow above the ground, it is resource and energy efficient to extract and produce wood as a building product. Wood has a much lower ecological backpack than traditional materials such as concrete and steel.

2.3. Prefabricated Construction Process
Austria has a long history of prefabricating high performance building components out of wood. The process begins with CAD software used to cut lumber using CNC machinery. The members are assembled in a carpentry shop, under a controlled environment where windows, insulation, sheathing, vapour barriers and finishes were installed. The components are made to very tight tolerances and can be quickly assembled on-site and meet the most stringent blower door test requirements. Modern timber technology is available and can deliver high-performance buildings using renewable resources (see Fig. 2)


*Fig.2: Prefabricated timber wall & floor panels for LCT ONE*

2.4. Operation and Maintenance
Existing buildings consume too much energy during their operational life. To reduce consumption, the LCT system was developed according to the Passive House Standard introduced in Germany. It is one of the most stringent energy standards in the world. The strategy is to drastically reduce consumption before relying on renewables. This is the surest path to reach Zero Net Energy. Highly efficient solar and mechanical equipment have an ecological backpack, therefore "less is more", no need to heat and cool is more sustainable than heating and cooling with renewables or high efficiency equipment.

The energy modelling software program Passive House Planning Package (PHPP) is an accurate tool for predicting heating demand and peak heating load in low-load buildings. The PH standard is based on energy performance (KwH / m² / year) and in Europe, the predicted energy consumption, during the design phase, has proven to be accurate when compared to actual consumption during operation. (CEPHEUS – Cost Efficient Passive Houses as European Standard – 1/98 to 12/01). These metrics and strategies are valid across different climate regions of the world.

To guarantee maintenance and durability, a building science consultant is part of the integrated design team and advises on the permeability and diffusion of the entire building enclosure. The most important aspect is air-tightness which prevents air and moisture from entering the building enclosure. Additionally, the exterior finish material of the building is always installed on a rain screen, creating a ventilation layer behind it and allowing any water penetration to drain before it reaches the building enclosure.

2.5. Urban Mining

All building products originated from mining the earth. At the end of their lives, buildings are typically added to landfills and new materials are mined. The Life Cycle Tower research project strived to develop a solution where, at the end of the life of a building, reusable materials are saved from landfills. Urban Mining conserves our natural resources, eliminates potential energy costs and greenhouse gas emissions. When a building has reached its full useful life, urban mining of the LCT system can be activated, extracting materials to reuse, recycle and convert into bioenergy, thus protecting landfills from unnecessary waste.

## 3. SYSTEM AND PRODUCT DEVELOPMENT

As a result of the research phase, LCT ONE was designed and built as a proof of concept that considers the issues mentioned above. The goal was to develop a system and products that can be used on any urban infill projects, but with wood replacing concrete and steel where possible. The goal was to introduce an industrial process for buildings, similar to the process car and computer companies design and build their products. Instead of miles per gallons, building performance can be guaranteed in kWh / ft² / year.

To reach this goal for tall, large volume wood buildings in urban settings, the LCT system integrates the planning, the off-site production and on-site assembly, the use and future conversion, the dismantling and recycling of buildings.

### 3.1. Structural System

The LCT system was developed as a “core and shell” that acts as the structural system and enclosure of a tall, large volume wood building. This system is analogous to “Intel Inside” of a computer. It is the hidden operating system that each manufacturer relies upon, but each computer looks and performs according to the manufacturers design and specifications. Similarly, the core and shell of the LCT system can be looked at as the “LCT Inside” and each architectural and engineering team can design the building according to their own aesthetics, integrating the site and client’s program requirements into the design.

Core: the core is where the elevators, stairs, wet rooms and shafts are located. It serves as the stiffening element of the building. While wood is the optimal choice as a material for the core, concrete and steel can also be used until taller wood buildings have reversed the bias and are more acceptable.

Posts: The gravity loads are carried by a series of exposed, heavy timber, glulam posts on the exterior of the building which are spaced approximately 10 feet apart. For fire protection, the size of the post is increased beyond the structural requirements. Approximately 1.5 inches of wood for one hour fire protection is added to each exposed surface of the posts which creates a charring layer in case of a fire. Wood burns “safely”, because science can predict how long wood will withstand the flames, therefore the building codes allow this additional thickness as fire protection (See Fig 3)

Hybrid Floor Slabs: Hybrid wood/concrete floor slabs span about 30 feet between the exterior heavy timber posts and the core, transferring all the lateral forces from the posts to the core. The benefits of a hybrid system is that it takes advantage of the properties of each material to meet all the structural, fire, acoustic and thermal requirements using the least amount of resources and energy. The hybrid slabs were tested in a full-size fire chamber and passed a two-hour fire test. The design of the slabs provides a built-in fire separation between each floor because there is no wood to wood contact between floors. (See Fig 3)

Fig.3: Posts and hybrid slabs (left). LCT ONE interior during construction (right)

### 3.2. Integrated Building Enclosure

The building enclosure is then integrated with the “core and shell” to give the building its aesthetic appearance. The façade is a curtain wall that does not carry any loads. It can be made of any material, preferably with wood as a renewable resource. The windows, insulation, water, air and vapour barriers, exterior finishes and other layers are designed with the collaboration of a building scientist, the mechanical engineer and the exterior wall manufacturer. These building sections take into consideration the orientation of the building as well as the energy performance and standard demanded by the client. (See fig 3)

3.3. Integrated MEP Systems
Similarly, the mechanical, electrical, plumbing and fire protection systems can be integrated within the "core and shell" and optimized according to the building orientation and building enclosure. The systems can be prefabricated and are easily accessible between the structural members. (See Fig 3)

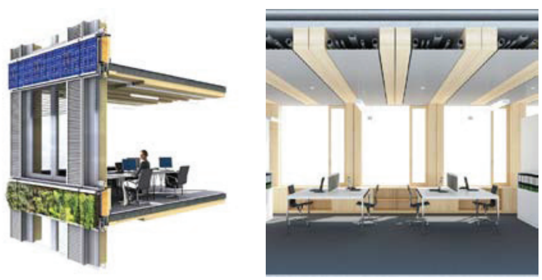

*Fig.3: Building enclosure and integrated MEP*

## 4. LCT ONE – PLANNING PROCESS

LCT ONE, as a prototype, is the proof of concept of the LCT system. It was built in Austria in 2012 as an eight story wood office building. The foundation and core were built on-site with traditional reinforced concrete construction. The building enclosure was timber frame and the floor elements were made out of the wood/concrete hybrid slabs.

As a solution designed to guarantee performance, the LCT system is designed to automatically meet the requirements of certification programs. However, as a prototype, it was necessary to compare the LCT system to mainstream certification programs. From an energy perspective, LCT ONE was designed to meet the Passive House Standard. It also applied and received DNGB gold certification from the German Sustainable Building Council. LCT ONE has also applied and shortly expects to meet the LEED Platinum standard. Following is a description of the design and construction of LCT ONE:

4.1. Energy Standards and Certifications.
The goal was to meet the energy requirements of the Passive House standard because it has proven to be accurate in predicting the actual energy consumption. In collaboration between the engineers and building enclosure manufacturer, the building envelope as well as the mechanical, electrical and ventilation systems were designed to optimize the performance of the building according to the given location and orientation. By using the PHPP software, multiple reiteration were attempted to optimize the balance between the orientation, building enclosure, mechanical, electrical and renewable energy systems.

4.2. Orientation
The building orientation was governed by the existing location of the property. The orientation created a negative effect on the energy balance. The building would have performed better if it could have been rotated by 90°. To mitigate the effect of the orientation, the thermal performance of the building envelope was improved by increasing the thickness of the wall and insulation and specifying higher performing triple glazed windows.

4.3. Building Enclosure
The building enclosure consisted of prefabricated timber frame walls, where the insulation, windows and sheathing were installed off-site. The connection and intersection between all wall, floor and roof elements were designed to minimize thermal bridging. Insulation was applied on the exterior of the window frames to decrease heat losses through thermal bridging. All joints were taped air-tight in order to meet the Passive House blower door test requirements (0.6ach at 50).

The shape, size and number of windows were optimized for low heat loss in the winter and low heat gain in the summer and to reduce demand for artificial lighting throughout the year. Tilt and turn operable windows were specified to allow for natural ventilation, and because they open to the interior, it allowed exterior shading devices to be installed to reduce heat gain in summer.

4.4. Passive Heating and Cooling
Passive heating is achieved by large windows in the staircase (eastern orientation). The morning sun heats up the concrete wall and heat is stored in the thermal mass of the walls. Passive cooling

is achieved by operating the chiller machine in a free-cooling-mode during most of the year. Furthermore, the optimized ratio between transparent windows and opaque walls, as well as deep window reveals, prevents the office building from overheating in the summer.

4.5. Building System
The following building systems were used on LCT ONE:

Heating System: District heating system – renewable fuelled Combined Heat and Power.

Cooling System: Conventional chiller machine with enhanced free-cooling-option.

Hot water system: high efficient, decentralized water boiler on each floor.

Heat Recovery Ventilation: Central system installed in basement with $CO_2$ sensors on every floor that control the amount of air that is introduced per floor.

4.6. Electrical and Building Controls Systems
Lighting: Installed a fully automated and daylight-dependent lighting system, including motion detection, automated dimming and zoning, daylight-dependent shading operation and positioning

Services: Fully automated building services system

Controls: Motion and window detector controlled heating and cooling, as well as $CO_2$ sensors

WC: Waterless urinals

4.7 Renewable systems
PV: Installed 10 kW (peak)-PV system on the roof. Prepared for future installation of a 10 kW (peak)-PV on the southern façade, which will be required to meet the Zero Net Energy standard.

4.8 Verification
Blower door tests were conducted in two stages. The first was a random test at two floors performed after the installation was completed. The core was excluded. The result was 0.35 air changes per hour at 50 pascal. Before commissioning, a blower door test was performed on the entire building, including the core. The results were 0.55 air changes per hour at 50 pascal, which meets the Passive House standard.

## 5.0 LCT ONE – CONSTRUCTION PROCESS

While foundations and concrete core where being built on site, the wall elements and the hybrid wood/concrete floor slabs were being produced off site. The assembly of the wall and hybrid floor elements took eight days on site, one floor per day. Following is a brief explanation of the prefabricated wall and floor elements and their installation:

5.1. Producing slabs
The industrial production of the hybrid wood/concrete slabs took place in a precast concrete shop. The heavy timber, glulam beams were supplied by a lumber manufacturer who cut them accurately with CNC machinery and attached the required metal fasteners and connectors. The slabs were delivered to a precast concrete manufacturer, who placed them in metal forms, added metal reinforcement and poured the concrete. This process was repeated each day for each form. The advantage of this system is it allows the concrete to cure off-site and prevents additional moisture into the building. Additionally prefabricated slabs are assembled quickly on site (8 minutes per slab) to very tight tolerances. (See Fig. 4).

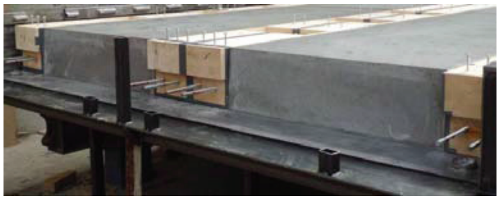

*Fig.4: Production of hybrid slabs. Wood in metal frame.*

5.2 Producing walls
The walls were produced in a local carpentry shop. Engineered lumber was used for all wood members, including studs. The panels were produced on tables, horizontally, where the timber frame, sheathing and insulation were installed. After standing up walls, the windows were installed. All joints, including around the windows were taped air-tight with high performance tapes. (See Fig 5)

*Fig 5: Production of timber frame walls*

5.3. Quick installation

After production, all the slab and wall elements were shipped to the site and the assembly began. Five skilled carpenters were able to assemble all the components, water-tight and air-tight in eight days, for all eight stories. (See Fig 6)

*Fig 6: LCT ONE: Day 2, 4 and 8 of installation process*

5.4. Verification

To verify that the energy standard will be met, blower door tests were performed twice as mentioned above, once when the installation was done and a final test prior to commissioning.

## 6. CONCLUSION

LCT ONE is an innovative design and construction project that introduces a sustainable building solution for future buildings in growing cities. LCT ONE begins with the premise that the building industry does not automatically have to rely on concrete and steel for urban buildings and demonstrates that there is the opportunity to substitute timber for many applications. Wood is a renewable resource. While one building is in construction, the sun is producing the timber for the next building, for free. Timber technology has advanced, where modern industrial machinery and processes make it possible to erect timber buildings quickly, economically, according to all building regulations and to high performance standards.

LCT ONE also introduces an industrial method to the design and construction of buildings. The building industry is still dependent on on-site manual labour and labour-intensive processes. It has the reputation of low productivity, waste and still uses antiquated technology. The building industry has made limited progress in industrialization and modern manufacturing processes while other industries have made considerable advancements. LCT ONE is pioneering a new way of building, based on guaranteeing performance. It was developed according to a system that can be the “shell and core” and offers flexible design solutions and architectural and aesthetic possibilities to make each building unique. By following this system approach, the performance of buildings can be guaranteed, similar to the performance of cars, computers and other products manufactured through industrial processes.

The aim of this paper was to present a new process for design and construction, based on modern techniques and renewable resources. Therefore, it was not necessary to list the specification for every product or system. The specification for every project is unique, and is developed with an integrated design and construction team, according to a specific location and climate, with the LCT system as a proven “core and shell” system.

Additionally, the LCT system can be applied as a worldwide solution. With its introduction in Europe and now in North America, it serves as an inspiration to wean the traditional building industry away from fossil fuel intensive products and systems. Less developed countries, especially the ones with forests can adapt the LCT system to modernize their building industry. They can introduce new sustainable forestry management policies and begin manufacturing modern engineered lumber products to build high performance timber buildings. A new process of education to create new green jobs and affordable housing solutions could be an alternative to attempting to develop building solutions which rely on fossil fuel based resources which less developed countries do not have and cannot afford.

## 7. REFERENCES

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# Modular system design for vegetated surfaces

## A proposal for energy-efficient buildings

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ABSTRACT: *A research project (GEOGREEN) is being developed based on the design concept of a modular system for vegetated surfaces suitable for new or retrofitted buildings. Designed to be demountable and adaptable to different surfaces and inclinations, it allows the creation of vegetated surfaces both in roofs, walls and other building elements. The modular system materials were selected to minimize the embodied energy and $CO_2$ emissions. It is based on alkaline activated binders (geopolymers), combining natural materials (insulation cork board) with the insertion of endemic vegetation resistant to dry mesomediterranean conditions.*
*The system is being designed not only to achieve a good performance itself, but also to contribute to the thermal performance of buildings envelope through the application of materials as design characteristics that allow it to function as a passive design solution.*

*Keywords: Modular system, vegetated surfaces, recycled materials, endemic vegetation, passive design*

### 1. INTRODUCTION

Buildings have a significant impact on energy use and on the environment, representing around 32% of total final energy consumption (IEA, 2013). In the European Union (EU) countries and in United States of America, residential and commercial sectors have a significant impact on energy use, achieving up to 40% of the total final energy consumption (EIA, 2012) (Eurostat, 2010).
Thus, it is important to find new strategies to reduce buildings energy dependency and greenhouse gas emissions.
The USA Department of Energy has already a classification system for net-zero energy buildings (NZEBs) considering the use of renewable sources and passive design strategies. The concept of NZEBs is used to classify residential or commercial buildings in which the energy needs can be supplied with renewable energy technologies (Pless and Torcellini, 2010).
In the EU all new buildings must be nearly zero-energy buildings by 2020. This target is focused on the Energy Performance of Buildings Directive (EPBD) from 2010 (AA.VV., 2010). It promotes the improvement of energy performance of new and existing buildings subjected to major renovations. To achieve this goal it is important to increase the use of efficient heating and cooling systems, renewable energy sources and passive design solutions.
Passive design solutions like, thermal insulation, thermal mass, natural ventilation (Carlos et al., 2010) and evaporative cooling (Pires et al., 2011), can contribute to interior comfort of buildings, minimizing their energy demands for heating or cooling, in particularly environmental conditions.
Green roof and green wall systems can have a significant impact on buildings energy efficiency, having the ability to be used as a passive design strategy (Pérez et al., 2011).
They are able to shadow the envelope, protecting it against direct solar radiation (Eumorfopoulou and Aravantinos, 1998) (Ip, 2010). Therefore, they contribute to the reduction of the heat flux through the envelope (Barrio, 1998).

They help reducing the energetic needs for cooling and heating (Liu and Baskaran, 2003) and contribute as an evaporative cooling system resulting from the evapotranspiration of plants and water evaporation from the substrate. Additionally, the implementation of green roofs or green walls can be an interesting strategy of greening in dense urban areas with lack of free space, considering the fact that they allow the integration of vegetation in buildings without soil occupancy (Virtudes and Manso, 2011).

On the other hand, green roofs or walls can reduce urban pollution. Plants have the ability to absorb $CO_2$ and heavy metals (Bruse et al., 1999), and trap dust particles circulating in the air (Köhler, 2008). Therefore, urban air quality can be improved by the filtering effect of green surfaces. Studies have also proven that green areas with a considerable dimension have the ability to cool the surrounding atmosphere (Oliveira et al., 2011).

Vegetation absorbs sunlight to develop its vital functions (e.g. photosynthesis, respiration and evapotranspiration) while it protects buildings envelope from external agents (e.g. sun, wind, rain). This avoids overheating and degradation of external materials, increasing their life expectancy (Luckett, 2009).

Thus the integration of vegetated surfaces in the urban environment apart from contributing as a passive design strategy to save energy in buildings, they have other advantages.

In fact, several researchers have been studying the multiple benefits of different green roof and green wall systems to buildings performance, as summarized in Figure 1.

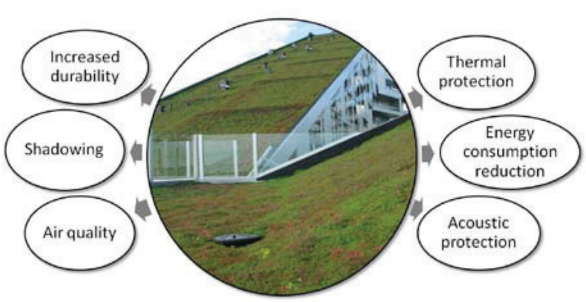


*Fig. 1: Benefits of vegetated surfaces to buildings performance*

## 2. EXISTING SOLUTIONS FOR VEGETATED SURFACES

There are several systems on market to create vegetated surfaces in buildings. These are generally known as Green Roofs and Green Walls. The selection of which is more appropriate to a certain project depends on the building characteristics (e.g. scale, type of building, construction techniques, load capacity) and the surrounding conditions (solar exposure, localization, accessibility and local climate).

Green roofs can be defined as extensive, intensive or semi-intensive, depending on their composition. The system selection depends of available depth for the substrate layer, plant selection and irrigation and maintenance needs.

Current developments on green roofs are centered on lighter systems, either modular or continuous, using resistant and adapted vegetation with low irrigation and maintenance needs.

Green Walls can be classified as Green Facades and Living Walls (Köhler, 2008).

Green facades include climbing plants, evergreen or deciduous, growing in the soil or in vessels, which cover a vertical surface by attaching themselves with their adhesive suckers or climbing roots to the vertical surface or a complementary support structure.

Living walls can be subdivided as Vertical Gardens and Modular Systems. These systems allow the application of a wider variety of plants and the creation of green walls with higher dimensions than Green Facades.

Vertical Gardens are continuous systems based on the application of a lightweight elements and an external permeable screen where plants are inserted individually in pockets. These are usually hydroponic systems, where water and nutrients permanently supplied by the irrigation system. The most known work in this field is from the French botanist Patrick Blanc, who has several examples all over the world.

Modular Living Wall Systems are mostly trays fixed to a support structure attached to the vertical surface. Most modular systems include a container filled with growing medium where plants can grow.

A literature review was based on the analysis of several green roof and green wall systems, studying their features, construction techniques and materials. It is now possible to understand the main difficulties for their implementation.

Their limitations are mostly centered in the installation and maintenance (Manso et al., 2012).
Intensive green roofs and living wall systems like Vertical Gardens enable the creation of vegetated surfaces with a wider variety of plant species. However, they are usually expensive, requiring periodical maintenance and high irrigation levels. In the case of intensive green roofs we must also take into account the building load capacity, and consider that it can require structural reinforcement, which represents an additional cost to the building construction.
Simpler solutions as extensive continuous green roofs and green façades including climbing species are more cost-effective, but have limitations in plants diversity. When there is the necessity of plants replacement, these systems show difficulties in ensuring vegetation continuity. In the case of green façades we must also consider the fact that climbing plants have some growing limitations. Some species achieve 5 or 6 meters, others 10 meters and some 25 meters heigh (Dunnet and Kingsbury, 2004). Most of them take around 3 to 5 years to achieve full coverage (AA.VV., 2008).
The alternative to these solutions can be the application of modular green roof and green wall systems. Modular systems are still relatively new (Dunnet and Kingsbury, 2008). They enable the installation and removal of each module individually. This can be beneficial, considering that it allows the integration of different plant species to create vegetated designed surfaces and simplifies the system maintenance.
From the analysis of all types of green roofs and green wall systems, it appears that most solutions focus on solving one constructive solution. In fact most solutions are not able to function as green roofs and green walls simultaneously (Manso et al., 2012).

## 3. SYSTEM DESIGN

An on-going research project is based on the design concept of a modular system for vegetated surfaces.
The main goals of the GEOGREEN modular system (Fig. 2) design are: adaptability to different supports; simplification of the construction and maintenance processes; ensure continuity and uniformity of the vegetal layer; minimization of plant irrigation; minimization of its environmental impact and improvement of buildings characteristics.
Designed to be more versatile then the existing green roofs and green walls, this system intends to allow the creation of green roofs and green walls simultaneously, considering the particularities of each surface. It can be suitable in new buildings and retrofitting and adaptable to surfaces with different shapes, sizes, inclinations or accessibilities. Therefore, it must be taken into account the materials selected and the operational requirements of the system when applied to different surfaces.
Designed to simplify the installation and maintenance processes, it allows the insertion and substitution of each module individually when in normal functioning.

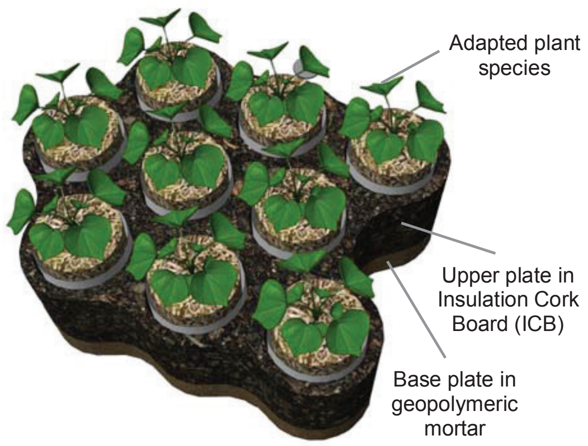


*Fig. 2: GEOGREEN modular system design*

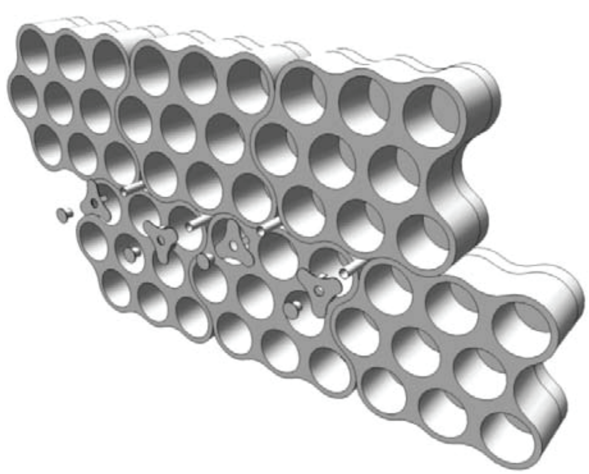

*Fig. 3: GEOGREEN interlocking system*

Each GEOGREEN module comprises 9 circular openings for substrate and plants insertion. The openings are aligned in each row and unaligned in different rows.
The application process consists in placing the modules parallel one to the other in the same row and mismatched between rows, so that they remain locked together.
In vertical or sloped surfaces, each module can be hold by a support structure inserted in the voids between them and sustained by locking pieces (Fig. 3).
This solution allows the system continuity and a reinforcement of its stability in vertical position.
The GEOGREEN modular system is based on pre-fabricated panels incorporating pre-planted vegetation. One of the developed studies consists in the selection of autochthonous or endemic plant species that are able to minimize the system irrigation and maintenance needs.
The intention of GEOGREEN modular system is to develop a passive cooling solution with environmentally sustainable concerns.
One of the purposes is to find strategies that allow the minimization of its environmental impact, by reducing the system embodied energy and therefore the $CO_2$ emissions. Furthermore, this solution combines the application of local recycled materials with endemic vegetation.

## 4. ELEMENTS SELECTION

The intention of the GEOGREEN modular system is to promote materials recycling through the development of a high value product from waste materials. The purpose is to provide unique properties to the system with the selected materials and contribute to a more sustainable solution.
It aims to differ from other systems based on the application of non-conventional materials, introducing certain thermal, acoustic and environmental benefits that other systems do not integrate.
Each module comprises two main elements (Fig. 2): a geopolymer base plate; and an upper plate made with Insulation Cork Board (ICB).
The study is complemented by the selection of endemic vegetation, adapted to the Beira Interior Region were the project is being developed.

### 4.1. Base plate

Previous studies have shown that mine waste mud from Panasqueira mines is rich in alumino-silicates and can be used to produce alkaline activated binders (geopolymers) (Torgal et al., 2008).
Geopolymers reveal excellent properties, in particular on their durability, resistance to acidic attack, behavior at high temperatures and fire resistance, resistance to frost attack (Rangan, 2009). Studies based on the development of geopolymers using mine waste mud from Panasqueira mines as precursor show that alkaline activation is a secure process of encapsulation of heavy metals (Torgal, et al., 2009) (Torgal, et al., September 2010).
In this research, the base plate is being developed with alkaline activated binders (geopolymers) using a blend of mine waste mud and other waste materials. Preliminary results indicated that a compressive strength of 6 MPa can be obtained, after 7 days of curing at a temperature of 60ºC in a ventilated oven.
The geopolymeric mixes have a capillary absorption coefficient between 0,63 and 1,33 $Kg.m^{-2}.\ h^{0,5}$.
Introducing expanded cork granules in the mix can minimize the density of these plates. A percentage of 50% cork enables a final density of 1.3 $g/cm^3$. This corresponds to 2.4 Kg per module and a total weight of 26 $Kg/m^2$.
So, the base plate final properties combine good water absorption, low density and good mechanical resistance.
The water absorption rate shows that the geopolymer plate can absorb the water quickly and supplying it to the plant substrate, minimizing the irrigation needs.

### 4.2. Upper plate

Insulation Cork Board (ICB) is a natural eco-friendly material made from the agglomeration of expanded cork granules.
The upper plate is made by cutting ICB boards with a density of 160 $Kg/m^3$ and 8 cm (3,15 inches) thickness, with the shape presented in Figure 2. Each upper plate presents a weight of 0,650 Kg, comprising a total weight of 7$Kg/m^2$.
The main advantages of using ICB are the fact that it is a sustainable material, with low density, which is capable to support the substrate and plants.
We believe that considering that ICB is an insulation material with a heat transfer coefficient

of 0.5 $W/m^2.K$, it will contribute to increase the thermal performance of buildings envelope.

4.3. Plant species

Plant selection was based on the study of herbaceous and shrubby associations adapted to local climate conditions (Delgado et al., 2011) and construction restrictions. Consisting of plant species resistant to the Beira Interior Region climate, with dry mesomediterranean conditions, it was given privilege to autochthonous or endemic species with different leave forms and textures and variations in blooming periods.

The main purposes are the promotion of biodiversity, while minimizing adaptation problems and irrigation requirements.

The tests were based on survival rate evaluation of ten samples of sixteen selected plant species for each irrigation period and each substrate.

These plants were submitted to three irrigation periods of ten minutes using micro sprinklers (daily watering, three times weekly watering and once weekly watering).

They were also installed in three different substrates: Siroroof substrate, available on market, with 60% organic and 40% inorganic components; *Sedum* substrate, containing 30% organic and 70% inorganic components (mainly expanded clay); and *Inverted Sedum* substrate with 30% organic and 70% inorganic components (mainly volcanic rock).

The results show that *Achillea millefolium* and some of the *Thymus* species survived to three times watering per week and *Sedum* species survived to watering once per week. However, most plant species can only resist to a daily irrigation in the first year of growth.

From the tested substrates we can conclude that *Siroroof* substrate showed greater results in most plant species.

Based on these conclusions, next phase consists in the evaluation of selected species adaptation to the materials, considering their pH conditions.

## 5. CONCLUSION

Green roof and green wall systems must evolve to: more sustainable solutions; simpler to install and maintain; made with materials with less incorporated energy and $CO_2$ emissions; including climate adapted plant species with less irrigation needs.

Considering the benefits of vegetated surfaces, these systems must be designed to complement the thermal performance of buildings envelope. And therefore, contribute to the reduction of buildings energy consumption, for heating or cooling.

The GEOGREEN modular system is designed to contribute as a passive design solution for buildings, associating the benefits of adapted vegetation with the thermal, acoustic and environmental characteristics of the associated materials.

The following work will consist in identifying the geopolymer mixture with best combination of porosity, density and compressive strength; understand if the ICB layer is effective; and evaluate the performance of the selected plant species when in contact with the system materials.

Finally, it should be noted real climate studies will be carried on in future to evaluate the thermal performance of the GEOGREEN system and its contribution as a passive design solution.

The real climate studies can be of particular interest for the application both Portugal and other countries with similar weather conditions.

## 6. ACKNOWLEDGEMENTS.

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# Pierce Library Learning Crossroads

## A High Performance Library Design

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**ABSTRACT:** *The Pierce Library Learning Crossroads building is designed and built using strategies aimed at achieving high performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality. It is through a combination of passive design strategies, mechanical systems, and renewable systems and through a detailed high performance design process that the project is able to attain an energy savings of 50% (per ASHRAE 90.1). The design of the library is intended to enhance the learning environments of the students that use the spaces within; however, and perhaps most importantly, through its resulting design it aims to educate building users about how they can contribute to the realization a low carbon world.*

*Keywords: high performance, library, energy efficiency, low carbon*

### 1. INTRODUCTION

The Pierce College Library Learning Crossroads is a two-story, mixed use, 119,900 GSF building located in Woodland Hills, California (climate zone 9). It is sited at the northwest end of the campus, adjacent to the main pedestrian artery of the Pierce College campus. The project occupies a very prominent location on campus, and will serve as both a gateway and a beacon to the entire campus community. In addition, it will be highly visible from the interior of the campus and from the approach along Victory Boulevard and the western access points to the college.

*Fig. 1: Pierce LLC site plan*

Pierce LLC is designed with high performance strategies and processes, which results in a building that is a living laboratory for the campus. The building is predicated upon the philosophy that good design *is* sustainable design; these terms are synonymous. As such, the design process for Pierce LLC implements a hierarchal structure of strategy approach. Passive systems form the basis of the approach; Mechanical systems are then supplementary; and lastly renewable systems are enhancements to the overall energy performance. The process also includes a rich integration of high performance studies such as daylighting, glare analysis, shadow patterns, energy modelling, and life cycle cost analysis. These studies are critical to producing a data based design by providing a solid set of rules and justifications for each design decision. The high performance design process allows the project to achieve a 50% energy savings per AHSRAE 90.1.

### 2. PASSIVE DESIGN ANALYSIS AND STRATEGIES

2.1 Daylight Harvesting

The importance of daylight is perhaps most important within a library space. Building occupants rely upon adequate lighting conditions in order to read and study. To optimize interior occupant comfort and performance while enhancing energy performance of the buildings, a detailed daylighting analysis was conducted during the design process. Ectotect software was utilized to generate daylight simulation models of the first and second floors for three cases in order to determine the best daylighting option for the project. For reading areas, a daylight illumination level of 25 horizontal footcandles was targeted as a minimum, (per LEED for New Construction, v2.2):

Case 1: Perimeter glazing which is supplemented by entry skylights and intermittent solatubes. In Case 1, adequate daylighting levels are not achieved, with most spaces receiving between 0-12.5 footcandles on the first floor. Substantial artificial lighting would be required in order provide optimal lighting requirements. The second floor of the Case 1 is supplied with 25 footcandles to most spaces, with exception to a few areas along the north and east of the building.

Case 2: Supplementing case 1 with daylight harvesting fixtures. Daylight analysis indicates that by employing daylighting strategies such as skylights and solatubes, spaces which were previously receiving between 0-12.5 footcandles (Case 1), would be able to receive up to 25 footcandles (Case 2). The second floor of Case 2 would be supplied with 25 footcandles within most spaces, with exception to a few areas along the north and east of the building.

Case 3: Additional skylights, solatubes and increased window area. By implementing additional skylights, solatubes, and larger windows areas, additional spaces on the second and first floors would be able to receive natural daylighting levels at 25 footcandles.

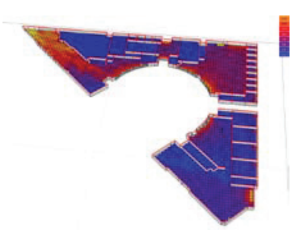

*Fig. 2: Ecotect analysis of Case 1, First Floor*

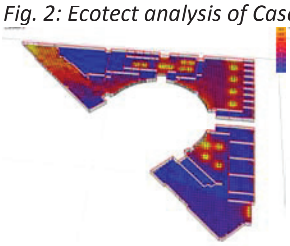

*Fig. 3: Ecotect analysis of Case 2, First Floor*

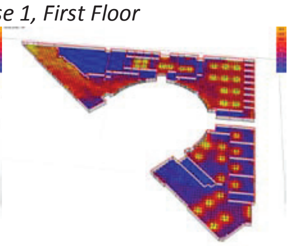

*Fig. 4: Ecotect analysis of Case 3, First Floor*

## 2.2 Solar Control Glass

In order to ensure optimal daylight conditions, daylight simulation studies were conducted which demonstrated the advantage of using solar control glazing to reduce glare. RADIANCE was used to analyze the luminance performance in the main reading area along the atrium. Two side by side cases were studied and compared:

1. Case A: Clear Solarban Solexia 70XL glass
2. Case B: Sage glass

These two cases were studied at 4:00 p.m. in the afternoon, in the summer season, when solar penetration is greatest. The studies use a color index to describe the degree of solar glare occurring in a space. The greater the contrast between the light coming in from the glass and the surrounding interior environment, the greater the glare. The less contrast between the two, the less the glare.

Each color represents a level of luminance. The units are expressed in terms of lumens per square meter, (NITS). The goal is to achieve the least amount of contrast, or values between the colors, while still providing adequate daylighting levels.

A signature design feature of the building includes a large, centrally located atrium space. This atrium is an exterior oculus which encloses an outdoor courtyard. Light from the courtyard daylights the interior of the library. However, left untreated, the glass along the atrium could cause uncomfortable glare conditions within the library space during certain times of the year. By testing the daylight effects of the spaces located off of the atrium, the design team was able to mitigate glare issues.

Case A indicates a high level of contrast between the light entering the glass at the courtyard atrium and the surrounding interior reading area. Three basic colors are apparent in the diagram: bright green (437.5) at the window surface, red along the floor surface (937.5), and blue (62.5) for all surrounding library interior surfaces.

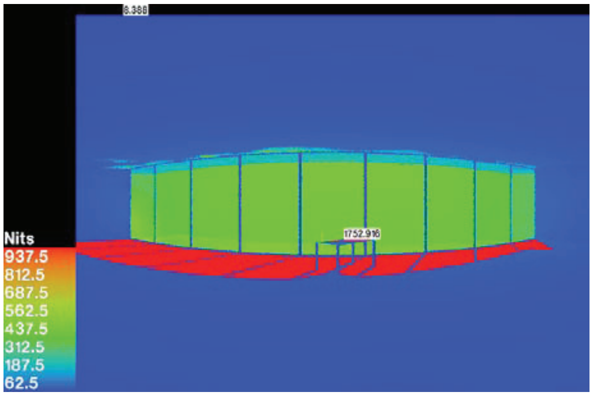


*Fig. 5: Radiance analysis of Case A at the atrium.*

Case B indicates minimal contrast between the light entering the glass at the atrium and the surrounding interior reading area. There is a much more gradual blend between tones of blues and greens (62.5-312.5). This indicates that the space would be optimally daylit, without the inconvenience of solar glare.

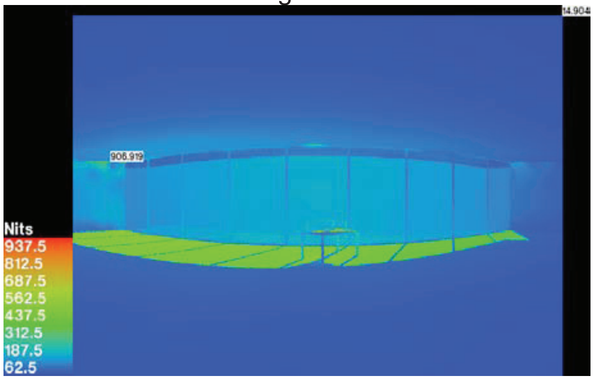


*Fig. 6: Radiance analysis of Case B at the atrium.*

Sage glass in the atrium space was initially selected based upon these finding in order to provide the interior reading areas with minimum glare and optimum daylight. However the material was later substituted for Okawood glass due to aesthetic client preferences. Okawood is composed of static wooden louvers sandwiched between two panes of low-e glass. The glass provides 50% visible transmittance, thus reducing the amount of glare entering the reading space as well. Okawood replaced all instances of Sage Glass, and maintains a more consistent pattern of light throughout the year, as the wooden louvers are static members.

2.3 Responsive Facade Design

Exterior shading devices and overhangs were carefully calculated in order to provide ample daylight while minimizing glare, and to minimize heat gains coming into the building. Deep overhangs, and a central atrium space provide the proper balance of light within the library. Shadow analysis was conducted in order to study the effects of glazed areas on reading spaces within the library. This allowed the project team to better determine window areas, transparency, and locations of electrical lighting.

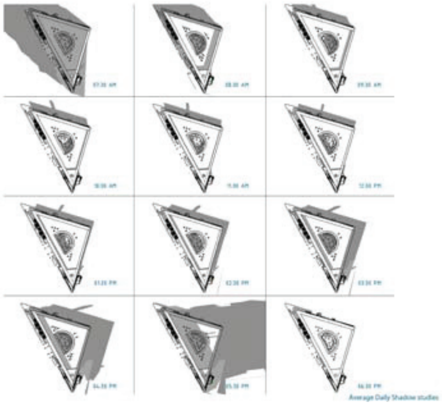

*Fig. 7: Shadow studies of exterior design*

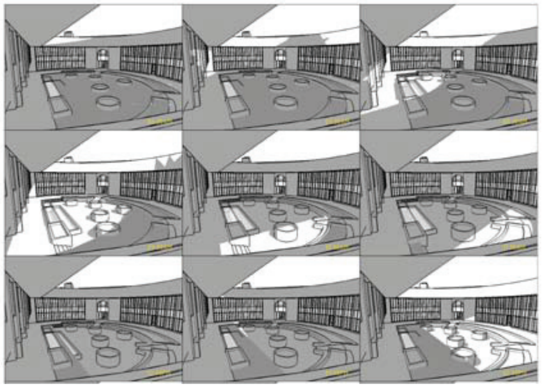

*Fig. 8: Shadow studies of the interior atrium space.*

2.4 Building Envelope Assembly

The building envelope is designed to be responsive to the temperature swing from winter to summer which is characteristic of Woodland Hills. As such, superior insulation is chosen for the walls (R21) and roof (R38); high performance glazing is specified to combat solar glare and heat gains, (Solarban 70xl Starfire and Okawood), and a high solar reflectance clay tile roof is specified to deter solar gains from penetrating the roof membrane.

## 3. MECHANICAL SYSTEMS

3.1 Mechanical System Components

As the daylighting systems, building envelope and facade design are determined, mechanical systems are also studied. The mechanical system of the building provides multiple forms of efficiency without altering the building program layout. These efficiencies are realized from an energy, floor space and operational/academic perspective.

3.2 Under Floor Air Distribution

The under floor air distribution system provides cooling energy savings. First and foremost, the higher supply air temperature of 63 to 65°F greatly increases the potential for free cooling. In climate zone 9, there are more than 2,000 hours annually that the outside temperature is between 55 °F and 65°F. Secondly, the higher supply air temperature also increases the efficiency of mechanical cooling equipment. Thus, there is less work required from the chilled water central plant.

3.3 Fan Wall Air Handling Units

By using Fan Wall Air Handling Units, the units have multiple fans to deliver the air to the space. Multiple fans provide a more compact Air Handling Unit and produced less noise and vibration than conventional AHUs. Fan Wall Air Handling Units furthermore provide redundancy to air condition the space more effectively and consistently.

3.4 DV systems

Finally, as warmer air is exhausted from the ceiling return, DV systems reduce cooling coil loads. There are two zones in the building, a stratified occupied zone and a mixed upper space zone. Much of the heat from the upper part of the space does not enter the occupied zone and thus does not have to be removed by the cooling system.

3.5 Boilers and Tankless Water Heaters

The Xtherm Boilers in the building produce up to 99% efficiency at low fire during peak demand, thereby contributing to the building's overall energy performance.

Tankless Water Heaters employ an on-demand system, which does not require a pilot light and can save approximately half the cost of water heating bills due to the fact that there is no re-heating of water, as with traditional water heaters. Compared to conventional water heaters at 60% efficiency, Tankless Water Heaters are able to achieve an 83%-94% energy-efficiency.

## 4. RENEWABLE SYSTEMS

4.1 Photovoltaic Panels

The roof of Pierce LLC is designed to support a future rooftop photovoltaic installation. However, a portion of the campus on-site photovoltaic farm was allocated to the Pierce LLC project. A 120kW system was dedicated to the library project, thereby providing 18% of the building's total energy use. This allowed the overall energy savings to become 50%, per ASHRAE 90.1

As a design philosophy however, daylighting, building envelope and facade design are given primary focus in order to optimize building energy use, and in order to reduce reliance upon costly, active systems.

## 5. ENERGY RESULTS

5.1 Energy Modelling Analysis

EnergyPro energy modelling software was utilized as a design tool throughout the project in order to propose, test and validate decisions. As a result of the various passive, mechanical and renewable systems integrated into the design of the building, and energy savings of 50% is achieved. These savings are projected, modelled savings of the design.

**TABLE 1: ENERGY AND COST SUMMARY BY FUEL TYPE**

**Energy and Cost Summary by Fuel Type**

| Type | Proposed Use [kWh or therms] | Proposed Cost | Budget Use | Budget Cost | Proposed / Budget Energy % | Proposed / Budget Cost % |
|---|---|---|---|---|---|---|
| Electricity | 806,875 | $ 85,883 | 1,220,921 | $ 139,281 | 66% | 62% |
| Natural Gas | 7,010 | $ 6,601 | 13,818 | $ 12,384 | 51% | 53% |
| **Total Nonrenewable** | | $ 92,484 | | $ 151,665 | | 61% |
| PV | 164,675 | $ 17,527 | | | | |
| **Total including Renewable** | | **$ 74,957** | - | **$ 151,665** | | |
| | | **Percent Savings without Renewable Energy =** | | | | **39.02%** |
| | | **Percent Savings with Renewable Energy =** | | | | **50.58%** |
| | | **EA Credit 2, Solar Percent Savings =** | | | | **18.95%** |

Construction of the building was recently completed in December of 2012. Full occupancy of the building occurred in February of 2013. Real time energy data will be pulled and analyzed within 6 months of occupancy in order to test and adjust the mechanical and electrical systems accordingly. This is also part of the requirement per LEED credit EAc5, Measurement and Verification. In addition, a post-occupancy evaluation will be administered to occupants of the building within a year. This POE will provide the design team with feedback regarding occupant comfort, and will allow for an opportunity to take any potential corrective actions in order to attain optimal occupant satisfaction and comfort.

## 5.2 Life Cycle Cost Analysis

The building systems specified for the Pierce LLC project are constructed of components and materials that are high quality, long-lasting, economically feasible, operationally maintainable, and that minimize adverse affects on the environment and human health. These qualities have a direct impact upon the life cycle cost of a building. The Life Cycle Cost Analysis for the Pierce LLC project provides an opportunity to assess the durability of systems and their associated life cycle costs over a 20 year life period. The following parameters were assumed for the evaluation:

| | |
|---|---|
| Discount Rate | 5% |
| Inflation | 4.6% |
| Maintenance cost escalations | 2% |

The following systems are analyzed for the purpose of the life cycle cost study:

Mechanical System:

- Air Handlers
- Boilers
- Pumps
- Electrical System:
- Transformers
- Plumbing System:
- Water heaters

Architectural System (building envelope):

- Walls (plaster, metal stud, R-21)
- Roof (red clay tile, PVC, R-38)
- Glazing (Solarban 70XL and Okawood)

Analysis of each system indicates that an average of 15-20 years would be realized. The life cycle cost analysis also provides a realistic indication of the costs required to maintain building systems. This allows the client to allocate resources effectively. The study illustrates how the proposed design will provide lowest overall cost of ownership relative to the longevity, quality and function of the building systems.

**TABLE 2: LIFE CYCLE COST ANALYSIS OF WALL ASSEMBLY**

LIFE CYCLE COST SPREADSHEET

PROJECT DATA

PROJECT: Pierce College Library Learning Crossroads Building     Design Build Team: Bernards/HMC Architects

SYSTEM: Building Envelope: Walls

DISCOUNT&ESCALATION

| | Years: | | Rate: |
|---|---|---|---|
| Discount Rate (i) ............ | 2010 - 2,030 ........ | | 5.0% |
| Maintenance ................ | 2010 - 2,030 ........ | | 2.0% |
| Inflation.................... | 2010 - 2,030 ........ | | 4.6% |
| Equipment Life.............. | 40 | (Actual life to be entered by DB Team) | |

ANNUAL REAL CASH FLOWS

| (Begin) Year 2,010 | First & Replace. Costs $1,641,200 | Annual Maint. Costs $7,400 | Total Annual Costs $7,400 | Present Worth Factor (1+i)^-n | Present Worth of Annual Costs | Age of Equipment | Residual Value of Equipment | Present Worth of Cumulative Costs |
|---|---|---|---|---|---|---|---|---|
| 2,010 | $1,641,200 | -- | $1,641,200 | 1.00 | $1,641,200 | 0 | ($1,641,200) | $1,641,200 |
| 2,011 | $0 | $7,548 | $7,548 | 0.95 | $7,189 | 1 | ($1,600,170) | $1,648,389 |
| 2,012 | $0 | $7,699 | $7,699 | 0.91 | $6,983 | 2 | ($1,559,140) | $1,655,372 |
| 2,013 | $0 | $7,853 | $7,853 | 0.86 | $6,784 | 3 | ($1,518,110) | $1,662,155 |
| 2,014 | $0 | $8,010 | $8,010 | 0.82 | $6,590 | 4 | ($1,477,080) | $1,668,745 |
| 2,015 | $0 | $8,170 | $8,170 | 0.78 | $6,402 | 5 | ($1,436,050) | $1,675,147 |
| 2,016 | $0 | $8,334 | $8,334 | 0.75 | $6,219 | 6 | ($1,395,020) | $1,681,365 |
| 2,017 | $0 | $8,500 | $8,500 | 0.71 | $6,041 | 7 | ($1,353,990) | $1,687,406 |
| 2,018 | $0 | $8,670 | $8,670 | 0.68 | $5,868 | 8 | ($1,312,960) | $1,693,275 |
| 2,019 | $0 | $8,844 | $8,844 | 0.64 | $5,701 | 9 | ($1,271,930) | $1,698,976 |
| 2,020 | $0 | $9,021 | $9,021 | 0.61 | $5,538 | 10 | ($1,230,900) | $1,704,513 |
| 2,021 | $0 | $9,201 | $9,201 | 0.58 | $5,380 | 11 | ($1,189,870) | $1,709,893 |
| 2,022 | $0 | $9,385 | $9,385 | 0.56 | $5,226 | 12 | ($1,148,840) | $1,715,119 |
| 2,023 | $0 | $9,573 | $9,573 | 0.53 | $5,077 | 13 | ($1,107,810) | $1,720,196 |
| 2,024 | $0 | $9,764 | $9,764 | 0.51 | $4,932 | 14 | ($1,066,780) | $1,725,127 |
| 2,025 | $0 | $9,959 | $9,959 | 0.48 | $4,791 | 15 | ($1,025,750) | $1,729,918 |
| 2,026 | $0 | $10,159 | $10,159 | 0.46 | $4,654 | 16 | ($984,720) | $1,734,572 |
| 2,027 | $0 | $10,362 | $10,362 | 0.44 | $4,521 | 17 | ($943,690) | $1,739,092 |
| 2,028 | $0 | $10,569 | $10,569 | 0.42 | $4,392 | 18 | ($902,660) | $1,743,484 |
| 2,029 | $0 | $10,780 | $10,780 | 0.40 | $4,266 | 19 | ($861,630) | $1,747,750 |
| 2,030 | $0 | $10,996 | $10,996 | 0.38 | $4,144 | 20 | ($820,600) | $1,751,894 |
| Totals: | $1,641,200 1st+Repl | 183,397 Maint | $1,824,597 Total Annual | | $1,751,894 | | ($820,600) | $931,294 |

## 6. Additional Features

6.1 The ultimate design addresses not only energy, but water, waste, air quality, acoustics, stormwater, transportation and sustainable education. As a result of the high performance strategies integrated within the building, the project is able to achieve 40% water savings, 80% landfill waste diversion, superior air quality and acoustic performance, 10% recycled and regional construction content and will consequentially also achieve LEED Gold in the USGBC LEED NC 2.2 rating system.

### 6.2 Stormwater and Landscaping

A stormwater management plan which employs landscaped areas and underground water storage help the project achieve a 25% decrease the volume of stormwater runoff for the 2 year, 24-hour design storm.

Open space in the form of native and adaptive landscaped areas constitutes at least 20% of the total project area. No potable water is used to irrigate the project's landscaped or vegetated areas. Paving with a solar reflectance index (SRI) rating of 86 and landscaped areas designed throughout the open areas of the project site combat heat island effect.

### 6.3 Water Efficiency

By specifying low-flow fixtures, waterless urinals, and time sensored lavatory faucets the project is able to attain 40% water savings. At the site scale, the project relies upon non-potable water for the purposes of irrigation. Condensate water is collected from air handling units on the roof and redirected to an underground water storage tank on the north side of the site. Based on 10 hours operation of the library, calculations show that 117,000 gallons of water will be collected annually for irrigation.

6.4 Indoor Air Quality and Acoustics
Six feet long floor-recessed, metal grilles at doorways, separation and exhaust of hazardous gases and chemicals at janitorial rooms and MERV 14 filtration for mechanically ventilated space prevent indoor pollutants from entering the building. Underfloor air distribution throughout the library, upholds superior air quality by delivering air closer to occupants and then exhausting warm, contaminated air directly out. In addition, low emitting materials are specified throughout the building.

6.5 Transportation
The College is located nearby bus and train lines. In addition, a campus shuttle provides students and staff with easy access to the entire campus. LEV and ZEV preferred parking is also provided on campus. These campus actions aid in reducing overall emissions caused by transportation.

6.6 Waste Reduction and Landfill Diversion
During the construction process, an 80% landfill diversion rate was achieved, which included both construction and demolition. Within the building, central recycling areas and individual recycling bins are provided in offices and classrooms. The building itself is composed of recycled and regional materials which constitute 10-15% of the construction cost.

6.7 Sustainable Education
Pierce LLC will serve as a living laboratory from which building users can learn more about how to adopt low carbon practices and lifestyles. A sustainable signage program throughout the library will highlight the various high performance features of the building. A looping screen saver program which illustrates the sustainable features of the building will also be defaulted to all computer screens within the library, as to encourage building users to learn more about the built environment in which they are studying. Sustainable attributes, such as optimal daylighting and acoustics will naturally enhance the overall comfort and performance of those who use it, with the greater goal of inspiring occupants to emulate the resource conscious strategies which are demonstrated throughout the building.

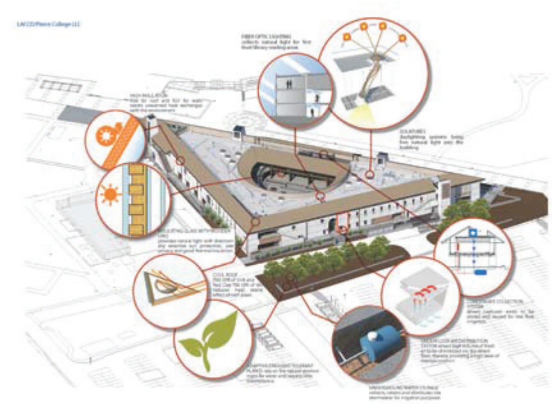

*Fig. 9: Pierce LLC Sustainability Diagram.*

## 7. CONCLUSION

The resource efficient design of Pierce Library is only possible through a high performance process which acknowledged a hierarchy of strategy approach. By focusing first and foremost on the building envelope and form to reduce overall heat gains and losses, mechanical and renewable systems are not burdened with the task of compensating for energy use. Furthermore by placing more importance on daylighting, glare and thermal comfort, occupant performance and satisfaction is supported. This approach allows the building to set a course toward net zero. However it is through consideration of the full gamut of high performance design strategies, (energy, water, waste, transportation, acoustics, and air quality) that the greater goal of a low carbon project is realized.

## 6. ACKNOWLEDGEMENTS.

The design of Pierce LLC was a collaborative effort of HMC Architects, Paul Murdoch and Associates, Glumac Engineers, Ahbe Landscaping, Penco Civil Engineering, Los Angeles Community College District, and Pierce Community College.

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# Thermal modeling of capillary micro tubes integrated in a thin-shale concrete sandwich element

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*ABSTRACT: The thermal performance of radiant heating and cooling systems (RHCS) composed of capillary micro tubes (CMT) integrated into the inner plate of sandwich elements made of High Performance Concrete (HPC) was investigated in the article. Temperature distribution in HPC element around integrated CMTs was studied. Thermal heat flux on the inner surface of HPC element was carefully investigated. Calculations were carried out for different temperatures of the circulating fluid, different spacing between CMTs and different thicknesses of the inner HPC layer covering the CMTs. This paper shows that CMTs integrated into the thin plate of sandwich element made of HPC can supply the energy needed for heating and cooling. The investigations were conceived as a low temperature concept, where the difference between the temperature of circulating fluid and air in the room was kept in range of 1 to 4°C.*

*Keywords: capillary micro tubes, radiant heating and cooling, sandwich element*

## 1.INTRODUCTION

Energy use in the building sector must be reduced in most European countries to approximately 20 kWh/m$^2$ /year by the year 2020 [EPDB]. Buildings with low energy use can be built by use of highly insulated building envelopes, high performance windows, high performance heating and cooling systems, and ventilation systems with heat recovery. Highly insulated sandwich panels of High Performance Concrete (HPC) offer good thermal insulation with a minimum of thickness of walls as the concrete plates are only 2-5 centimeters thick. New concepts of integrated heating and cooling systems need to be developed to allow a full prefabrication of HPC elements and provide the required indoor environment in an optimal way. New concept of radiant heating and cooling systems (RHCS) could be based on capillary micro tubes (CMT) cast in the inner concrete plate of HPC element.

Several RHCS, integrating pipes, ducts or electric cables in different building constructions, are available [Uponor 2012], [Fenixgroup 2012]. This article deals with water based RHCS using thin tubes (diameter of 2 to 4mm) to hold the heating or cooling fluid.
RHCS can operate with low temperature differences between the fluid circulating in the pipe and air in the room. Systems running with low temperature differences can regulate the power output from RHCS, a kind of passive control system. When there is a small decrease in room temperature, there is a corresponding transfer of heat from the surface to the room. Conversely, when there is an increase in room temperature, the corresponding heat flux increases as well.

When using RHCS in buildings, comfort of the occupants can be achieved at a lower room temperature compared to the use of convective systems (in the case of heating). This means that energy can be saved on heat losses for ventilation and on transmission losses. Similarly, the cooling can operate with higher air temperature in the room, resulting in lower energy consumption.
The uniform thermal environment is established in a designed space when using RHCS due to the radiant heat exchange between the activated

surface and surrounding surfaces in the room. As a result, there is improved comfort for occupants. When properly designed, the RHCS do not cause any draughts and do not produce any noise, which is often the case when using air-convective systems. RHCS can also add to the aesthetic value of buildings as they do not disrupt the designed space and therefore increase the architectural value of the building construction.

To date, there has been little research into the use of very thin tubes in RHCS. As far as heat transfer is concerned, the systems utilizing CMT could behave differently compared to systems using pipes with a bigger diameter. The overall thermal performance of RHCS technology using CMT needs to be investigated.

Hight Performance Concrete (HPC) is high strength and high density concrete containing different kind of additives resulting in very durable concrete with low permeability. This results in product very suitable for new generation of complete building system for low energy and sustainable buildings.

## 2. MATERIALS AND METHODS

2.1. Model of the HPC Element
A small section of the HPC element was chosen for investigation in the program Heat 2. The element was composed of two plates of HPC with the insulation material placed in between. Fig. 1 shows the investigated section of HPC element. The dimensions of the HPC element were as follows (from exterior to interior): HPC layer-20mm, polystyrene insulation- 250mm, HPC layer- 30mm. The CMT were placed in the middle of the inner HPC plate, as can be seen from Fig. 1. The properties of the materials used in the investigations are given in Table 1.

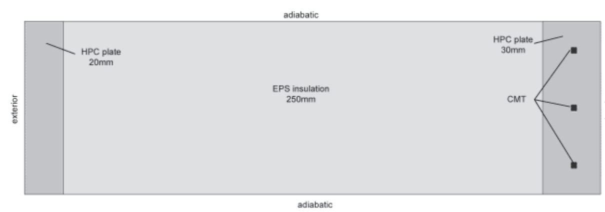


*Fig. 1: Section of HPC element built in program Heat 2*

**TABLE 1: PROPERTIES OF MATERIALS USED IN HPC ELEMENTS**

| Material | λ | c | ρ | C |
|---|---|---|---|---|
| | W/mk | J/kgK | kg/m3 | MJ/Km3 |
| High Performance Concrete | 1.9 | 1020 | 2320 | 2.3664 |
| EPS_ExpandedPolystyrene | 0.035 | 1270 | 35 | 0.04445 |
| Water | 0.6 | 4182 | 998 | 4.174 |
| PP_Polypropylene | 0.15 | 1800 | 930 | 1.674 |

2.2. Capillary Micro Tubes
The CMT are assembled into the capillary mats, see Fig. 2. Capillary mats are composed of two main manifold pipes and the CMT itself. The investigated CMT are circular with an outer diameter of 3.5mm, an inner diameter of 2mm, and a wall thickness of 0.75mm. CMT run in parallel and with a small distance between each tube, which creates evenly distributed temperature in the HPC element. The mat with CMT is a way of implementing RHCS into the surfaces where only a thin layer of construction is available, which is the case with HPC elements. Because of the relatively small size of the CMT, construction can be activated much quicker compared to RHCS using pipes with a bigger

diameter. The solution is very suitable for a construction made of HPC since the thickness of the concrete layer where the pipes are to be installed is only 30mm. Therefore it would not be even possible to install RHCS with bigger diameter pipes, for example pipes made of cross-linked polyethylene (PEX), which have usually outer diameter of 11 to 18mm.

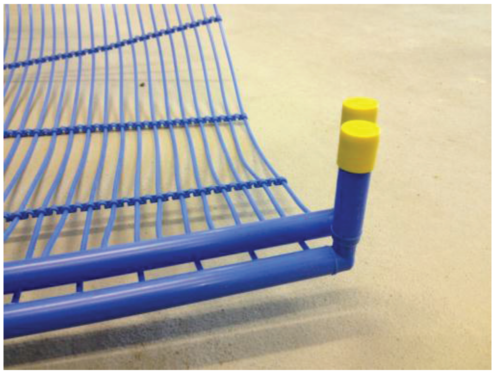

*Fig. 2: CMT mat*

2.3. Calculations

HEAT2 is a program designed to perform two-dimensional steady-state and transient heat transfer calculations. The program uses the method of explicit finite differences to solve the heat conduction equations. Investigated objects can be modeled only in rectangular mesh defined by the user [Blomberg 2000].

2.4. Energy Input Assigned to the CMT

The energy input to the CMT was assigned as a heat source with constant temperature of the fluid. The heat flow from the CMT depended on its total heat transfer resistance. Properly assigned properties of the water together with the precise value of the total heat resistance coefficient were presumptions for correct results of further calculations.

2.5. Boundary Conditions

The boundary conditions assigned in the Heat2 program can be seen in Fig. 1. Boundaries on bottom and top were assigned as adiabatic in order to avoid any influence of the resting part of the construction on calculations. The adiabatic condition ensured that no heat flow would go through those boundaries in any direction. The boundary at the interior side was specified with an air temperature, $T_{in-heating} = 20°C$ and $T_{in-cooling} = 26°C$, and total heat transfer resistance, $R_{in}$= 0.13$\frac{W}{m^2K}$.

The boundary condition for the outdoor environment was set to the value of the outdoor air temperature, $T_{out-heating} = 0°C$ and $T_{out-cooling} = 20°C$, and total heat transfer resistance for surfaces facing outside, $R_{out} = 0.04\frac{W}{m^2K}$.

2.6. Investigated Scenarios

The targeted value for heat flux to indoor environment was set to 10W/$m^2K$. This value was chosen as a reference so we could compare designed system to other radiant heating systems. For example, one of the most often used radiant heating systems, is composed of plastic PEX pipes (cross-linked polyethylene pipes) cast into the floor construction. The value of 10W/$m^2K$ is the design value for the required power of floor heating in very well insulated buildings. The required energy output of the system depends on the type of building and its location. The variables influencing the design of RHCS are heat loss of the building (including heat loss through constructions and ventilation heat loss), comfort issues (temperature of the surface, draught etc.), surface area available for installation of the RHCS and required reaction time of the system. Therefore the different scenarios were investigated in order to assess the performance of the system under different circumstances.

Four different configurations of the CMT mats were prepared for the investigations. The differences were in distance between the CMT imbedded in the HPC layer, which were set to 30, 50, 70 and 100mm.

Other variables during the investigations were the diameter of CMT (increased from 3.5 to 4.5mm) and thickness of the inner HPC layer. The originally investigated 30mm thick layer was increased to the 50mm in some calculations.

Assumed flow rate of working fluid is 0.1 m/s in all cases.

## 3. RESULTS AND ANALYSIS

3.1. Temperature Distribution on Inner Surface of the HPC Wall Element

The distribution of the temperature in the inner plate of HPC wall element can be seen in Fig. 3.

Four different configurations of CMT are presented with the distance of CMT of 30, 50, 70 and 100mm. The presented results were obtained from the Heat 2 software after steady-state conditions were reached. On the left side of Fig. 3 are shown the results for heating period and on the right side for cooling period. The temperature scale in Fig. 3 was set the same for all the configurations of CMT so that comparisons can be made. CMT with an outer diameter of 3.5mm were investigated.

Table 2 shows the differences between maximum and minimum temperature of the inner surface over the whole area of the HPC wall element.

The results showed that the distribution of the heat in the inner plate of the HPC element is sufficient to keep the temperature evenly distributed over the whole inner surface of the HPC element. This could be caused by rather small distances between CMT and by rather high thermal conductivity of HPC.

**Table 2: DIFFERENCES BETWEEN MAXIMUM AND MINIMUM TEMPERATURE OVER INNER SURFACE OF HPC ELEMENT**

| Max. Temperature difference over the surface of HPC wall | | | | | | |
|---|---|---|---|---|---|---|
| **Distance of CMT** | **Heating** | | | **Cooling** | | |
| mm | 21 | 22 | 24 | 18 | 21 | 22 |
| 30 | 0.006 | 0.01 | 0.018 | 0.031 | 0.02 | 0.016 |
| 50 | 0.024 | 0.042 | 0.076 | 0.136 | 0.085 | 0.067 |
| 70 | 0.055 | 0.06 | 0.173 | 0.31 | 0.216 | 0.152 |
| 100 | 0.11 | 0.125 | 0.347 | 0.622 | 0.385 | 0.306 |

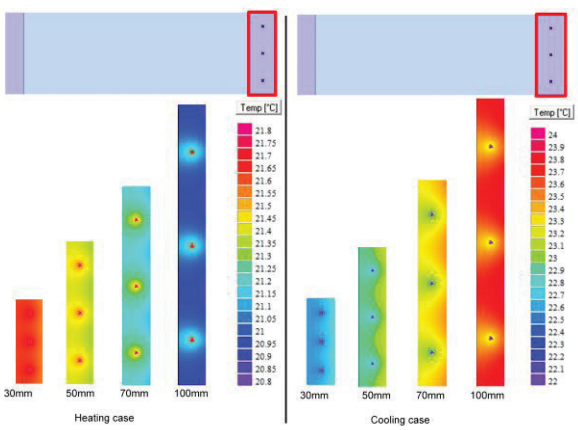


*Fig. 3: Temperature distribution in the inner layer of the HPC wall element for heating and cooling case*

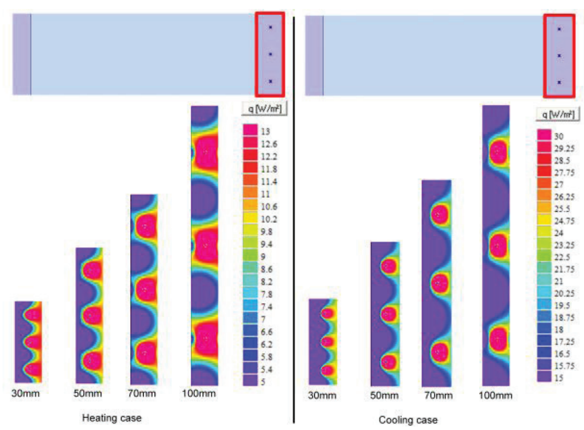


*Fig. 4: Heat flux distribution in the inner layer of HPC wall element for heating and cooling case*

3.2. Heat Flux Distribution on Inner Surface of the HPC Wall Element

Fig. 4 shows the heat flux distribution in the inner plate of the HPC wall element for four different configurations of the CMT. Just as in the temperature profile the heat flux on the inner surface is very uniform over the whole activated area of the HPC wall element. The heating case is shown on left side of Fig. 4 and the case for cooling on the right side. The temperature of working fluid was 22ºC for heating and 21ºC for cooling.

The different variations of CMT were prepared for purposes of further investigations. The first variation was to increase the outer diameter of CMT to 4.5mm. The second variation was to increase the thickness of the inner plate of the HPC wall element to 50mm. The results of the investigation can be seen on Fig. 5 and Fig. 6.

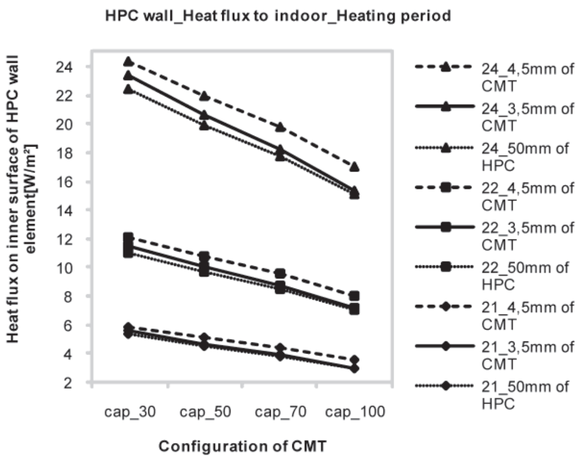


*Fig. 5: Heat flux to indoor environment from HPC wall element for different variations- heating case*

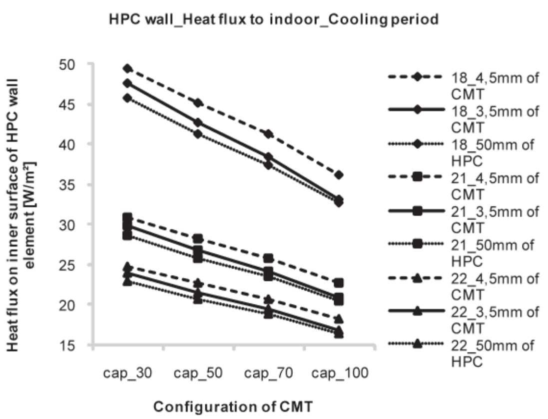


*Fig. 6: Heat flux to indoor environment from HPC wall element for different variations- cooling case*

3.3. Heat Loss to the Outside Environment

The temperature of the inner surface is higher in comparison when no CMT are embedded into the HPC element. Therefore, the increase of the heat transfer to the outer part of the wall element can be expected as a result. In other words, the heat loss of the HPC element with integrated CMT is increased as a result of its use. Fig. 7 shows the heat flux of the HPC element to the outside environment for the heating case. Increase of heat flux in comparison to the situation when no RHCS is activated can be seen in Fig. 8 .

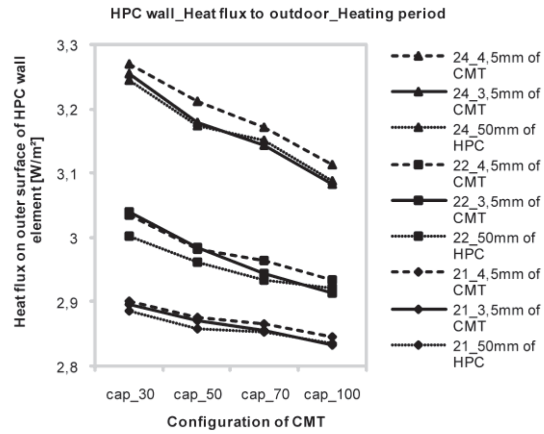


*Fig. 7: Heat flux to the outside environment*

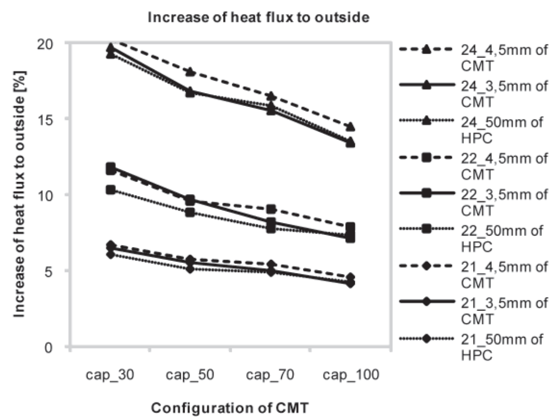


*Fig. 8: Increase in heat loss to the outside environment*

## 4. DISCUSSION

The aim of the research was to investigate how RHCS with various configurations of CMT behave under different operational conditions. In this way, the variables with strongest influence on the performance can be identified. These findings can be used for the future design of the RHCS using CMT integrated into the elements of building constructions. The suitability of this solution for use in very low energy buildings can be discussed.

4.1. Temperature Distribution in the HPC Wall Element

The results of the investigations showed that the temperature on the inner surface of the HPC wall element was evenly distributed. This was an important finding since occupants feel less comfortable when exposed to large differences in surface temperature on different constructions in the occupied space. An evenly distributed temperature is the main precondition for creating a comfortable indoor climate. [CEN CR 1752]

4.2. Heat Flux Distribution in the HPC Wall Element

The heat flux from the HPC element depends mainly on the temperature of the circulating fluid as can be seen from Fig. 5 and Fig. 6. The heat flux during the heating period can be doubled by increasing the temperature of circulating fluid by only about 2°C. Similarly during the cooling period the heat removed from the room can be increased to 60% by decreasing the temperature of circulating fluid by about 3°C. The main idea behind this project is however to keep the temperature difference between the circulating fluid and air in the room as low as possible. Therefore the focus should be on different ways of increasing the heat flux from the HPC elements. Alternative solutions include smaller spacing between the CMT and increasing the diameter of the CMT.
The heat flux decrease with increasing thickness of the HPC layer is shown in Fig. 5. This is caused by increased thermal resistance between CMT and the inner surface of HPC element. The differences are however rather small and should not particularly influence the design of RHCS integrating CMT. Therefore it can be assumed that the thickness of the HPC layer is not going to be a limiting factor during the design of RHCS in the HPC elements.

4.3. Practical features of CMT

Advantage of CMT over other available piping systems is its size, allowing us to situate the RHCS into the layer of concrete being just 30mm thick. This would be impossible with other systems known to author.
Concerning the pressure drop in the loop, it is rather low and very close to other systems (PEX pipe). Since the CMT runs in parallel to each other, the velocity of the fluid is very low, more precisely 0.1m/s. This velocity results in pressure drop of 0.02 bar, considering height of the wall element being 3 meters.
The life time of the system is more than 50 years depending on temperature of the fluid and operating pressure. The system should be installed in the environment with temperatures higher than 5ºC. Furthermore, contact of the system with direct sun radiation should be avoided.
The material used is polypropylene and is open to oxygen diffusion. Therefore all the parts installed in the system should be made from stainless steel materials or additional heat exchanger must be used to separate the system.

## 5. CONCLUSION

This paper has investigated the temperature and the heat flux distribution from capillary micro tubes through the element made of High Performance Concrete into the room space. Different configurations of the capillary micro tubes were investigated, concerning thickness and distance of the pipes. It can be concluded that a sufficient amount of energy can by supplied to the space through the radiant heating and cooling systems made of capillary micro tubes in a comfortable and economic way. Designed heating and cooling systems creates main preconditions for use of renewable energy sources.

## 6. REFERENCES

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# SECTION 2

## IMPROVING EXISTING BUILDING STOCK PERFORMANCE

# A Dynamic Simulation Approach for Visual Comfort Evaluation under Daylighting Conditions

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*ABSTRACT: Light plays a major role in the place making. A good number of today's buildings are unsuccessful in terms of visual conditions and comfort because they are only focused on function and structure. Connection with the environment turns the space into a place where occupants feel existence and dwelling. Movement through a space is an issue that was not addressed along with the time- dependency of the light source; the sun in daylit spaces; especially in museums and art galleries where lighting conditions are often strict. This research attempts to propose an innovative approach for evaluating visual comfort during the early stages of design, which will alter the design process. In addition to quantitative outputs, visual simulation renderings were used for qualitative analysis.*

*A case study was examined for visual comfort; the research inspected the effect of a creation of a passageway between two gallery spaces on visual comfort. Various parameters effects were examined. Preliminary results showed strong correlation between the transitional space and visual comfort enhancement. The research findings are expected to provide researchers, designers and decision makers with the efficiency of a given design space from the visual comfort perspective.*

*Keywords: Visual comfort, daylighting Museums, transitional spaces, Design Process*

## 1. INTRODUCTION

Today, a major interest is focused on the environment and energy consumption. Daylighting plays a major role in the energy efficiency and occupants' productivity, health and comfort. In addition, inhabitants' outside views provided by daylighting have a strong effect on psychological and physical wellbeing. In general, Daylighting dynamics create a sense of being existence in the place; transforms a space into a place where a feeling of awareness and dwelling is present. For all these reasons, knowledge of new skills and technologies are directed to enhance the visual environment in daylit spaces (Steemers 1994; Haddad 2010).

Building design community recognized the importance of building evaluation in terms of performance and comfort in the early stages of design as well as for post occupancy stages. The AIA proposed a new practice guide to help architects understand how an energy model works. It also discussed how to incorporate energy modelling in the early stages of the design process. Building simulation tools were proposed for their capability of showing qualitative aspects and identifying problems such as sustainability and comfort (AIA 2012; Kumaragurubaran 2012).

Visual comfort is defined as the state of mind that expresses satisfaction with the visual environment (Steemers 1994). Visual comfort is a human need that can affect task performance, health, safety, mood and atmosphere. Visual discomfort can result in moments of vision loss or longer adaptation time. The human visual system is very complex as it can adapt to a wide range of lighting conditions, varying from summer sunny day to starlight at night. Though, adaptation should happen without causing discomfort to the visual system where transitional spaces become significantly important. While daylighting a museum represents a distinctive, challenging design problem, many architects have successfully incorporated daylight into galleries. Natural daylight plays a major role in museum and gallery exhibitions quality; still consideration has to be given to the protection of the exhibition in relation to the architecture of the proposed gallery space. As a result, this paper attempts to incorporate the visual comfort issues with the transitional spaces in museums.

## 2. LITERATURE REVIEW

### 2.1. MUSEUM DAYLIGHTING

Many studies investigated daylighting quality in museums using survey questionnaires and physical measurements for existing conditions

(Morlock 1999; Betran 2004),(Oliveira and Steemers 2008). However, museum's exhibition can be categorized in the following simplified subdivisions in terms of lighting:

- Extremely susceptible to light damage: such as works on paper, textiles, naturally occurring dyes, Natural history exhibits. A strictly controlled lighting is required. Normally these spaces cannot be naturally lit and should be kept below 50 Lux.
- Susceptible to light damage: Such as oil paintings on canvas, most wood, bone and Ivory and other materials, usually lighting is kept below 200 Lux.
- Not susceptible to light damage: Metal, Stone, most ceramics, glass and some wooden objects. They can be displayed in outdoor lighting, upper lighting level of 1500 is accepted (Shaw 1995; Galleries 2011).

### 2.2. TRANSITIONAL SPACES LIGHTING

Transitional spaces are defined as the architectural area situated between two or more environments and acting as both buffer spaces (Kwong, Adam et al. 2009). Examples of such spaces are: foyer, entrance lobby, atriums, lift lobby and passageway. They are typically secondary not directly occupied spaces. These spaces may be perceived differently when compared to commonly occupied rooms. Previous research findings show that although people do not stay in transitional spaces for extended periods, the visual condition in these spaces can strongly affect occupants task performance and comfort during their stay in the building (Kwong, Adam et al. 2009).They are needed for eye adaptation, especially when moving through unusual lighting conditions. These spaces are significant in exceptionally-lit buildings like museums and art galleries where contrast from dark to light (or vice-versa) depending on the exhibition type is often acute.

They can be categorized to two types; a) intra-transitional space, generally created in existing buildings to achieve visual comfort, and b) inter-transitional space, usually studied in new designs where changes in the design are easier to happen. A simplified example of the two types can be found in Figure 1.

### 2.3. VISUAL COMFORT EVALUATION METHODOLOGIES

Many previous studies discussed daylighting in museums. a study made by (Betran, Atre et al. 2004) investigated three daylit art museums at the Texas A&M University campus. A diversity of tools was used; Physical scale models were used for spaces inspection. Furthermore, many studies incorporated RADIANCE and ECOTECT simulation softwares to evaluate the illuminance levels at different times. Previous studies found various lighting problems including direct sunlight, over-illumination and visual discomfort. Other researches goal was to present snapshots of the daylighting conditions inside the space during a specific period of the year (Morlock 1999).

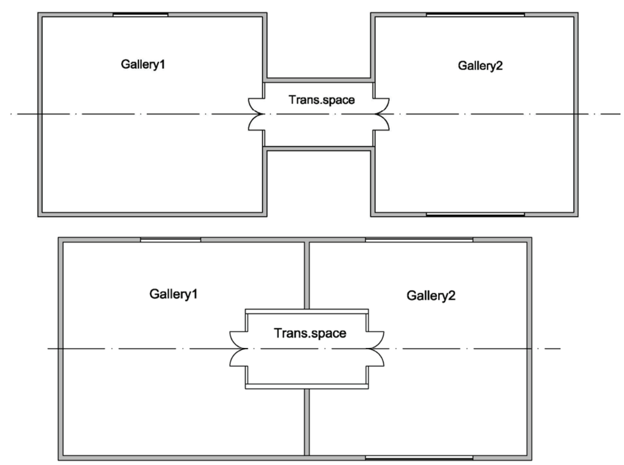



*Figure 1: Inter Vs Intra-Transitional spaces*

## *3.* PROBLEM STATEMENT

Although daylighting has several advantages including better quality and colour rendering that exceeds the electrical one, in addition to large energy saving achieved from this permanent source (the sun), there are two major negative effects associated with daylighting: glare and poor visual comfort. These two effects can strongly effect occupant perception and comfort in the space and discourage the use of natural lighting. These issues can be more challenging in museums where presence of daylight in the indoor environment could cause difficulties to achieve comfortable visual conditions.

While there are many studies for visual comfort, several issues exist with the implementation of the used methods. Energy modelling should be easy, accurate, and truthful. Most lighting and energy analysis tools do not allow for energy modelling to be done early and often during the design process. These tools are still only accessible to professionals and require specialized computing and programming skills. The lack of user-friendly tools, especially for architects, students and non-daylighting professionals makes it even harder to accept such tools. Few studies were performed on transitional spaces; particularly under daylighting conditions. A shift in the visual comfort model is needed to better understand possible daylighting conditions in the early stages of design. The proposed paper will focus on visual comfort evaluation in transitional spaces between daylit art galleries with different exhibits sensitivity.

## 4. RESEARCH OBJECTIVE

Numerous factors and physical features are affecting the design of daylit spaces. The research objective is to develop a new framework for visual comfort evaluation. A shift in the design process is proposed to achieve visual comfort in the early stages of design. In this paper, a case study is used to test the proposed algorithm. The impact of two parameters was examined: a) passageway length between two gallery spaces with different exhibits sensitivity and its effect on eye adaptation and visual comfort, and b) the impact of the window area (window to wall ratio) on visual comfort. Finally an investigation was made on the sensitivity of the three used methodologies Brightness Ratio, Simplified Daylight Glare Probability (for clear sky) and Daylight Factor (for winter overcast conditions).

## 5. METHODOLOGY

The study used multiple methodologies and tools that are briefly listed as follows:

### 5.1. GRASSHOPPER TOOL (GH)

Grasshopper is a graphical algorithm editor integrated with Rhino 3-D modelling software. It requires no knowledge of programming or scripting, but still allows designers to build form generators (PAYNE and ISSA 2009).

### 5.2. DIVA TOOL

DIVA is a virtual daylighting simulation and optimization tool, it allows for creating a series of daylighting performance evaluation in overcast/ clear sky conditions for the building during the early stages of design.

### 5.3. BRIGHTNESS RATIO (BR)

This method was created by the CIBSE code. It was used previously for visual comfort assessment by (Araji, Boubekri et al. 2007). The methodology used a set of stationary points where illuminance measurements were taken, compared illuminance values ratio. A set of threshold values from Subtle to Dramatic condition was used to evaluate the resulting ratios.

### 5.4. Daylight Factor (DF)

It is the ratio of internal light level to external light level in overcast lighting conditions (winter condition).

### 5.5. THE DAYLIGHT GLARE PROBABILITY METHOD SIMPLIFIED (DGPs)

This method is a new empirical approach for glare prediction. It is based on the vertical eye illuminance and the glare source luminance, its solid angle and its position index *(Weinold and Christoffersen 2005).* DGP calculation considers the overall brightness of the view, position of glare sources and visual contrast under clear sky. Figure 2 summarizes the main outlines for the proposed methodology.

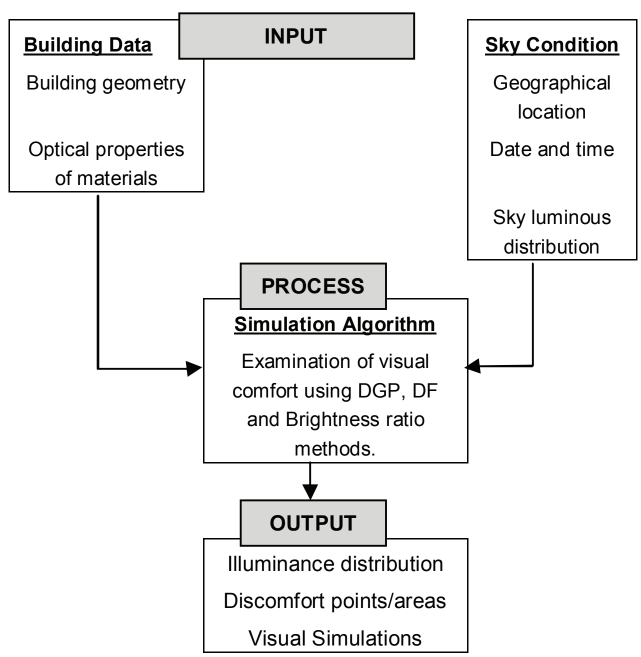



*Figure 2: methodology main outlines*

## 6. EXPERIMENTAL PROCEDURES

### 6.1. CASE STUDY (NASHER SCULPTURE CENTER)

In this study, the proposed framework was simulated on the Nasher Center. This Center is a 55,000 square foot with four acres of garden space. Arts exhibitions are located in an interior exhibition space and garden gallery. The centre was designed by Renzo Piano, daylight was the main light source. Main floor plan with the examined area is show in ***Figure 3***

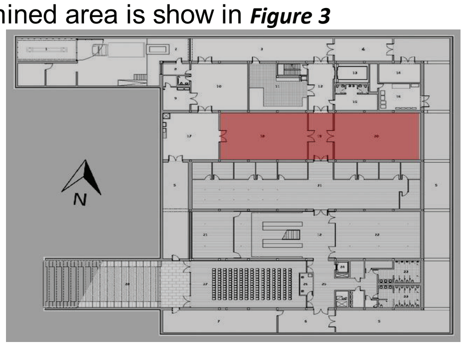



*Figure 3: Nasher Sculpture floor plan*

Simulations were conducted using Grasshopper and Diva-for-Rhino plug-in to interface Radiance and Daysim. The centre geometry and geographical location were used for demonstration purpose only. The methodology should be applicable to all gallery spaces. The galleries dimensions and material properties were extracted from the centre; roof and window treatments were not modelled as shown in TABLE 1

**TABLE 1: GALLERY SPACE PARAMETERS**

| ***Space Parameters*** | ***details*** |
|---|---|
| Gallery1 and 2 Dimensions (m) | 9.5*9.5*4.8 |
| Walls reflectance | 50% |
| Floor reflectance | 20% |
| Glass type | 48mm thick, double laminated clear glass |
| Window to wall ratio(North and South window) Gallery1 | Curtain wall of 0.9 |
| Corridor window to wall ratio range | 0.1-0.51 |
| Passageway width (m) | 2.5 |
| Passageway Length range (m) | 1-12 |
| Geographical location | Dallas, Tx |

### 6.2. EXPERIMENTATION STEPS

Inter-transitional space was examined in this research; the interior passageway length varied from 1 (No transitional space), to 12 meters between two gallery spaces; Gallery1 held sensitive exhibits, where the illuminance was controlled and kept at 52 Lux. Gallery2 contained non-sensitive exhibits, where illuminance can reach 1500 Lux. To obtain trusted conclusions, Gallery1 illuminance values were kept constant during all the experiment while examining the other variables (passageway length and Gallery2 illuminance values in different cases). Stationary points were located at 1.70 m height from the ground (eye level). They were set horizontally every 1.2 m (based on pedestrian walking speed) (Araji, Boubekri et al. 2007). The total number of points varied depending on the passageway length, from 2 points (no transitional space) to 11 points (12m passageway). Stationary points at 12m long passageway are shown in Figure 4

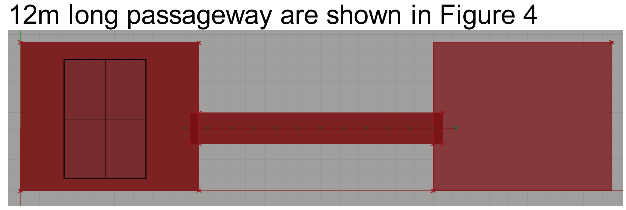


*Figure 4: Illuminance stationary points*

The study consisted of a series of commands in GH and its sub components and plug-ins to easily introduce art galleries evaluation from the visual comfort perspective. In our case study, a grasshopper definition for the proposed geometry was created. DIVA illuminance simulations were performed for Dallas, Tx on December 21st and June 21st at 10 AM, noon, 2.00 PM, and 4.00 PM. 8 simulations for each condition were established to conclude a total of 80 simulations. DGP, DF and BR were extracted for each stationary point as shown in Figure 5.

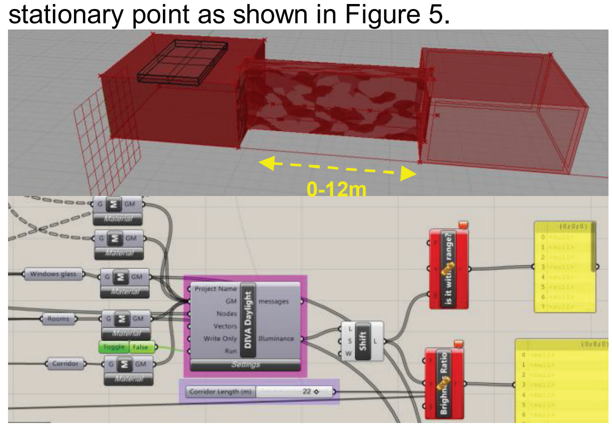



*Figure 5: DIVA simulation and results extraction*

## 7. RESEARCH FINDINGS

Simulations concluded two series of outputs:

### 7.1 QUANTITATIVE OUTPUTS

They were presented in graphs and tables. The results data were transferred from grasshopper to excel and Matlab where the case evaluation was made and final conclusions were extracted.

Through the experiment, it was found that the most acute contrast condition occurred between the first stationary point and the last point. Consequently for brightness ratio, illuminance between first point (Point1), located in Gallery1 and the last point (point X) located in Gallery2.

Preliminary results concluded for parameter A (passageway length) that the passageway length and the visual comfort was directly proportional up to a certain length (6-7meters), then with longer passageways, the illuminance values were indirectly proportional as shown in Figure 6

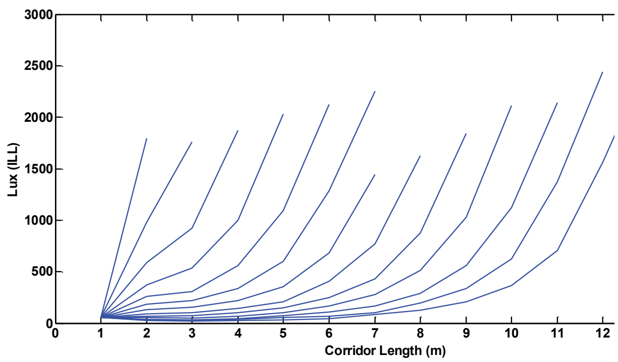



*Figure 6: Illuminance Flow*

The second stage of the experiment examined various window to wall ratio on a fixed corridor length (6 m). This allowed for the examination of the same number of points in different lighting conditions and different window size, 2 centred south and north facing windows were examined. Window to wall ratio varied from 0.1 to 0.50.

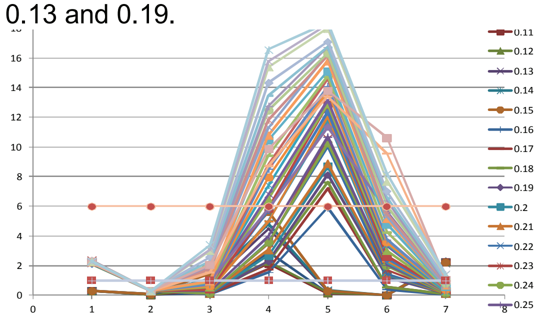
It was concluded that in a passageway, relatively smaller window size performed better (0.2 to 0.35). Smaller window to wall ratio below 0.15 may cause obscure areas in addition to glare areas. Successful window dimensions were found to be: 1.60*2.30 at 1.30m from the ground.

A comparison of different glare and visual comfort algorithms sensitivity was examined, as illustrated in Figure 7.

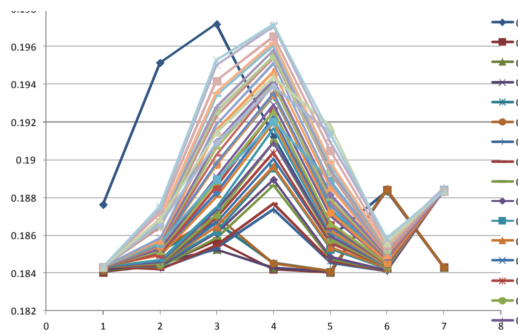
1-Daylight factor considered under-lit area with values below 1%, while over-lit values were above 6%. Window size with the least under-lit and over-lit points were between 0.16 and 0.2.

2-DGPs considered points of discomfort with DGPs above 0.35. In our case, minimum to no discomfort points were found. Most values were below glare threshold limits

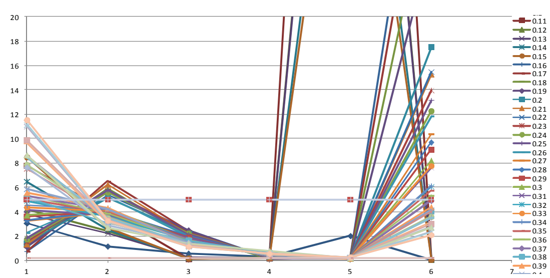
3-Brightness Ratio considered points of comfort areas between 0.2 and 5. A window size with the least under-lit and over-lit points were between 0.13 and 0.19.



(a) Daylight Factor sample outputs and thresholds



(b) DGPs sample outputs and thresholds



(c) Brightness Ratio sample outputs and thresholds

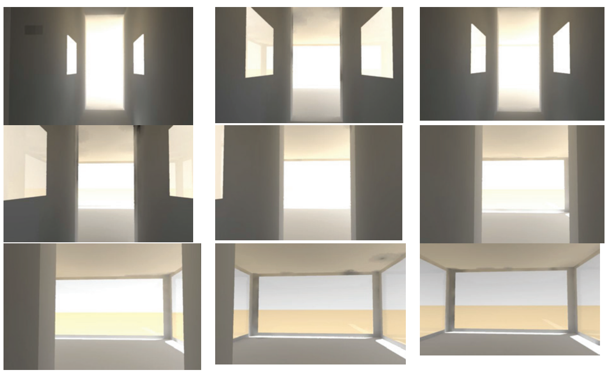
*Figure 7: Comparison between different visual comfort algorithms*

### 7.2. QUALITATIVE OUTPUTS

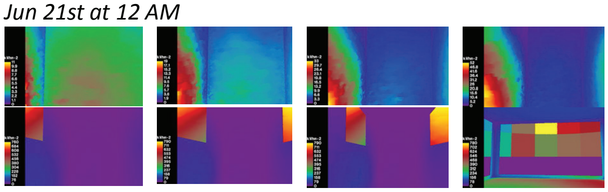
They were presented in virtual renderings and irradiation maps. The best condition in terms of passageway length (6m) and window to wall ratio (0.18) was presented with a series of graphical renderings. These renderings were used for better understanding and evaluation of the space visual conditions.

A simulation at the eye level (1.7m) rendered for each of the passageway points along the path in peak times of the year as shown in Figure 8

*Dec 21st at 10 AM*



*Jun 21st at 12 AM*



*Annual Irradiation maps*

*Figure 8: Visual simulations*

## 8. FINAL CONCLUSIONS

A creation of a transitional space in acute lit buildings such as art galleries is important for eye adaptation and visual comfort. A lack of such spaces may cause discomfort; occupants may lose the sense of existence and dwelling in the space. A passageway length was found to be directly proportional with visual comfort then with longer passageways obscure points were found; consequently visual discomfort may occur. While DGPs is considered a great method for high luminance glare, it does not sufficiently represent contrast based glare. With no direct glare problems, DGPs underestimates the visual discomfort points along the path. BR and DF (only in overcast condition) showed better correlation with the virtual simulations.

## 9. FUTURE RESEARCH

It is anticipated in the future to extend the proposed research to generate a decision-support tool for building evaluation from the visual comfort perspective. Furthermore, It is expected to cover more time slots to run the simulations, this provides more accuracy and more trusted outputs. Moreover, Including building urban surroundings and landscapes as in reality is considered necessary. Still some considerations are required concerning eye direction and way finding. Finally, tool validation is considered necessary through practice; designers and researchers feedback is needed for tool modification and adjustment.

## 10. RESOURCES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# Construction cost and energy consumption resulting from energy retrofitting in an apartment building in Madrid (Spain)

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*ABSTRACT: This theoretical study analyzes the relation between the measures necessary for the energy retrofitting of a residential building constructed in Madrid, their cost and the improvement of the energy rating of the dwellings.*
*The aim of this work is to establish an evaluation methodology that allows developers and architects to obtain conclusions and orientates them in the decision-making process. It will allow finding the most suitable cost-effective solutions in each case.*
*This paper describes the methodology and the findings obtained. Energy retrofitting and the improvement of the energy behaviour of the building depend on the selection of the retrofitting solutions and also on the investment. In this case study to achieve the best energy rates it is necessary to improve the thermal performance of the envelope as well as the energy systems.*
*Energy retrofitting means an increase in property value but it can't only be considered in economic terms. It is necessary to take into account unquantifiable aspects as increased comfort, improved sound insulation, livability, health, or the elimination of energy poverty situations.*

*Keywords: energy retrofitting, energy rating, cost-effectiveness, existing building stock*

## 1. INTRODUCTION

The European Union (EU) adopted in 2008 the communication "20-20 by 2020. Europe's climate change opportunity" which established three goals: 20% reduction of $CO_2$ emissions, 20% increase in energy efficiency, and 20% renewables of total primary energy consumed by 2020 (European Commission, 2008). 40% of total energy in the EU corresponds to buildings. Thus, they are a key element to achieve these goals.

The European Commission approved in 2010 the Energy Performance Building Directive (EPBD) 2010/31/EU. This document establishes energy efficiency minimum requirements and develops the methodology for calculating the energy efficiency of buildings and their energy certificate (European Parliament, 2010).

Buildings represent 26% of final energy consumption in Spain, 17% of homes and 9% of tertiary sector buildings. 53% of those homes, of a total of approximately 25 million (in 2008), were built before 1979, when the first legislation related to energy efficiency was passed. In the last 18 years the energy consumption of households has increased by about 50%.

In order to achieve the 20-20 targets it is necessary that energy retrofitting is taken into account by the Spanish construction sector. The study "Potential energy savings and reduction of $CO_2$ emissions of the existing housing stock in Spain in 2020" (WWF, Adena, 2010) estimates that the Spanish residential sector has technical and economic capacity to reduce at least 30% energy consumption in existing housing at 2020.

In this context this study examines the relation between cost-effective technical solutions that enable the energy retrofitting in a building in Madrid, their cost, the reduction in consumption and the new energy rating of the dwellings. It also establishes an evaluation methodology that allows developers and architects to draw conclusions to guide them in the decision-making process, to find in each case the best solutions from environmental and economic point of view.

## 2. METHODOLOGY

The steps followed to analyze the case study are:
• The selection of the building and the analysis of its documentation.

• The analysis of climate data and elaboration of Olgyay's and Givoni's bioclimatic charts.

• Building’s characterization study.

• Verification of compliance of existing normative of energy efficiency and the calculation of the energy rating of the building with Calener VyP program.

• The study of average consumption of natural gas, electricity and water.

• The cataloguing and evaluation of measures for improving the building envelope: the description of strategies to reduce energy demand, and the definition of technical solutions and 2 cases of rehabilitated envelope.

• The cataloguing and evaluation of measures to improve energy systems.

• The definition by combining measures to improve the envelope and the energy systems of 26 retrofitting hypotheses and their calculation.

• The achieving of the results of the energy rating and economic assessment of all scenarios.

• The achieving of conclusions.

## 3. THE CASE STUDY

The case study is a building of 95 apartments built in 48 Paseo Alameda, in the center of Madrid (Spain) (Fig. 1). Madrid is located in the center of the Iberian Peninsula and has a Mediterranean climate with cold winters.

*Fig. 1: East facade of the building.*

The building is free standing, of dimensions 10.80 m and 126.11 m, and it is composed of five separate blocks, each with a vertical core communication. Its surface is 9,317.6 built m² above ground level. Of the 95 apartments, 65 are 2 bedrooms and 30 are 3 bedrooms. Their floor space is between 65.31 and 71.05 m² for 2 bedrooms, and about 80.20 m² for 3 bedrooms.

The building was projected in 2003 and was finished in 2005.

### 3.1. The Envelope

The building envelope does not meet current regulations. These rules, called Basic Document of Energy Savings: Limitation of the energy demand (DB HE-1) are the implementation of the EPBD directive in Spain. The transmittance values of the building enclosures and their limits according to the rules for the climate of Madrid are as follows (Table 1).

**TABLE 1: TRANSMITTANCES OF THE BUILDING ENVELOPE**

| Construction element | Description | U Building (W/m²K) | U Limit DB HE-1 (W/m²K) |
|---|---|---|---|
| Roofs | Inverted roof (40 mm XPS) | 0.56 | 0.38 |
| Main facade | Doble facade (PUR 40 mm) | 0.55 | 0.66 |
| Secondary facade | Concrete wall of 30 cm / Partition of 12 cm | 2.82 / 2.70 | 0.66 |
| Windows | Aluminum window frame | 5.70 | 2.2 (North), 2.6 (East-West), 3.4 (South) |
| | Glass 6-8-4 (g=0,75) / Glass 5+5 (g=0,85) | 3.00 / 5.50 | |
| Outside floor structure / Ground floor structure | Concrete waffle slab (PUR 30 mm ) | 0.68 | 0.49 |
| Internal partitions | Partition of 12 cm | 2.40 / 2.70 | 1.2 |

### 3.2. The Energy Systems

Each house has a domestic hot water (DHW) and heating system, comprising: a conventional boiler with a nominal capacity of 27.6 kW and an energy performance up to 91%; an accumulator of 43 l integrated in the boiler; and aluminium radiators.

There are no refrigeration nor renewable energy facilities.

3.3. Selection Criteria

The building was selected for the following reasons:

• It is representative of the buildings constructed in those years: it is a block building, with average surfaces, located in an urban center and with conventional constructive characteristics.

• It was built before the entry into force of the current normative of energy efficiency, as most of the existing building stock likely to be rehabilitated.

• The building has no structural problems, of health, risk of social exclusion or other circumstances preventing consider a case study.

3.4. Consumption

In this case study, the consumption of natural gas and electricity are slightly lower (up to 10%) than the average values for a similar building in the same climate zone according to Calener VyP and the study “Analysis of energy consumption in the residential sector in Spain” (IDAE, 2011). Water consumption is 60% of the estimate by the National Statistics Institute.

It is thus considered that the real consumption are among the average values, but several variables such as schedules, consumption habits, the number of inhabitants, etc… must be taken into account.

3.5. Building Energy Rating

Calener VYP is the tool used to assess the energy efficiency of the building. It is the official program of energy rating for dwellings and small tertiary sector buildings in Spain.

The program inputs are the geometry and thermal characteristics of the building envelope (U, thermal bridges, etc.), and the characteristics of the heating, cooling and DHW facilities (nominal capacity, energy performance, etc.)

Calener VyP generates a label with the energy rating of the building from A, for more efficient buildings, to G (Fig. 2). The rating is established based on CO2 emissions (kgCO2 / m² year) but the program also provides results of the consumption of primary and final energy.

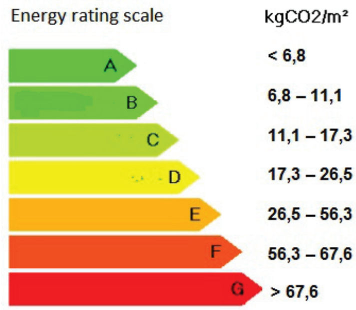


*Fig. 2: Energy rating scale for existing housing blocks in Madrid.*

The building energy rating obtained with Calener VyP is 29.4 (E).

## 4. CATALOGUING OF MEASURES TO IMPROVE THE ENERGY EFFICIENCY OF THE BUILDING

The energy efficiency of a building is increased by improving its envelope and reducing energy demand, with the substitution of energy systems with more efficient ones and renewable energy use.

It has been considered that the rehabilitated dwellings are inhabited. The solutions adopted must avoid inconvenience to tenants.

Strategies to reduce energy demand are defined based on Olgyay's and Givoni's bioclimatic charts and the study of the characteristics and the consumption of the building. They are divided in strategies to reduce heating demand and to reduce cooling demand. These strategies are implemented by means of the measures to improve the envelope.

4.1. Measures to Improve the Envelope and Elaboration of Envelope Hypothesis

The first step to increase the building's energy efficiency is to reduce energy demand by improving the characteristics of the envelope.

Each of the measures to improve the envelope is defined, budgeted and evaluated with Calener VyP to establish its ability to reduce energy demand and CO2 emissions. A final study of the solutions is done by comparing the results of all the measures, taking into account the relation between the final energy savings and cost of each intervention as shown in Fig. 3.

The measures evaluated are:
• Energy retrofitting of the facades with external thermal insulation composite systems (ETICS) (1.1 and 1.2), ventilated facades (1.3) and interior insulation for exterior walls (1.4).

• Energy retrofitting of the roofs with external insulation in inverted roofs (2.1 and 2.2), green roofs (2.3), and insulated ceilings (2.4).

• Energy retrofitting of the ground floor and exterior floors with insulated ceilings (3).

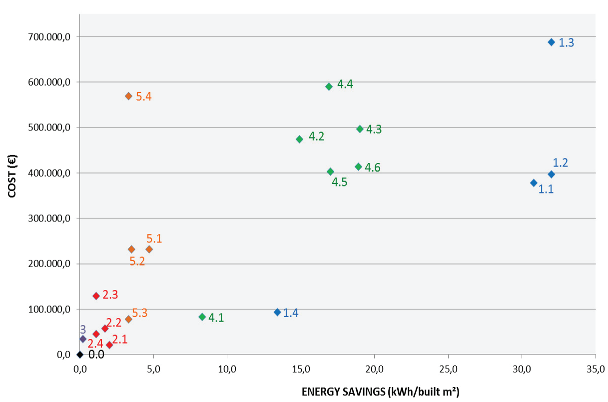


*Fig. 3: Relation between the cost and the energy savings in the measures to improve the envelope*

• Energy retrofitting of windows and glass doors. The solutions evaluated are: replacing existing glass by a low emissivity one (4.1); replacing the existing windows (4.2, 4.3 and 4.4); placing a new window on the outside (4.5 and 4.6); and place sun protection in east and west facades through slats or awnings (5.1 to 5.4).

Two cases of rehabilitation of the envelope are defined considering the results obtained with the evaluation of the measures and their comparison.

The criteria for the selection of measures are:
• The relation between the energy saved (kWh) and the cost of the intervention.

• The adequacy of the measures to the characteristics of the case study: constructive and architectural features, unique property, apartments for rent, etc…

The target of the first case of envelope (E1) is to meet the current Spanish energy efficiency normative. E1 reduces annual $CO_2$ emissions 6.20 kg $CO_2$/ m² and its energy total demand (heating, cooling and DHW) is 81.5 kWh/m² per year. The second case (E2) reduces energy demand at least at 50% taking into account the cost-benefit relation of the measures. E2 reduces annual $CO_2$ emissions 14.92 kg $CO_2$/ m² and its energy total demand is 52.8 kWh /m² per year.

**TABLE 2: ENERGY RATINGS, ENERGY DEMANDS AND COSTS OF THE ENVELOPE HYPOTHESIS**

| | E0 | E1 | E2 |
|---|---|---|---|
| Energy rating (kgCO2/m²) | 29,4 E | 23,2 D | 14,5 C |
| Heating demand (kWh/m²) | 73,3 | 49,2 | 31,1 |
| Heating demand variations (kWh/m²) | 0,0% | -32,9% | 57,6% |
| Cooling demand (kWh/m²) | 13,1 | 14,4 | 3,8 |
| Cooling demand variations (kWh/m²) | 0,0 | 9,9% | 71,0% |
| Cost (€/m²built building) | 0,0 | 71,1 | 132,9 |

The energy systems will be subsequently evaluated in these 2 envelope options.

4.2. Measures to Improve Energy Systems
Improving the efficiency of energy systems is achieved by replacing existing facilities with more efficient ones and the use of renewable energies (solar thermal DHW systems and biomass).

Thirteen common energy systems in residential buildings that suit the characteristics of the building and its climate zone are selected, sized and budgeted. They are divided into:

• Heating and DHW systems: 3 individual and 4 centralized systems have been analyzed. They include the installation of: individual and collective condensing boilers, a biomass boiler, microgeneration technologies, a solar thermal system that covers 70.2% of the needs of DHW and underfloor heating (Systems S1 to S7).

• Heating, cooling and DHW systems: 2 individual and 4 centralized systems have been analyzed. These systems, in addition to the above, include direct expansion equipment and ducts, chillers, electric heat pumps, natural gas heat pumps and underfloor heating and cooling (Systems S8 to S13).

Energy systems are evaluated with Calener VyP on the 2 envelope hypothesis, E1 and E2. In each case reduction of CO2 emissions (kgCO2 / m² year), consumption and energy savings (kWh / m² year), the cost (€ / m²) and the relation between the cost of the solutions and final energy savings are obtained (Fig. 4).

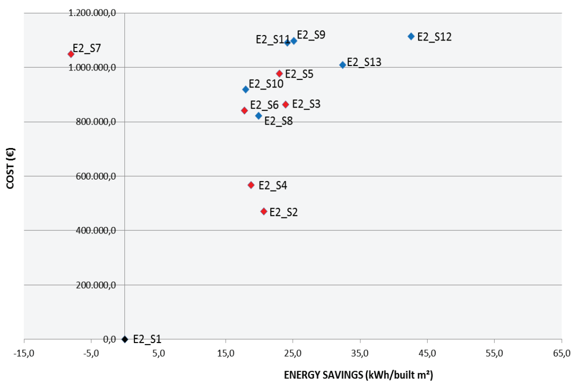


*Fig. 4: Relation between the cost and the energy savings in the measures to improve the energy systems in E2 envelope.*

## 5. FINAL HYPOTHESIS. RESULTS

The final hypotheses are 26, the result of the combination of the 2 envelopes and the 13 energy systems. The hypotheses are named after its envelope type, E1 or E2, and the number of the energy system.

The energy rating of each hypothesis is calculated with Calener VyP. Results of energy demands for heating and cooling (kWh / m² year); DHW and cooling CO2 emissions (kgCO2 / m² year); and consumptions of primary and final energy (kWh / m² year) are also obtained.

To evaluate the cost-effectiveness of the hypotheses the relation between the reduction of CO2 emissions and energy consumption, and their cost is established (Fig. 5 and Fig. 6).

With the data obtained from Calener VyP and the fuel prices in Spain, considering only the cost of fuel and regardless of the fixed term, rents and taxes, the cost of consumer spending is also calculated.

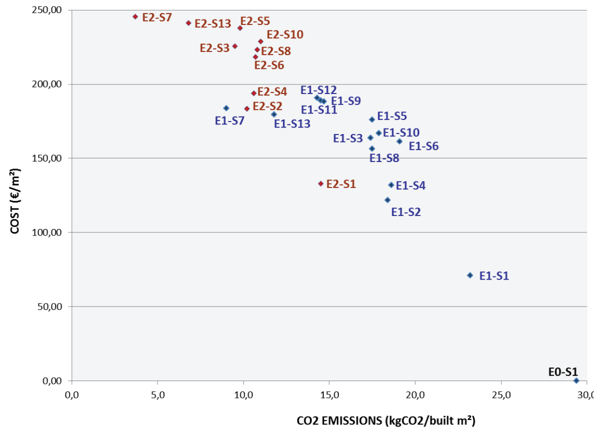


*Fig. 5: Relation between the cost and the CO2 emissions (energy rating) of the 26 hypotheses*

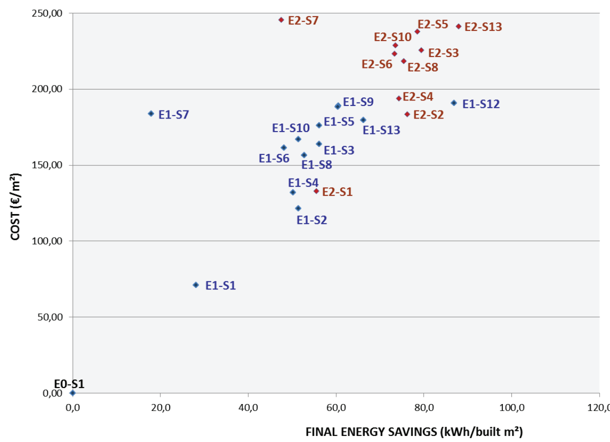


*Fig. 6: Relation between the cost and the final energy savings of the 26 hypotheses.*

## 6. CONCLUSIONS

6.1 Economic Conclusions
The relation between the hypotheses, their energy ratings and budget, as well as the savings in energy consumption and energy costs is analyzed (Table 3).

The highest scores and energy savings of up to 80% are only achievable with the largest investments, up to 23,440 € for a two-bedroom dwelling (77.67 built m²). But energy savings around 50% are achieved with intermediate investment, around 23,440 € for the same two-bedroom dwelling. Successful energy rehabilitation depends on both economic investment and the appropriate selection of the improvement measures that are implemented.

**TABLE 3: ECONOMIC RESULTS**

| | Hypotheses | Cost | | Energy savings | Energy cost savings |
|---|---|---|---|---|---|
| | | (€/ built m²) | 2 bedroom dwelling (€) | | |
| D | E1-S01 | 71.14 | 6,602.37 | 23.7% | 38.2% |
| | E1-S02 to E1-S06, E1-S08, E1-S10 | 121.6 - 176.0 | 11,289.04-16,335.75 | 42.5% - 47.4% | 50.6% - 53.9% |
| C | E1-S09, E1-S11, E1-S12, E1-S13 | 179.4 - 190.7 | 16,650.2-17,700.2 | 51.1% - 70.0% | 60.9% - 68.9% |
| | E2-S01 | 133.0 | 12,342.6 | 47.0% | 61.2% |
| B | E1-S07 | 183.7 | 17,050.7 | 15.2% | 51.0% |
| | E2-S02 to E2-S06, E2-S08 to E2-S13 | 183.5 - 252.6 | 17,029.2-23,440.3 | 55.9% - 80.7% | 61.1% - 81.6% |
| A | E2-S07 | 245.6 | 22,790.9 | 40.2% | 70.7% |

6.2 Final Conclusions

In energy retrofitting the improvement of the energy performance of the building depends on the investment and on the selection of the appropriate solutions (solar protection, thermal insulation, energy efficient systems and renewable energies) by a methodology that takes into account the cost-benefit of the interventions. In this case study, to achieve the best energy rates it is necessary the thermal improvement of the envelope (passive systems) as well as the energy systems (active systems) to achieve the best energy rates.

Better insulation of facades is the intervention with the best relation between economic profitability, energy savings and $CO_2$ emissions reduction. The improvement of the thermal characteristics of the windows and their sunscreen (which reduces the cooling demand by up to or 60%) produce also a significant energy savings, but has longer repayment periods.

Installation of condensing boilers and a solar thermal system for DHW heating are the more profitable interventions in the facilities. The energy systems that present a better relation between profitability, energy saving and reduction of $CO_2$ emissions are those with gas or electric heat pump with underfloor heating and cooling. Anyway energy retrofitting is not only justified in economic terms even if it means an increase in property value and fuel prices continue to rise. Energy rehabilitation involves improving aspects of the building that are not quantifiable, such as increased comfort, improved sound insulation, livability, health, or the elimination of energy poverty situations. If that is done when rehabilitating the constructive elements, then the difference between constructive and energy rehabilitation is minimal and easier to repay.

## 7. ACKNOWLEDGEMENTS

This paper is the result of the agreement signed by the promoters of the study, ASPRIMA Foundation, Gas Natural - Fenosa, Ursa - Pladur and Uponor, and the Research Group on Sustainability in Construction and Industry, from the Technical University of Madrid, giSCI-UPM.

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# Designing a Breathing Skin

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*ABSTRACT: This paper provides information on the potential overall energy efficiencies of the Incheon International Airport passenger terminal 2.*

*The first steps are to fully optimize the building envelope to reduce and or eliminate solar gains and conduction heat gains to the space, to keep the required condition loads as low as possible. The building skin presently being considered is controlled using outside air or space exhaust air to make it adaptable for different outside conditions.*

*Due to internal loads in the spaces such as people and equipment ventilation and heating and cooling systems will be required. The ventilation system is proposed as being a variable volume displacement ventilation system together with radiant floor for heating and cooling.*

*The results show that a hybrid system consisting of a variable volume displacement ventilation system together with a radiant floor for heating and cooling provides occupant comfort even when spaces are occupied with 500 occupants.*

*The results shown in this paper also indicate that a climate roof can be made to function as an adaptable skin to adapt to the different climatic conditions and greatly reduce space loads and help increase occupant comfort.*

*Keywords: energy, comfort*

## 1. INTRODUCTION

This paper shows the analysis of the building envelope and mechanical systems to determine if occupant comfort can be maintained.

This paper shows with the interaction of the exterior climate, temperature and solar radiation on the building surfaces and assesses the perceived comfort level being provided by the mechanical system at the supply air temperature and average space air velocity. The performance of the air conditioning system diffuser in providing large volumes of air in a draft free delivery is important to achieving the comfort goals.

Terminal 2 will be designed in a way that the building envelope and the resulting ventilation and air conditioning systems are functioning together to create a comfortable environment.

Traditional design methods would consider operating the spaces within temperature constraints of say 22-24°C. These constraints do not take into account the architectural form of the building and the materials used. The building has been designed to provide a spacious and natural daylight environment for its occupants.

Through the course of the design of the building's HVAC systems it became apparent that special designs would be necessary to achieve the objective. The buildings envelope and materials have been analysed and simulation results show us the predicted loads. Once the loads are determined the details of ventilating the occupants and removing heat from occupied areas were pursued. This resulted in a hybrid ventilation system that is a cross between a displacement and variable volume system.

## 2. BUILDING CONFIGURATION

The proposed building is in the form of an H and is constructed from a fabric material for the roof areas and high performance glazing. The whole terminal and parts of the concourse are shaded by solar shading devices and roof overhangs.

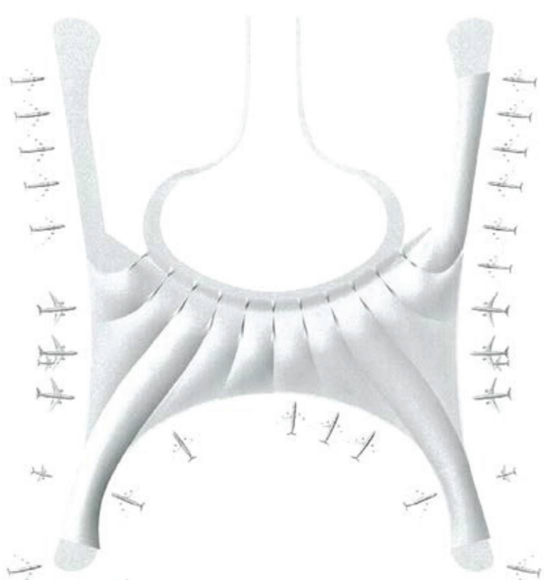

Figure 1 shows the configuration of the proposed airport design

The glazing used in the design of the building will be high performance glazing. However the roof could be constructed from a double walled Teflon material.

The thermal resistance of both Teflon and single glazing are relatively low and the conductive heat gain to the space would be quite high if traditional indoor temperatures of 24°C were to be maintained. During August is the warmest month ambient temperatures vary from 34-36°C, there would be a 10-12°C temperature difference across the envelope. The design produced by enhances stratification in the space which decreases the temperature difference to 1°C and in some cases the indoor temperatures is higher than the ambient temperature allowing heat to escape from the space.

The roof material could be a double layered construction to allow the passage of air within the cavity. By controlling the passage of air within the cavity and the temperature of the cavity, we can create a 'living skin' which would be adapted for the various differences in the climate.
The climate roof would be a sort of living skin where it performs in many different ways. During cold periods the climate roof will take exhaust air from the spaces through the cavity which will increase the temperature in the cavity and therefore reduce the heat loss from the spaces which will conserve energy.
During neutral ambient conditions, outside air will be ventilated through the cavity to reduce the temperature in the cavity and the inside surface temperature of the climate roof, which will provide "free' radiant cooling to the space. During hot ambient conditions the conduction heat gain and solar heat gain will be absorbed into the air in the roof cavity. As the results show during summer design days, the stratification instigated by the displacement ventilation system together with the radiant floor results in an increase of space temperature outside of the occupied zone. These temperatures are between 28-30C, this drastically reduces the conduction gain to the spaces and conserves a great deal of energy.

The glazing for the concourses is clear single glazing to obtain an average shading coefficient of 0.35.

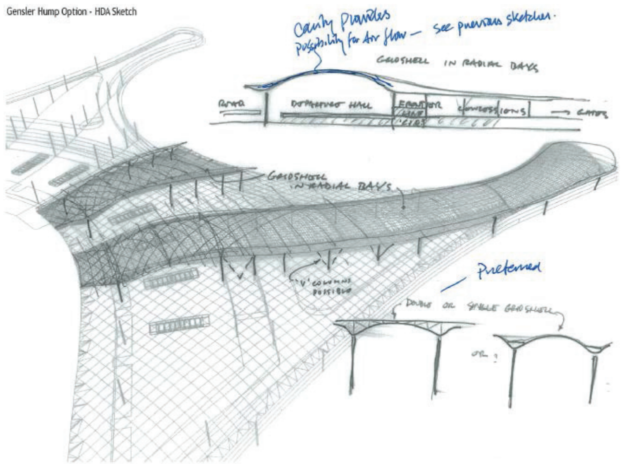


**Figure 2 shows some of the development of the roof structure.**

### 3. Simulation Model

A simulation model was constructed in the computer program. The model is based on a 40m rectangle with one glass façade and a curved roof to emulate the latest architectural and structural designs.

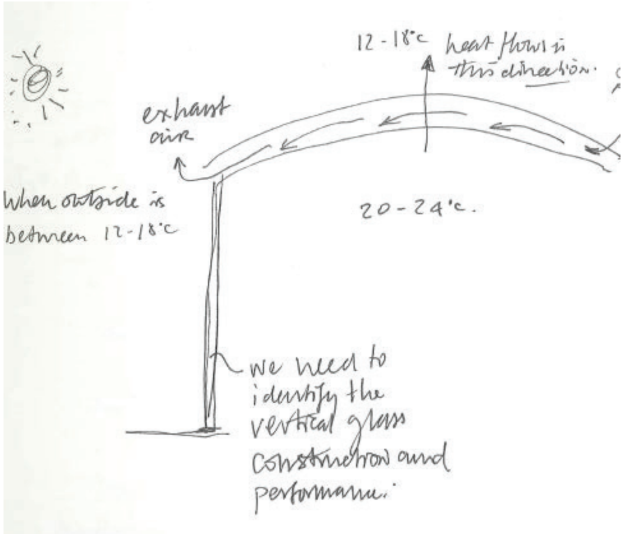


Figure 3 shows a sketch of the section constructed in the computer model.

The exterior glazing is 15m high and constructed from a fairly clear monolithic glass.
The roof is constructed from a double membrane material with a ventilated cavity. The cavity can be ventilated with both outside air and exhaust air from the space.

Air is supplied to the space via a displacement ventilation system at 17C.

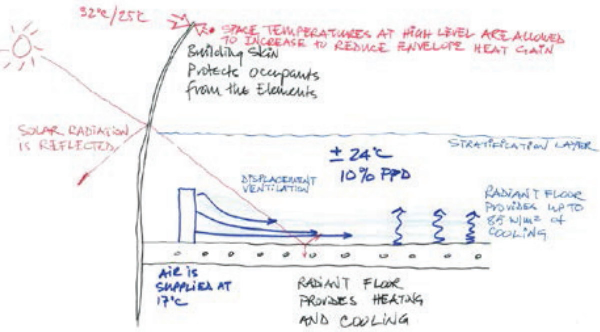


Figure 4 shows the displacement ventilation system and the radiant floor

### 4. Alternatives

To investigate the effects of the different components the following alternatives were studied in this analysis:

1. An all air system, where the conditioning for both summer and winter is provided by the displacement ventilation system.

2. A hybrid system consisting of a displacement ventilation system for ventilation purposes together with a radiant floor for heating and cooling. Ventilation air will be supplied at 17C and the radiant floor surface temperature will be controlled between 19C and 28C depending upon space load requirements.

3. The hybrid system as described in alternative 2 together with the roof being operated as a climate roof. For this alternative we have assumed the supply air is exhausted through the cavity between the membranes of the roof construction.

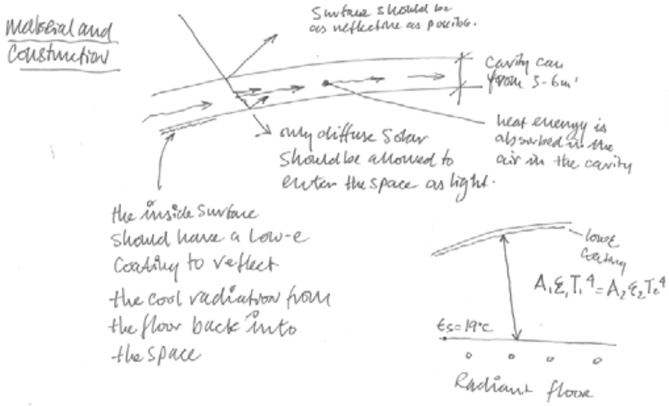


Figure 5 shows the roof construction simulated in alternative 3.

**5. RESULTS**

There are two sets of results one for the cooling design day of 23rd July and for the heating design day of 16th December.

*23 July*

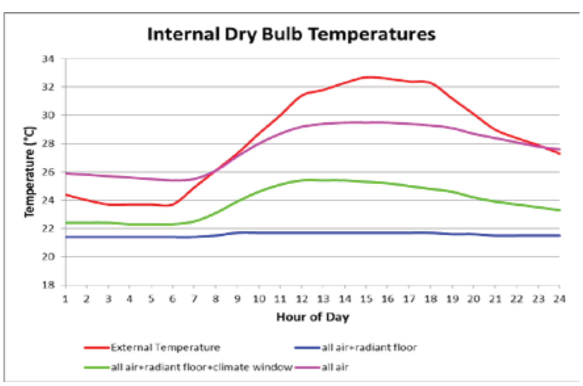


Figure 6: Internal Dry Bulb Temperature under three conditions (cool design day).

The ambient design condition is 32C. The all air system supplying 23,000 m3/h of air at 17C can only maintain internal temperatures of 29C in the occupied space. When the radiant cooled floor, operated at 19C is introduced, space temperatures are below 22C. This would be non-optimal for energy consumption and will be adjusted by increasing the surface temperature of the radiant floor. This adjustment will be made after all the construction materials have been finalized. The radiant floor results show how efficient a radiant cooled floor is for this application. The results of the hybrid system together with the climate roof show higher temperatures, this is due to the high temperature of the air being exhausted through the cavity. This will be updated in future models.

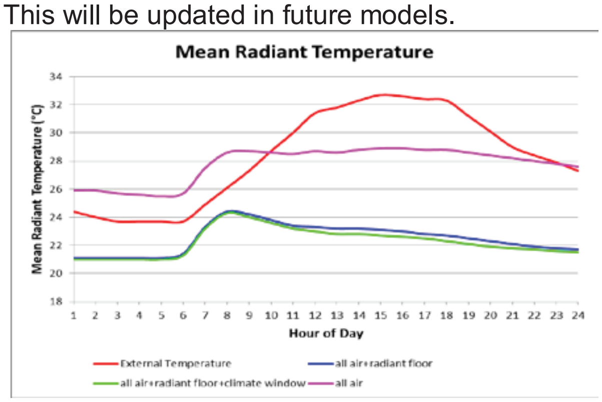


Figure 7: Mean Radiant Temperature under three conditions (cooling design day)

The mean radiant temperature is important for occupant comfort. The results for the all air system show the MRT to be about 29C which is very warm for an occupied space. The results for the alternatives with a radiant cooled floor show MRT temperatures between 22 and 24C. The climate roof doesn't seem to be providing any difference in the results; this is probably due to the temperature of the air in the cavity and will be investigated further in the coming days.

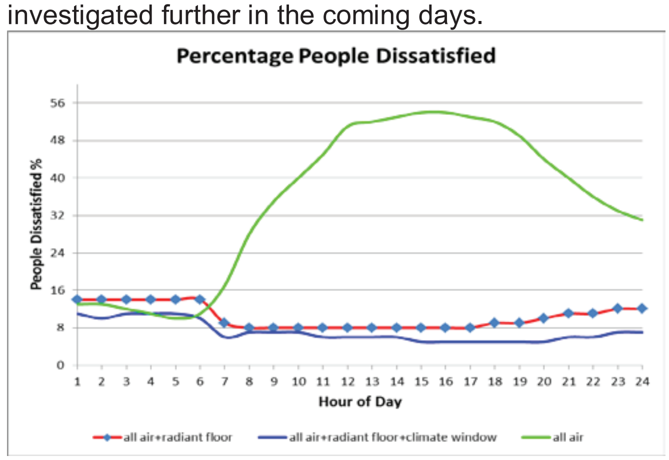


Figure 8: PPD under three conditions (cooling design day)

The Percentage of People Dissatisfied results should be below 10% for a comfortable space. Here the all air system is more than 50%. The other two alternatives provide results lower than 10% PPD and the space will be comfortable.

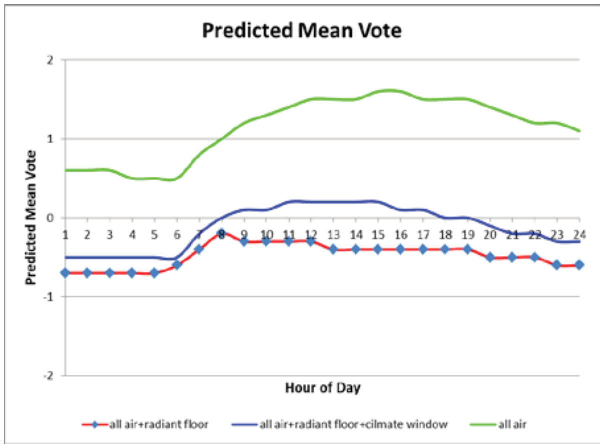


Figure 9: PMV under three conditions (cooling design day)

The Predicted Mean Vote provides an indication of whether occupant's sensation is warm or cold. The results should be between +/- 0.5. The all air system has PMV results higher than +1 which is an 'over' warm sensation. The other two alternatives have PMV results between -0.5 and 0 which indicated the spaces are on the cold side, but still comfortable. By reducing the output of the radiant floor the PMV results would be kept lower than +0.5 to maintain comfort conditions, but by reducing the output of the radiant floor cooling energy would be reduced.

Winter Design Day

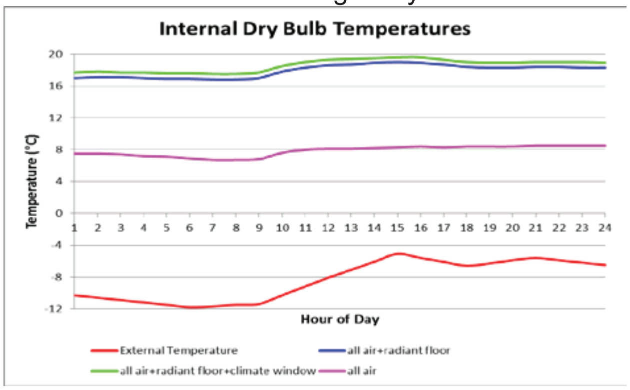


Figure 10: Internal Dry Bulb Temperature under three conditions (heating design day)

During the winter design day when outside temperatures are about -11C, heating conditions through the all air system can only maintain 8C. The supply temperature can be increased but due to the coanda effect the air will rise out of the occupied zone.

The alternatives with the radiant floor for heating provide conditions slightly lower than 20C,

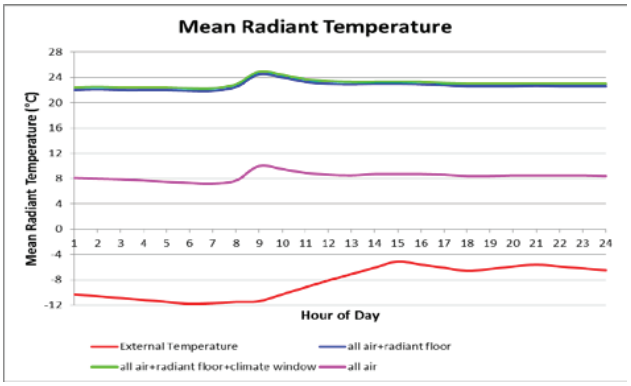


Figure 11: Mean Radiant Temperature under three conditions (heating design day)

The MRT results show the all air system to provide MRT temperatures around 8C, which is very low, but this is expected from an all air system. The alternatives with the radiant floor for heating show MRT temperatures of around 23C. Which could be high, but we will refer to the PPD and PMV results to see if this is true.

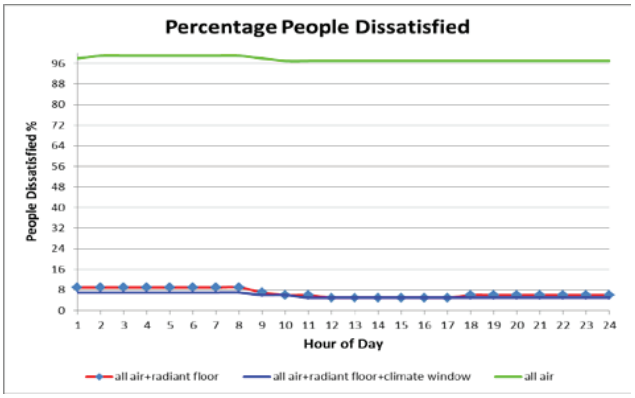


Figure 12: PPD under three conditions (heating design day)

As indicated from the MRT results the PPD conditions for the all-air system are nearly 100%, which would mean all the occupants would be uncomfortable. For the two alternatives with the radiant floor the PPD conditions are lower than 10%, which is in accordance with ISO 7730 and ASHRAE Standard 55, 2010.

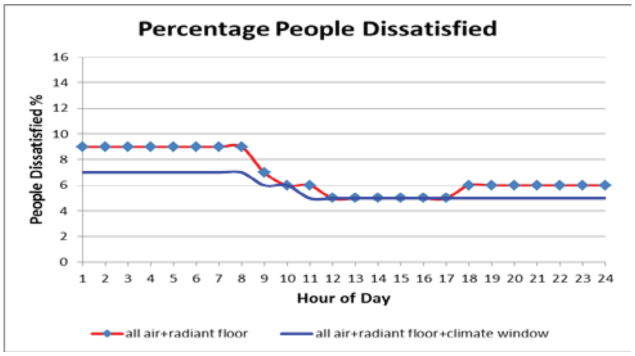


Figure 13: PPD under all air +radiant floor and all air +radiant floor +climate window conditions (heating design day)

The PPD results shown in figure 13 show the difference between the hybrid system and the alternative of the hybrid system with the climate roof

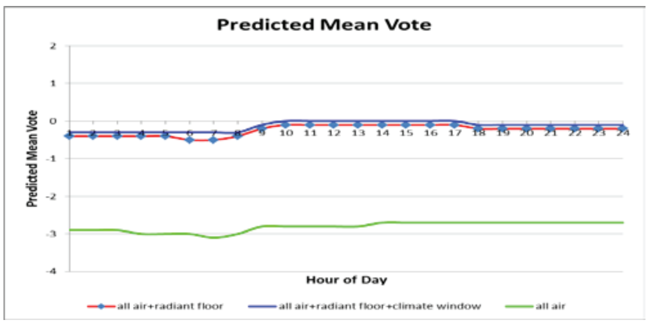


Figure 14: PMV under three conditions (heating design day)

The PMV results show the all air system to be about -3.0, which is the bottom of the PMV limits. The other two alternatives show PMV results to be about 0, which is thermal neutrality. The output of the radiant floor could be reduced slightly to conserve energy, yet still maintain comfort conditions.

## 6. CONCLUSION

By carefully controlling the flow of air through the roof cavity it is possible to control the mean radiant temperature exchange in the space and improve occupant comfort.
The control cycles for the different seasons are shown in figure 15.
As the roof membrane is designed and operated to perform in different climates, we have called this a breathing skin.

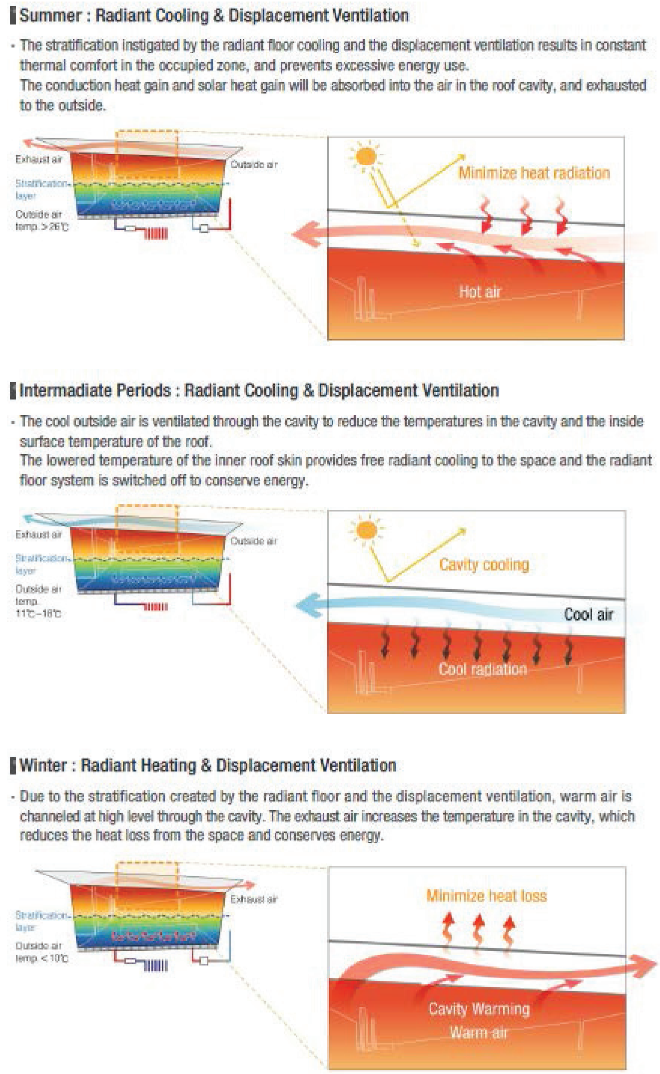


**Figure 15 shows the different control cycles for the roof membrane for the different seasons**

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# Energy Efficient Configuration of Non-Conventional Solar Screens Using Hybrid Optimization Algorithm

## Optimizing Screen Depth, Perforation and Aspect Ratio

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*ABSTRACT: Performance optimization could be utilized in designing sustainable energy efficient buildings especially in harsh desert environments. External solar screen is one of the traditional shading techniques that could be used to reduce energy use by blocking the beam solar radiation prior to reaching the façade. This research investigates the use of simulation-based building energy optimization in finding the most energy efficient non-conventional solar screen configurations by changing its perforation percentage, depth, and perforation openings aspect ratio for a typical living room. Series of parametric runs were conducted using the EnergyPlus simulation software coupled with GenOpt optimization software using the hybrid GPS/PSO algorithm. Optimum non-conventional solar screens achieved energy savings up to 30.7, 31, 24 and 6.8% compared to the non-shaded window in the South, West, East and North orientations respectively. These provided choices for architects in selecting different screen designs with expected performative behavior. Optimization results were verified by conducting a narrowing down manual search method for other conventional screen types. Simulation results proved the accuracy of previous optimization models. Conclusions were drawn recommending screen configurations that achieved the most significant energy savings. Those were screens having wide openings and large depth ratios with square perforation or rectangles stretched horizontally.*

*Keywords: Energy, Solar Screen, Desert, Shading, Window, Configurations.*

## 1. INTRODUCTION

Performance optimization can be used in effectively simulating designs to arrive at optimum solutions rapidly. The solutions can be generated through automating the process of design parameters investigation by employing the appropriate search algorithms. In an attempt to facilitate the optimization process, a generic optimization program GenOpt was created to help designers find optimal solutions through successive iterations by the use of several optimization algorithms. This program can be joined to any simulation software as EnergyPlus to optimize buildings energy performance (Wetter, 2001). The precedence of using GenOpt with ESP-r energy simulation software was investigated in a study. Input files arrangement and an optimization example were discussed, where several scripts were prepared. The goal was to find the minimum annual energy consumption by optimizing the window to wall ratio of an office building in several cities and comparing the results to the initial assumed values. Optimum WWR for Brussels, Montreal and Palermo were 8.5, 4.8 and 21.3% respectively (Peeters et al., 2010). Moreover, an adaptive precision control algorithm was proposed to fix the discontinuity resulted from approximations in building energy optimization programs. It succeeded in fixing the divergence of an optimization problem resulted by using Hooke-Jeeves algorithm with EnergyPlus software. In addition, the processing time was reduced by 77% (Polak and Wetter, 2006). Moreover, two optimization algorithms were investigated and compared (hookjeeves and the genetic algorithms) in solving a design problem that includes 13 design parameters. Genetic algorithm optimization showed better performance. Energy savings reached from 7% up to 32% depends on the geographical location (Wetter and Wright, 2003).

1.1 GPS/PSO optimization Algorithm

Particle Swarm Algorithm was first proposed by Kennedy and Eberhart in 1995. It was inspired by social behavior of bird flocking or fish schooling. PSO algorithm can be viewed as a swarm-intelligence based multi-agent heuristic search method where potential solutions are coded as particles. Particle Swarm Algorithm (PSO) initializes with a population of random solutions and searches for optima by updating generations. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. PSO is based on the exchange of information between individuals (particles) of the population (swarm), which is called social and intelligence interaction. Each particle adjusts its own position according to its previous experience and towards the best previous position obtained in the population. It is worth noting that PSO particles perform both a global and a local search as each particle learns from itself and its neighbors.

Generalized Pattern Search (GPS) algorithms carry out their exploration on a mesh, looking for the optimum solution. When the algorithm couldn't find further improvement, it refines this mesh to guarantee system convergence to an optimum solution. However, PSO algorithm is used for large exploration spaces hence requires long processing time to find the optimum solution. Consequently, the GPS algorithm is utilized instead for PSO results refinement. Therefore, the GPS performs a local search to arrive at the optimum solution rapidly (Peeters et al., 2010).

1.2 Nonconventional Screening Approaches

Nonconventional cable structures screening system was examined, where they reduced the cooling loads and preserved privacy at the same time. It was found that decreasing the spacing between the cables achieved significant savings in cooling loads, while obstructing the view. Finer cables provided dense shading and enhanced the view aspects (Hatice and Raymond, 2008). In another study, the design and analysis of solar screens with circular openings was investigated algorithmically by using a generic optimization procedure to control daylighting levels. Altering the openings position of a couple of solar screens generated desirable light and shadow patterns (Lockyear, 2010).

## 2. METHODOLOGY

2.1 Optimization Model Set-up

An optimization procedure was carried out to algorithmically generate solar screen configurations based on energy performance. Generic optimization program GenOpt was used together with EnergyPlus simulation software using text configuration files. These configuration files identify the objective function location and detect any errors. GenOpt examines each parameter by successive iterations in the simulation input file until the optimum solution is reached.

The search algorithms investigated a variety of solar screen perforation percentages and depths, where the perforation percentages ranged from 20 to 98% and the depths ranged from 0.1 to 3. The initial screen was assumed to have 80% perforation and 0.25 depth ratio (Table 1).

**Table 1: Lower bound, initial values and upper bounds for optimization of the tested living room.**

| | Lower Bound | Initial value | Upper Bound |
|---|---|---|---|
| Perforation % | 20% | 80% | 98% |
| Depth Ratio | 10% | 25% | 300% |

2.2 Selection of Hybrid GPS/PSO Optimization Algorithm

A combined system of particle swarm algorithm was selected for solar screen parameters optimization coupled with GPS algorithm. This was based on the results of a previous study that compared between five different algorithms such as genetic algorithms, memetic algorithms, particle swarm, ant-colony systems, and shuffled frog leaping. Results of this study revealed that the particle swarm algorithm produced the best results and found the optimum solution rapidly (Elbeltagia et al, 2005).

A hybrid GPS/PSO algorithm was utilized as a method to simulate the performance of a number of solutions through control nodes, as generations were created, tested and selected through repetitive iterations and simulations. The two algorithms were joined together to form the hybrid GPS/PSO so that the entire area of possible solutions is being extensively searched. First, the PSO performs a global search after a certain number of generations. Afterwards, the

GPS begins its local search beginning with the best solutions reached by PSO to improve the exploration and achieve adequate accuracy. Kennedy and Eberhart recommended using from 10 to 50 particles (Wetter, 2009). Accordingly, the hybrid solar screen configurations evolved by performing more than 500 iterations for each orientation and were controlled by producing 25 particles.

2.3 Base case parameters

A typical living room with a number of assumed fixed parameters was used for experimentation. These architectural parameters were chosen to represent the principal features of a representative living room in the desert environment (Table 2).

**Table 2: Base case parameters.**

| Living Room Space Parameters | |
|---|---|
| Floor level | Zero level |
| Dimensions | 4.20 m * 5.40 m * 3.3 m |
| **Window Parameters** | |
| Dimensions | 2.30 m * 1.20 m |
| Sill Height | 1.0 m |
| WWR | 20% |
| Light Transmission | 0.75 |

The focus of the simulation process was to evaluate the energy demand resulting from the cooling, heating and artificial lighting loads of the modeled space. A living room with a split-type air-conditioning system was modeled. The base case was opening-tuned to focus on the energy performance of the tested screens. The floor, roof and three of the room walls were assumed adiabatic. The fourth wall had a double clear glazed window at its centre where the solar screen was attached. This wall was modeled as a 350 mm thick double brick insulated cavity wall with a U- value of 0.475 W/m² –k. The solar screen was externally mounted at a distance of 50mm from the wall and 0.7m height from ground. Artificial lighting was set to be dynamically controlled by sensors according to daylighting adequacy. A Daylighting control was set up with an illuminance set point of 300 lux at the centre of the tested space. The internal occupants' load was accounted for, while the energy consumption of appliances was not considered (Table 2). Different cases of external perforated solar screens were applied in front of the window of the base case "window without screen". Results were tabulated and analyzed numerically, and the corresponding geometries were reproduced and analyzed visually. A comparative analysis was conducted between the optimized screens generated from the optimization software and the base case.

## 3. RESULTS AND DISCUSSION

The optimization software generated a diversity of solar screen alternatives that showed high energy saving potentials (Figure 1). In the South, energy efficient screen design was achieved by increasing the depth of the horizontal screen bars and decreasing the depth of the vertical screen bars. In other words, increasing the screen depth/width ratio and decreasing depth/height ratio achieved maximum energy savings. In the West and East, energy efficient screen designs were achieved by increasing the depth of the horizontal screen bars especially in the upper and middle parts, while increasing the depth of the vertical screen bars only in the middle parts and of the solar screen i.e., increasing depth/width ratio and decreasing depth/height ratio achieved maximum energy savings. On the other hand, in the North, energy efficient screen design was almost a regular 1:1 perforation: depth ratio with an increase in the depth of the vertical screen bars and a decrease in the depth of the horizontal screen bars i.e. decreasing the screen depth/width ratio and increasing depth/height ratio achieved maximum energy savings.

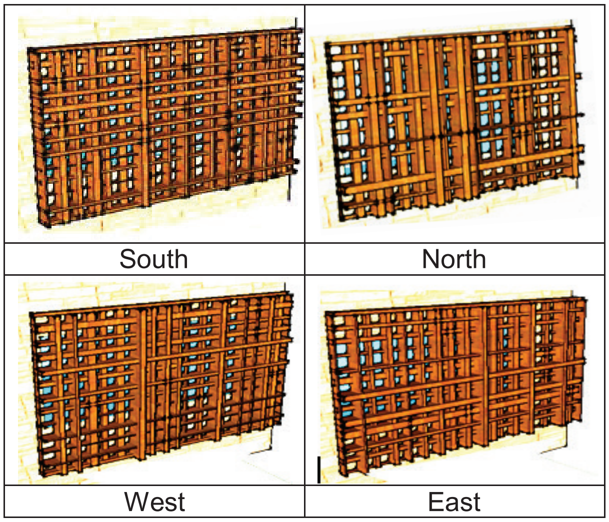


*Figure 1: Energy efficient nonconventional screen configurations – All orientations.*

The Energy Consumption of the optimum energy efficient nonconventional screen configurations decreased significantly compared to the unshaded window of the base case. Difference between the energy consumption of the base case in each orientation and the optimum screen configuration reached 54, 55, 39 and 8 KWh/m² in the South West East and North orientations respectively (Figure 2).

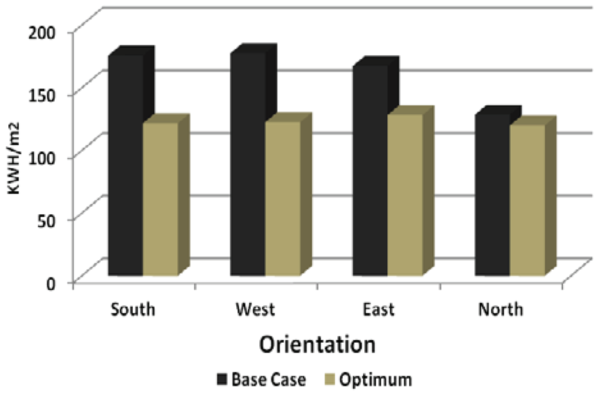


*Figure 2: Energy Consumption of optimum energy efficient nonconventional screen configurations compared to the base case- All orientations.*

For the South orientation, the five most efficient alternatives with a maximum marginal error of 5% were selected. These near optimal solutions provided a variety of choices for solar screen designs. Optimal screen design was achieved by increasing the depth of the horizontal screen bars especially the upper screen horizontal bar which acts as overhangs providing shading to the indoor space of the living room. However, in alternative 2, the increase in the depth of the horizontal screen bars was clearly shown in the middle parts. In alternative 3, an increase in the depth of the vertical screen bars is demonstrated only in the middle parts and the ends of the solar screen in addition to its large screen horizontal depth bars. The significant increase in the solar screen depth of both the horizontal and vertical bars of alternative 4 was clearly observed. Alternative 5 has the shape of a regular screen with a depth ratio of almost 1, where the difference in energy savings between alternative 5 and screen with depth ratio of 1 is almost negligible (Figure 3). Results demonstrated the importance of the horizontal depth bars in the South orientation, where significant energy savings can be achieved by using solar screens with square shaped perforations or rectangular shaped perforations stretched in the horizontal direction.

*Figure 3: Alternative energy efficient nonconventional screen configurations - South.*

In the South orientation, 164 iterations were required to reach the optimum screen configuration with a total of 157 EnergyPlus simulations, where the lowest energy consumption was found in alternative 1 (54 KWh/m² less than the base case). The near optimum zone included alternatives 2, 3, 4 and 5 with 49.9, 50, 51.2 and 53 KWh/m² less than the base case (Figure 4). The optimum solar screen outperformed the solar screen with depth ratio of 1by almost 1 KWh/m².

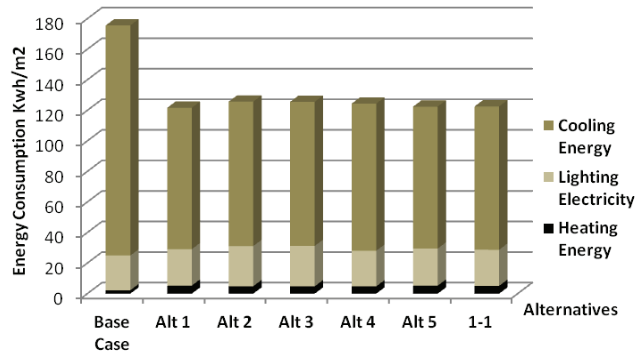


*Figure 4: Energy Consumption of Alternative energy efficient nonconventional screen configurations compared to the base case- South.*

The total annual energy savings resulting from use of different solar screen depths and perforations alternatives in comparison with the base case and a typical solar screen with squared perforations and depth ratio of 1 were calculated to obtain energy saving values. The highest total energy savings reached 30.7%. For the near optimum alternatives 2, 3, 4 and 5, savings reached 28.4, 28.5, 29.2 and 30.3% savings respectively (Table 3). The optimum solar screen outperformed the solar screen with depth ratio of 1 with 0.5%.

**Table 3: Energy savings resulted from using Alternative energy efficient nonconventional screen configurations and screen with depth ratio of 1- South.**

| Alternatives | Alt 1 | Alt 2 | Alt 3 | Alt 4 | Alt 5 | 1-1 |
|---|---|---|---|---|---|---|
| Energy Savings | 31% | 28% | 28% | 29% | 30% | 30% |

For the source energy consumption, the optimum solar screen cooling energy consumption values which represented the highest component dropped from 151 KWh/m² in the base case of the unshaded window to 92.5 KWh/m², while lighting electricity slightly increased from 23 KWh/m² to 24 KWh/m² and heating energy which were almost negligible increased from 3.5 to 5.2 KWh/m² (Figure 5).

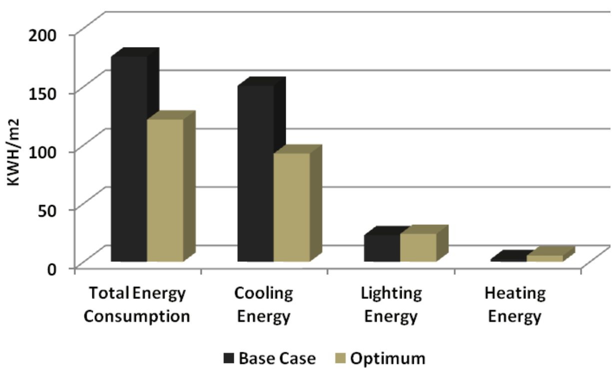


*Figure 5: Source Energy Consumption- South.*

## 4. RESULTS VERIFICATION

For verification, the optimization results were compared to the results of a previous study which identified the configuration of conventional screens that result in most significant savings in comparison with the un-shaded windows (Sherif et al., 2012). These screens had a depth: perforation ratio of 1:1 with an 80% perforation percentage in the West and North orientations, and a 90% perforation percentage in the East and South orientations. Energy savings resulting from the use of orthogonal squared screens reached 30%, 30%, 25% and 7% for the West, South, East and North orientations respectively in comparison with a non-shaded window. Energy savings resulting from use of the optimum screen alternatives in the South West, East and North orientations reached 31, 30.7, 24.1 and 6.8 % respectively compared to the base case. The energy savings were barely significant in the North due to limited solar exposure on that orientation (Figure 6).

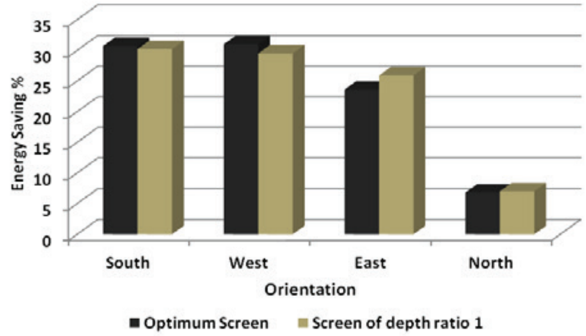


*Figure 6: Energy savings of optimum screen configuration generated from the optimization software and screen with depth ratio of 1 in comparison with the base case- South.*

To verify the influence of changing the aspect ratio and depth of the conventional solar screen perforations on the energy loads, the effect of rectangular perforations with different aspect ratios, and proportions (depth: height: width) was studied. Two main screen configuration parameters were tested (Figure 7); these were:

- **Depth / Width Ratio (D/W):** The ratio between the depth and the width of the perforation opening.
- **Depth/ Height Ratio (D/H):** The ratio between the depth and the height of the perforation opening.

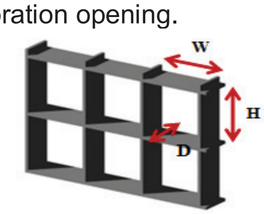


*Figure 7: Screen cell configuration parameters represented by Depth (D), Height (H) and Width (W).*

For the conventional screen, the importance of screen horizontal bars is demonstrated in the South, where adequate cases increased in the Depth/Width (D/W) of 1/4 till 2/1 when the square proportions of the opening were changed in ratio to become horizontal rectangle-like (Figure 8).

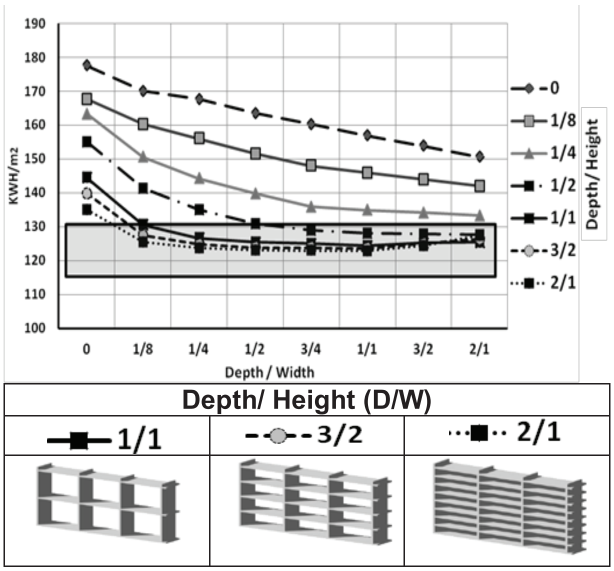


*Figure 8: Effect of Changing Opening Proportions (Depth/ Width D/W and Depth/ Height D/H) on the Annual Energy Consumption in South orientation.*

## 5. CONCLUSION

A diversity of non-conventional solar screen configurations that showed high energy saving potentials was generated using hybrid optimization algorithm. In building energy optimization, when the number of independent parameters exceeds two, the designer usually cannot understand and quantify the nonlinear interactions of the various system parameters. By using hybrid GPS/PSO optimization, solar screens with highest energy savings were determined in each building orientation. Non-conventional solar screen design that includes 64 design parameters which are the solar screen bar nodes was explored. Implementing the optimization algorithm gave a variety of design solutions to the designer together with a better understanding of the system behavior.
Simulation results complied with the optimization ones, where the optimum and near optimum solar screen alternatives values and energy savings are close to the solar screen with square perforations and depth ratio of 1 that achieved a high saving potential in all orientations. It was found that the energy savings resulting from use of the optimum screen alternatives in the West, South, North and East orientations reached 30.7, 31, 6.8 and 24.1% respectively compared to the base case. For, South, West and East orientations, significant energy savings can be achieved by using solar screen with bars of large horizontal depth or in other meaning square perforation or rectangles stretched horizontally. This agrees with previous results that investigated the screen aspect ratio. Adequate non-conventional screens are presented with different alternatives. This research reported on orthogonal screens with square and rectangular bars. Further research would be oriented to testing the effect of rotating the screen horizontal and vertical bars on the energy loads.

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# Energy efficiency in Spanish social housing stock.

## Review of façade composition and energy demand recent literature

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*ABSTRACT: Characterization of the energy performance in social housing is taken as the point of departure for proposals for construction-related improvements. The improvement in vertical enclosures can contribute to avoid energy poverty, urban vulnerability, and energy dependence while improving indoor comfort.*

*Though the specific characteristics of the enclosures are difficult to determine for spanish social housing stock, different reports and prior studies are reviewed, concluding that the potential for improvement in existing buildings is huge taking into account also social and economic aspects.*

*Keywords: energy demand, social housing, vertical enclosure, U value, existing buildings,*

### 1. INTRODUCTION

The paper submitted forms part of a study on the possibility of improving vertical enclosure systems in Spanish **social housing** to enhance both the quality of the indoor environment in and the energy efficiency of these buildings. (Project number BIA-2012-39020-C02-01).

Meeting those aims calls firstly for an accurate diagnosis of housing type, present condition and energy performance. The city of Madrid was taken as the reference starting point for the study for its temperate climate, and because its housing stock distribution is representative of multi-family dwellings nation-wide.

Characterization of the energy demand in social housing is taken as the point of departure for proposals for construction-related improvements, in which the use of **passive systems** can raise the number of hours of indoor comfort per year with no need to resort to active energy systems. Such improvements in passive performance are particularly necessary where the use of active systems is constrained for want of financial resources, i.e., in segments of the population that endure **energy poverty**. Energy **consumption** is found to be low in these buildings due to occupant constraint in the use of environmental control, which translates into less comfort and consequently a lower **quality of life**. The increasing energy price also worsens this situation.

In addition to energy performance, improvements in vertical enclosures involve the renovation and enhancement of features such as building aesthetics, with the concomitant beneficial impact on the surrounds and in subjective vulnerability perception.

Lower energy demands for heating and cooling also have a beneficial impact on **power generation and distribution** infrastructures. Although the upward trend in residential energy consumption has flattened somewhat with the economic crisis, meeting that demand entails enlarging such infrastructures with the concomitant intensification of environmental impact and **energy dependence**.

Lastly, a number of reports have quantified the **job generation potential** of this type of measures, significant taking into account the increase in unemployment in the construction sector.

Energy efficiency is on political agendas at every scale, from the International Energy Agency down to local governments. Improving energy efficiency constitutes one of the clearly established lines of action in many long-term plans.

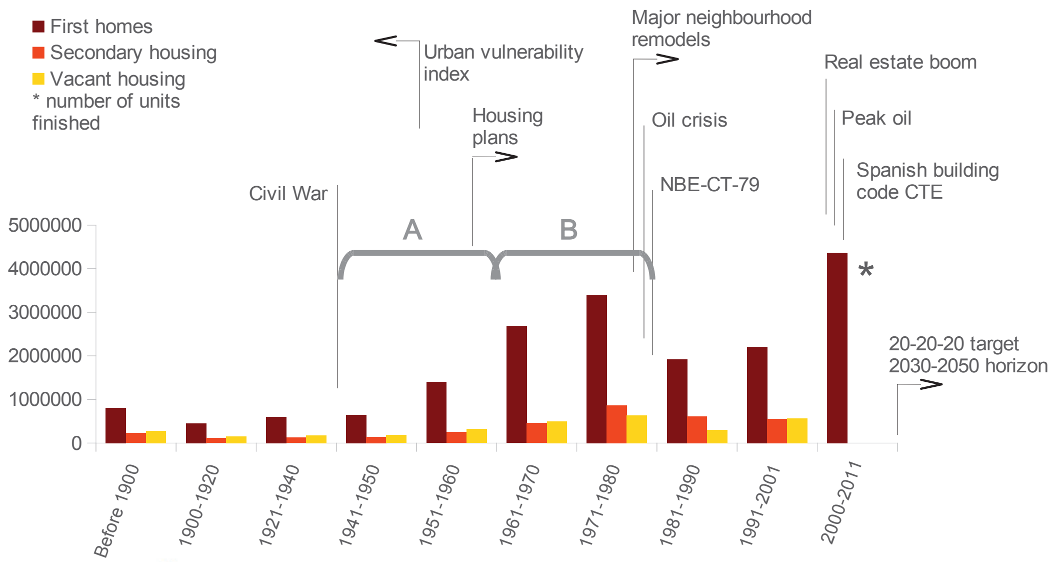


*Fig.1. Number of first and second homes and vacant units in Spain (INE, 2001) and number of newly built homes (Ministry of Internal Development, 2011).*

## 2. SHARE OF SOCIAL HOUSING IN THE OVERALL STOCK

A discussion of the milestones and indicators that characterize the existing housing stock in Spain and its energy performance is a necessary first step to study multi-family social housing refurbishment in cities.

The data in Fig. 1 characterizes the existing stock: number of first and second homes and vacant units in primarily residential buildings (INE, 2001); number of newly built units since 2001 (Ministry of internal development, 2011). The Civil War is also marked (1936-39), buildings prior to 1951 as an indication of residential vulnerability (Hernandez, 2001); the start-up of the successive housing plans, in particular the Third National Housing Plan during the dictatorship (1961-1976), with the concomitant neighborhood remodels, conducted in Madrid by the local housing institute (Spanish initials, IVIMA) beginning in the nineteen seventies; the oil crisis in the same period and the introduction of energy criteria in legislation enacted in 1979; the real estate bubble and subsequent economic crisis when it burst in 2006; the publication of Spain's Technical Building Code (CTE, 2006); and the transposition of recent European energy efficiency-related plans and directives clearly designed to reduce greenhouse gas emissions in the short and long term.

The figure also identifies the two selected periods of this study, A and B (1940-1960; 1961-1979) with obvious differences in terms of number of housing units, whose construction and energy characteristics are described below. Housing needs began to rise in Spain after the country's Civil War. Mass migration to urban centers and the paucity of resources generated a housing stock heavily impacted by successive plans and actions undertaken during the dictatorship. Beginning in the nineteen seventies, neighborhood remodels driven by grassroots organizations began to raise quality standards, generally in response to the appearance of infra-housing of different types. In Madrid these included "urban villages" consisting essentially of shanties, small shantytown enclaves, ethnic minority (mostly Gypsy) settlements, and districts created around precarious public housing built by the National Housing Institute and the Trade Union Homebuilding Initiative (Casanova, 2008).

In 2001 only 67 % of the existing housing units were first homes. At this writing, the housing stock is estimated to include 16.7 million first homes, 4 million second homes, 3.7 million vacant dwellings and an unsold stock, in 2011, of one million units (Silva, 2012).

Region-wide, social housing in the city of Madrid can be divided into districts under criteria of **urban vulnerability** (Hernandez, 2001) refered to a combination of social disadvantages that increase threats and risks affecting people, societies, social groups, or states and weakening the mechanisms to address them. These districts have been identified on the grounds of 21 indicators grouped under four main headings: socio-demographic, socio-economic, residential and subjective vulnerability. In the present study the indicators of residential vulnerability focused on size of unit, condition, availability of a bathroom or toilet and building age (built before or after 1951). Fig. 2 depicts the vulnerable areas in Madrid's historic quarters and in districts located mostly in the southern part of the city.

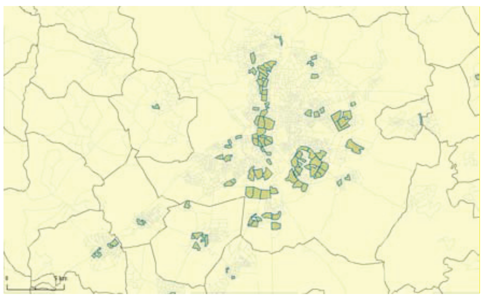

*Fig. 2. Vulnerable areas in Madrid identified in the 2001 Atlas of urban vulnerability (Hernandez, 2001)*

A second conceit addressed in this study is **energy poverty**, defined to be the situation existing in households unable to pay for sufficient energy services to meet their domestic needs or that spend an overly large share of their income on residential energy bills. Further to that definition, 10 % of Spanish households are estimated to be energetically impoverished (Tirado, 2012). The increasing energy prices and the financial crisis that has afflicted the country in recent years has had an enormous impact on society and in particular on the real estate industry, worsening this situation for many households. According to Silva (Silva, 2012), the rise in housing energy consumption, a substantial share of which is used for thermal comfort, and consequently greenhouse gas emissions, has tapered in recent years (Fig.3).

Current European policy pursues cost-effective or optimal levels of energy efficiency for new and existing buildings and their elements, defining the necessary improvements in terms of reference models (EC, 2012)

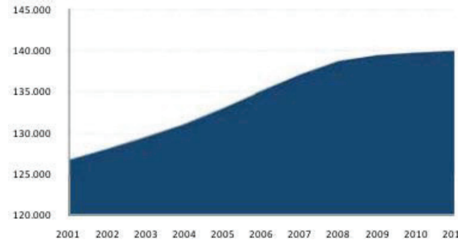


*Fig 3 Total housing consumption in GWh/year (Silva, 2012)*

## 3. THERMAL PERFORMANCE

The factors that determine thermal performance include environs-related questions such as climate, urban surrounds and user behavior. Buildings respond to these conditions depending on their design, construction and systems.

In light of their social significance, housing units in multi-family buildings have been chosen as a reference, even though their mean consumption, at 7 859 kWh/year (0.028 TJ), is 25 % lower than the national average. Mean consumption in housing located on the part of Spain with a continental climate is 13 141 kWh/year or 0.047 TJ, 27 % higher than the national average. Heating accounts for 55.3% of total consumption in this region, followed by household appliances with 17.6%, DHW with 17.4%, kitchen appliances with 6.5%, lighting with 2.6% and air conditioning with 0.7% (IDAE, 2011).

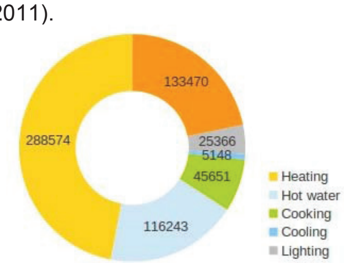


*Fig.4. Housing energy consumption (Spain, TJ) (IDAE,2011)*

Uncertainty about the housing sector's contribution to energy demand is high due to the total lack of either energy consumption monitoring in the Spanish building stock or indirect estimates (García, 2011) The stock performance can be characterized, on the one hand, by estimates based on theoretical simulations for the residential sector as a whole or for specific buildings, and on the other, from some admittedly scant real data collected by monitoring thermal behaviour.

One of the aims here was to ascertain the thermal performance of multi-family residential buildings from different reports and prior studies, reviewing: the estimated energy required to heat and cool multi-family buildings erected between 1939 and 1979 and the behavior of opaque vertical enclosures in these buildings.

3.1 Energy demand

The main parameters that determine heating and cooling demands include climate, urban environs (obstruction, wind), building design (compactness, solar radiation), construction elements (percentage of openings) and materials and systems (conductivity, inertia). A wealth of data on heating and cooling demand calculations can be found in the literature. The energy certification scheme for multi-family buildings in Madrid (table 1) provides reference data for new buildings (IDAE, 2009) and for existing buildings (IDAE, 2011):

**TABLE 1. HEATING AND COOLING DEMAND IN ENERGY CERTIFICATION SCALE FOR MULTI-FAMILY BUILDINGS IN MADRID**

| | Heating demand ($kWh/m^2K$) | Cooling demand ($kWh/m^2K$) |
|---|---|---|
| Reference (new) | 43,2 | 10,8 |
| A-B | 9,4 | 3,96 |
| B-C | 21,8 | 6,48 |
| C-D | 39,6 | 10,08 |
| D-E | 66,3 | 15,48 |
| Reference (existing) | 121,2 | 19,1 |
| E-F | 119 | 18,2 |
| F-G | 130 | 22,6 |

In a prior study, the present authors reported their heating and cooling demand findings for a variety of façade types (Alonso, 2011) exposed to different conditions. Demand was logically small compared to the values for older buildings, because transmittance in these enclosures was lower (0.3, 0.6 and 0.9 W/m2·K, fluctuating with the indoor mass). As the figure shows, the diversity of conditions found when envisaging this type of action calls for individual solutions.

The final essential factor in such studies is **user behavior.** In social housing especially, information on household use profiles is the key to characterizing energy consumption and user comfort, in light of the significant differences from one profile to another. Standardized values based on seasonal use estimates are applied in simulations and legislative calculations.

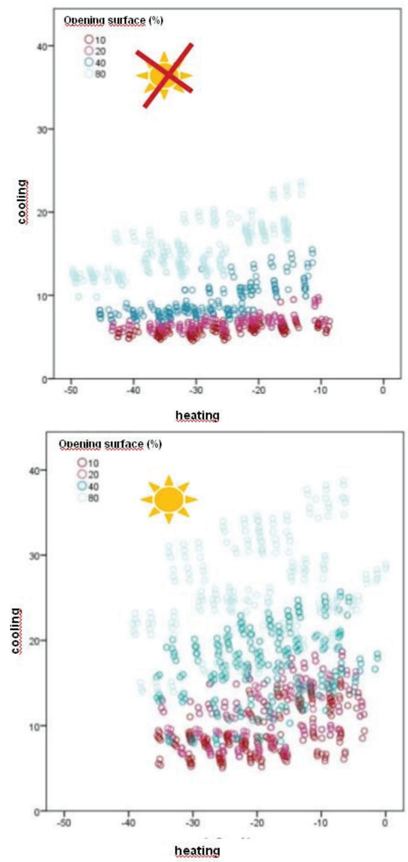


*Fig.5 Heating and cooling demand by changes in facade composition and sun exposure (Alonso, 2011)*

Broken down by the respondent's occupational status, while 74 % of the employed and 67 % of people not in the workforce had heating, only 53 % of the dwellings occupied by the unemployed were so equipped (last data for Spain is 26% population unemployed, 2012). The respective percentages for air conditioning are 40, 29 and 31 %. Income levels are also observed to be associated with behavioral differences (INE, 2008).

3.1 Opaque vertical enclosures

The establishment of increasingly demanding energy quality standards has identified the need for some manner of action in virtually the entire stock of existing residential buildings.

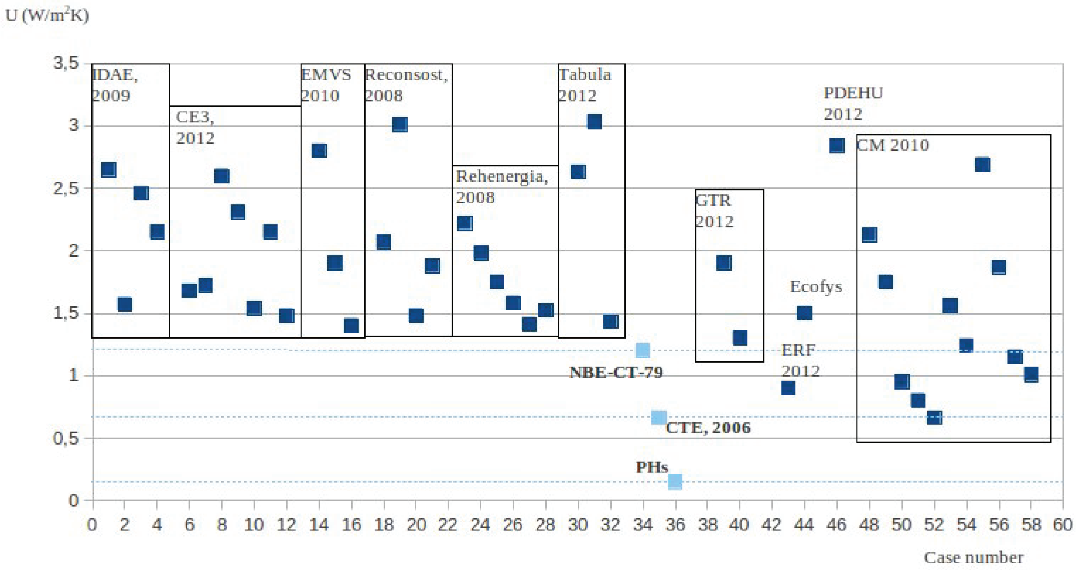


*Fig 6 U value for different standards (NBE-CT-79, CTE, 2006, Passivehaus PHs) reports and studies in existing buildings (1939-1979).(IDAE 2009,2011 CE3tool 2012 Luxan, 2010 Martin, 2008 -2008, Ortega 2011 GTR, 2012 Capdevila 2012 Ecofys, CENER, 2012 CM 2010)*

A study conducted specifically in the city of Madrid (Luxan, 2010) found that the effectiveness of such action is highest in buildings where energy performance is lowest. That study made specific reference to buildings erected prior to the enactment of building code NBE-CT-79 as well as to the important energy savings role of enclosures, outer walls especially, which in some cases may provide over 70 % of the total savings possible.

The specific characteristics of the existing enclosures are difficult to determine. In Fig.6 different types of reference enclosures have been defined by assuming transmittance, U (W/m2·K), to be the property with the greatest effect on energy performance.

The reference data for the various enclosures are widely scattered, a finding attributable to the diversity of initial situations.

In most of the enclosures to be rehabilitated, thermal transmittance lies between 1.2 W/m$^2$K (minimum required in the 1979 code) and 3.0 W/m$^2$·K, and always above the building code requirements for Madrid (CTE 0,66 W/m$^2$K )

The improvements proposed envisage values very close to the present code requirements and all of the cases reviewed fall far short of complying with the 0.15 W/m$^2$·K Passivehaus recommendation (Diaz, 2012), necessary for achieving net zero objectives.

## 4. DISCUSSION AND CONCLUSIONS

Bearing in mind the relevance of the construction and housing industries for medium- and long-term emissions reduction, ambitious strategies and objectives should be envisioned to guarantee the sustainability of the housing stock and to reduce energy vulnerability. Certain issues along these lines have been addressed in earlier papers, including the importance of diversity in the type of actions pursued, with adapted and adaptable solutions for renovation cycles, and life cycle analysis based on comprehensive and detailed case-by-case reviews.

The conclusion to be drawn from this initial analysis is that the reference data are widely scattered, both as regards heating and cooling demand and the type of reference enclosure used in the calculations. Despite this dispersion, the general consensus is that the potential for improvement is huge. Most of the papers reviewed propose general building overhauls to attain substantial long-term improvements in a short period of time, with significant reductions in energy demand and consumption. These improvements can also be achieved gradually, with individual solutions at element scale.

Energy demand for environmental control has been used as a reference for determining a building's thermal quality. Such demand is determined from standardized use and comfort parameters, however, which should be reviewed to ascertain whether they are in keeping with the local social and cultural context and needs to be compared to actual in-service values.

At a time when major rehabilitation operations are being put forward, the lessons learnt from the errors and experience accumulated in large Spanish cities during past neighborhood remodels and similar types of action provide very helpful background information. A number of factors characterize each period of the residential sector history: the appearance of environmental concerns in the nineteen seventies, essentially ignored by the industry until the advent of European initiatives, or the housing construction boom over the last 10 years. A further source of useful information lies in the rehabilitation proposals under consideration in other net energy importer cities in Europe, and in general in other cities with climates similar to Spain's that pursue residential energy savings and efficiency.

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# Existing Building Energy Upgrades

## BUSINESS MODEL FOR HEALTHCARE SECTOR

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ABSTRACT

*Healthcare buildings are resource intensive due to the complexity of the program, regulatory requirements, 24/7/365 operating schedule amongst many other reasons. The low cost of utilities has allowed us to stay with the old and inefficient building systems here in the United States. Even now this factor makes a hard sell for the more sustainable technologies that are perceived somewhat more expensive considering just the upfront cost.*

*Most new construction projects are geared at meeting the program, achieving the desirable aesthetics and addressing sustainability issues if possible. However after the building is operational, its carbon footprint and the operating cost affects the well being of our planet, profitability and ultimate feasibility of the program that it was designed for. With the new Affordable Care Act legislation, it is anticipated that the healthcare delivery systems will have to be lean and efficient to be sustainable.*

*Additionally the increasing energy prices and mounting political pressure on national and international front has heralded an era of self -evaluation of building systems and operations in general. This has led to some ground breaking research here in US on how the systems are being specified around the world where the energy prices are astronomical or the population is more environmentally ethical.*

*Many healthcare providers are starting to take advantage of this and discovering that the sustainable strategies align their goals of creating healthy environs for patient well being with reducing the operating cost. The strategies extend into building design, construction, operations, maintenance, and procurement methods and are constantly evolving.*

*A brief review of existing research will be done to understand the factors that can help reduce the Energy Use Intensity (EUI) of the hospitals. This paper will also evaluate the potential financing to reduce the upfront project cost for the owner. It will use the concepts derived from Public Private Partnership (P3) system of project delivery for the basis of proposed business model.*

*Keywords: healthcare, existing buildings, EUI, financing, Performance Contract*

**INTRODUCTION**

The healthcare building systems form a crucial link in our emergency preparedness. Reducing their appetite for resources would help create more resilience.

The last couple of years saw the emergence of various financial products backed by the various levels of Government and non-profit organizations to facilitate the transition of buildings from previous centuries into the 21st century. This generated interest and the desired business environment in the construction industry.

The showcase projects listed on EPA website are just starting to touch the tip of the iceberg. A significant progress can be made when the sustainable buildings will start making the economical sense both on short and long term basis.

We are fast approaching a time where the promise of modern approaches will outweigh the operating and maintenance cost of older building systems. The scale is tipped favourably towards healthcare sector due to the shear intensity of its size and potential impact. It makes a strong case for outside investments with the promise of steady returns.

Healthcare facilities are always in the midst of a change in their physical environment due to the constant growth and change in the technologies. This presents an opportunity to switch to the sustainable approaches. The financial concerns should not deter these efforts as this paper would present a variety of options that would reduce the upfront cost.

## 1. THE HEALTHCARE ENERGY EFFICIENCY OVERHAUL

The energy consumption in healthcare sector in the US is estimated to be 60% more than similar size facilities in Scandinavian countries.

*Targeting 100 study* presented these interesting statistics based on the context and prototypes that were developed:

- A baseline Energy Use Intensity of 270kbtu/sf/year can be reduced to 100kbtu/sf/year with efficient design of the systems.
- Financial savings of about -$500,000-750,000 each year.
- Taking 1300 cars off the road or planting 300,000 trees

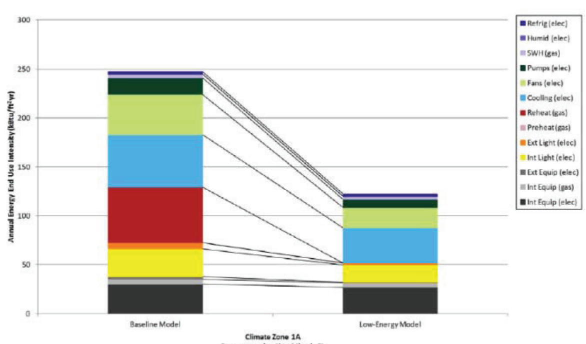


*Fig 1.0 Comparison of Baseline to prescription 50% reduction of large size healthcare facility*
*Source AEDG 50 Large Hospitals*

### 1.1 THE ENERGY UPGRADES

According to *Targeting 100 study* there are four areas which can enhance the energy performance of an acute care hospital:

#### 1.1.1 ARCHITECTURAL SYSTEMS

- Day lighting – Increase interior environmental quality and decrease electric lighting use. It also includes specifying high performance windows with better U values. This factor goes beyond the realms of energy efficiency. It has big impact on reducing patient stay time, reducing medical errors and increasing staff retention.
- Solar control- Provide shades to minimize peak loads.
- High Performance Envelope- Increase the building insulation. Reduce the energy losses by providing air & vapour barriers.

#### 1.1.2 BUILDING SYSTEMS

- De- Centralized, De coupled system- Separate thermal conditioning from ventilation air. This has a great potential in reducing reheat which is considered a major waste of energy. The hospitals have various types of spaces that serve critical and non critical areas. Regulatory codes and functionality of these spaces govern the HVAC design. Energy efficiency is achieved by separating the systems to serve the unique requirements.
- Optimized heat recovery from space heat & large internal equipment sources
- Advanced HVAC & lighting controls

#### 1.1.3 PLANT SYSTEMS

- Advanced air system heat/cool recovery with enthalpy wheels at the central plant with heat pumping or heat recovery chillers and high efficiency boilers

#### 1.1.4 ON SITE POWER GENERATION

- Combined Heat & Power cogeneration (CHP) - This is 90% efficient than the traditional plants that are 60 % efficient. The benefits of this have to be evaluated in the proposed context. It is most beneficial in areas where electricity is coal based.
- Solar /wind harvesting systems

A potential energy makeover of an existing facility may include all or some of these systems. Due diligence for such an exercise would create the most beneficial route. Figure 1.1 illustrates the energy usage split in an acute care hospital that can help identify the targets for energy saving measures.

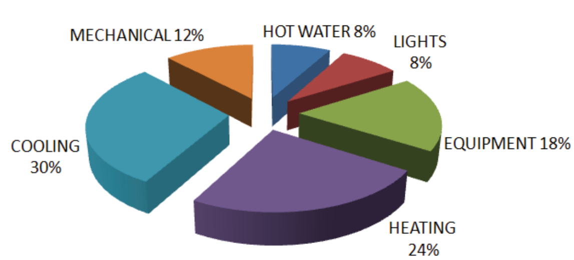


*Fig 1.1 Energy usage break down in Healthcare*
*Source: Target finder*

## 2. OPPORTUNITIES & PATH

*Energystar for Healthcare* indicates that every dollar a non profit healthcare organization saves on energy increases the revenues by $20 for hospitals and by $10 for MOB's based on a 4% profit margin. This factor varies from region to region due to the cost difference in utilities.

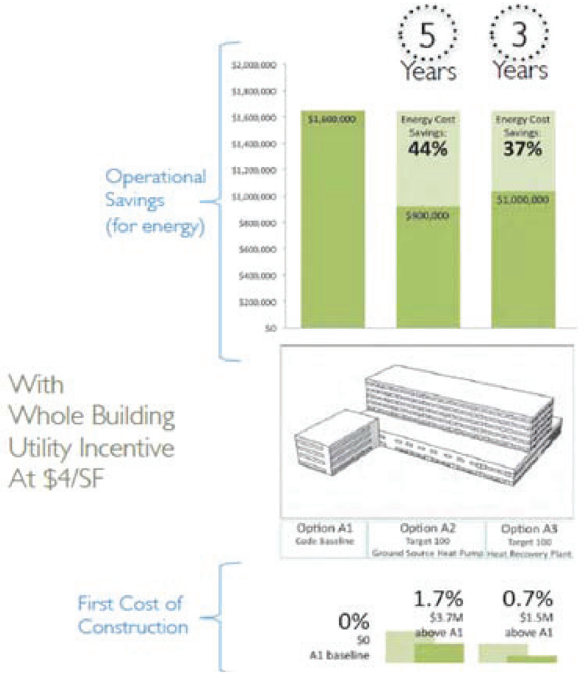


*Fig 2.0 -One of the two prototypes presented by Targeting 100 study that compare upfront cost with the operational savings*

Figure 2.0 indicates ground up hospital prototype that utilized energy efficient central plant technologies and distribution systems. They also take advantage of building form, daylighting and solar shading.

*AEDG 50 for Large Hospitals* estimates that 80% of building's life cycle cost is attributed to operational cost. Most of the existing healthcare building systems are aging and need replacement sooner or later. *Providence Healthcare* estimated that out of every dollar of operational cost, 67 cents goes to utilities, 13 cents to water/sewer, 6 cents to supplies, and 14 cents to salaries. Clearly the main target of savings was utilities.
As these statistics become more popular, the hospital owners would be faced with the following scenarios:

- Tired of paying high energy bills and knowing that most of the building systems are outdated, energy intensive and unhealthy in some cases.
- The only potential capital they have is the cost of utilities at the end of each month

This presents an opportunity for an entrepreneur seeking an initial investment and reaping gradual returns over a period of time. Here is what the business arrangement in simple terms should look like:

- The entrepreneur agrees to finance, design, build, operate & maintain the current utility systems of the hospital.
- In return the hospital would continue to pay the current average utility bills until the capital investment amount is paid off with the agreed upon interest and profit to the entrepreneur.
- Afterwards the hospital has a choice either to renew a contract of services, choose a different operator or they can operate by themselves.

Conceptually it is similar to P3system of project delivery. In energy sector there is a similar contract called Energy Savings Performance Contract (ESPC).

## 3. P3 SYSTEM OF PROJECT DELIVERY

This is a popular arrangement in Europe and has been actively used in Canada in recent years for the sectors that are owned and operated by the government entities including healthcare.

A public private partnership is a legally-binding contract between the government and private sector for the provision of assets and delivery of services that allocates responsibilities and business risks among the various partners. The private sector is responsible for project design, construction, finance and operations.

It embraces the sustainability initiatives that have the potential of reducing the operating cost in the long run. Since the operations and design are controlled by the same entity.

### 3.1. PRIVATELY OWNED HEALTHCARE

Largely speaking, the term *Government* could be replaced with the *hospital owner* in the P3 definition. It would require transferring the portions of facilities management to the private sector. It would allow the healthcare sector to focus on their business and leave running the facility to the experts who have a financial interest in running it efficiently.

### 3.2. THE ADVANTAGES OF OUTSIDE INVESTMENT

The hospital pays only when the infrastructure is available and performs. This generally means that no payments are made until the infrastructure is built. A substantial portion is paid over the life of the asset, if it is properly maintained and performs. It also means that the profit motive is harnessed to ensure effective results. The focus is on the systems that perform for the life of the building.

Finally, this requires the private sector to raise equity and debt capital, meaning that there is substantial oversight by lenders and investors in both the upfront due diligence and project execution.

This creates a discipline that is hard to match for the hospital that does not have the expertise or the capital to create a system that pays for itself as it runs. It also reduces the risk for the owner in investing on the systems that may not perform ultimately.

### 3.3. POTENTIAL PRIVATE PARTNERS

It would consist of a conglomerate of some or all of the following:

- Construction company

- Operations & Maintenance Team
- Financing authority
- Utility Companies
- Systems manufacturers
- Architectural / MEP consultants

The risk could be individual or shared.

## 4. PRECEDENCE

This section lists some energy upgrade projects that are being carried out successfully in healthcare. Some of these projects have been done with the help of private investments with a stake in operations as well.

### 4.1. ENERGY SAVINGS PERFORMANCE CONTRACT

According to Wikipedia *Energy Savings Performance Contracts (ESPC) are an alternative financing mechanism authorized by the United States Congress designed to accelerate investment in cost effective energy conservation measures in existing Federal buildings. ESPCs allow Federal agencies to accomplish energy savings projects without up-front capital costs and without special Congressional appropriations. The Energy Policy Act of 1992 authorized Federal agencies to use private sector financing to implement energy conservation methods and energy efficiency technologies*

A similar contract is being executed between Siemens and Manchester Memorial Hospital. The hospital is a 249-bed acute care facility that offers inpatient and outpatient medical and surgical services to communities east of Hartford, Connecticut. Here are few highlights of the contract:

- Replacement of outdated oil-fired boilers with new high efficiency, low-emission dual-fuel boilers that will use natural gas. The new boilers are expected to save energy, improve reliability and significantly reduce maintenance and repair costs, which will help reduce the hospital's fuel expenses up to 35 percent.
- Upgrade and retrofit of building lighting systems,
- Water conservation measures,
- A new upgraded energy management system,
- New high-efficiency chillers

In the end the project is intended to save the hospital $500,000.00 per year in utility costs. It would also reduce operations and maintenance costs by approximately $28,500 annually. Environmental benefits will also accrue as the program will help to reduce the hospital's yearly carbon footprint by 5,308,357 pounds of $CO_2$, the equivalent of planting 16 acres of trees or taking 441 cars off the road.

### 4.2. COGENERATION-CHP & TRI-GENERATION

*AEDG 50 Large Hospitals* indicates that it takes 3 kwh to produce and distribute 1 kwh of energy to end user due to transmission losses and other factors. Additionally when a hospital purchases both electricity from the national grid and in parallel gas or another fuel for heating this can lead to high costs. Using a gas engine-based CHP plant facilitates the purchase of a single fuel source to achieve both the production of electricity and heat. The conversion efficiency of a gas engine is around 80% and therefore can result in long-term operational cost savings.

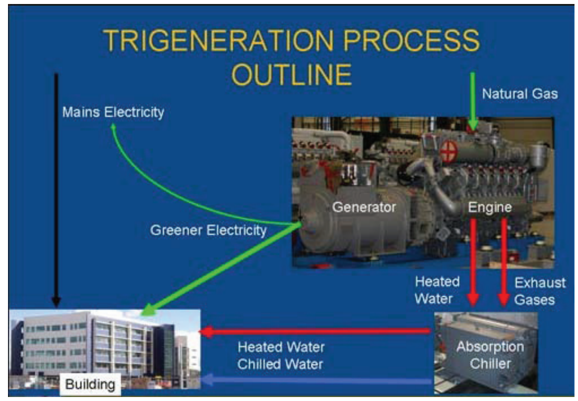


*Fig 4.2 Tri-generation enables the hospital to generate energy onsite. It prevents waste heat from going into the atmosphere. This heat is utilized by building systems for hot water, steam and chilled water. Image source: Rudds Consulting Engineers*

The examples of tri-generation plant are non-existent in the United States. But a similar system in Women's & Children's Hospital Adelaide, SA has resulted in a significant cost savings for the hospital and has reduced carbon dioxide emissions by at least 1,000 tons per year. A privately owned energy company undertakes planned maintenance & provides technical support on behalf of the hospital.

#### 4.2.1. ALTERNATIVE SOURCES OF FUEL FOR CHP

Hospitals with 100-700 bed capacities generate anywhere between 2000-17000 LB of solid waste. Some of the waste generated in hospitals has heating values ranging from 1000 btu's to 8000 btu's per pounds. The University of Michigan saved $400,000 in yearly steam bills by coupling medical waste incinerators with cogeneration.

Sterilization equipment, laundry, and kitchen operations can all benefit from heat-recovery systems. Waste heat from boiler exhaust stacks can also be effectively recovered and used to preheat boiler makeup water.

Landfill gas is another resource that can provide a steady source for fuel while reducing the man made methane emissions. Gundersen Lutheran Healthcare selected a turnkey engineering firm to design and build the landfill gas renewable energy project at the Onalaska campus. Through the health system and the county teaming up on this project, it is estimated that the waste management company will collect approximately $300,000 a year from selling the landfill gas to Gundersen Lutheran who would generate $800,000 a year in revenue from selling the electricity to the utility company while realizing thermal energy savings from the recovered heat and avoided boiler fuel consumption. Once operational, the landfill gas-fuelled power and thermal generation projects are expected to offset approximately 12% of Gundersen Lutheran's total energy use.

The source of fuel needs a careful evaluation with respect to context. A Natural gas based CHP would be an excellent choice where the electricity is coal based but not in a region where it comes from cleaner sources.

### 4.3. LIGHTING UPGRADES

On average, lighting costs are 16% of hospitals total energy consumption; composing over 40% of a hospitals electricity usage. Two cost-saving techniques that hospital executives utilize are LED lights and harvesting natural light. In addition, linear fluorescent lighting, which optimizes wattage without sacrificing quality, is growing in demand in hospital energy improvement.

One such case study demonstrating the effectiveness of these lighting retrofits is Resurrection Health Care in Chicago. After switching from high energy usage T12 lamps and ballasts, to the F28 T8 lamps and electronic ballasts, Resurrection is saving $900,000 annually; a reduction of 9 million kilowatt hours in annual energy. Instead of the typical 15,000-hour life of the T12 lamps, the F28 T8 lamps are expected to last 30,000 hours.

The installation process across Resurrection's 6 acute care hospitals and several other types of medical and office buildings took 3 years. This enormous hospital retrofitting project was done with the financial assistance of the local electric utility.

### 4.4. SOLAR ELECTRICITY SYSTEM

In the past few years this energy sector has made a tremendous progress in founding arrangements that would enable solar power generation to be delivered at the door step of the facilities. This prevents transmission losses and reduces land use for the construction of new plants.

In essence they are requiring the real estate from the owner in the form of parking lots or roofs. This would benefit the owner too by providing:

1. Shade from the sun
2. Reduced utility bills
3. Choice of no initial investment

A solar panel manufacturing company and Bayer Healthcare are planning a 1,000-panel solar power installation. This is the largest in the city of Berkeley. It would help power Bayer's manufacturing facilities. The project was financed, designed, and installed by the solar panel manufacturer. In addition they will also provide ongoing maintenance and monitoring as part of the standard agreement.

The parking lot of this facility will be covered with the solar panels to generate electricity and provide shade to the vehicles under the proposed plan.

This is not a healthcare project, but the vast parking lots of healthcare facilities can take advantage of such an arrangement.

## 5. A BUSINESS CASE

The numbers tell the most compelling story in any business. For an existing facility here is how the whole pursuit can be broken down:

Operational cost = $ A per year
Potential savings= $0.6A per year*

New Operational cost after the potential savings=
$A-0.6A= $0.4A

Investment required= 6A*

Return of Investment= 6A/0.6A= 10 Years

Profits generated after ROI period =0.6A per year

Assuming that systems are designed for a life cycle of 30 years, total savings generated for 30 years = 30-10=20x0.6A= **$ 12A**

These savings can be claimed in by any of the following entities:

1. Owner if he is the primary investor
2. Entrepreneur can claim part of these savings in terms of fees, interest or profit depending on the financial arrangement.

Other observations:

1. The longer the period for life cycle, the higher the savings would be. That allows for higher investment for better systems on the front end.
2. To make the most out of this venture, the investor should have a stake in the operations and maintenance of the systems. That would facilitate the due diligence and longevity of systems.
3. The cost of energy has gone up steadily in the past years. If the same trend continues, the savings accrued would be much higher than the projected numbers.
4. The government grants for energy upgrades have not been factored in as the potential source of investment.
5. A multi disciplinary team that addresses the energy usage from all sources can provide one time long term solution rather than piecemeal approach.

**Factor varies on the following:*

1. *The systems that will be upgraded and projected savings.*
2. *Energy audits and other due diligence procedures.*
3. *Investment available*

In other words maintaining a status quo for the healthcare industry that has outdated systems and operations should not be an option.

The healthcare industry needs to open its doors to operate in a new era of energy efficiency. Already the precious profit margins are flying out the door due to outdated technology of the building systems.

With the Affordable Care Act Implementation, The dynamics of healthcare industry are bound to change. It will be expected to create an environment that fosters better patient care, ensures safety, controls cost and eliminates waste.

As *Providence Healthcare* discovered that the operational cost of the hospital budget holds the key for keeping the jobs and making the buildings and environment healthy. They also proved that every one dollar that they spent on energy efficiency brought back four dollars in savings.

## CONCLUSION

Besides the business of sustainability, Healthcare infrastructure needs to be efficient to reduce energy consumption and if possible energy independent in an emergency scenario. The resources used efficiently in that time can save precious lives.

The finiteness of the resources got tested during the super storm Sandy recently. A portion of the population in affected area was forced to manage with the minimum.

Life support systems depend on the emergency power back up systems. The storms of the last decade have proven the inadequacy of their reliability.

Healthcare industry needs to adopt an aggressive approach for energy management of existing and future building systems. It is both a top down and bottoms up process that needs to have clear objectives and focused approach at all times. The future holds many challenges in terms of population growth and economic uncertainty. Streamlining the processes and systems to create efficiency in general would set the right path forward.

Carbon neutrality of buildings is one of the defining forces of our times. It enforces a discipline and also creates a world of opportunities that has largely stayed hidden until now….


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5.

# Net Zero Station Design for The Cooper Centre for the Environmental Learning in Tucson, Arizona:
## Improving the performance of existing buildings

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*ABSTRACT: Many old buildings in Tucson have been built in the pre-energy code era, have poor performance, and consume immense amount of energy. By optimizing performance of those buildings, energy gets saved and the buildings can be converted into energy generating stations. This research project focuses on promoting environmental awareness by ensuring that the reader acquires relevant conceptual tools and skills to address climate changes and reduce air pollution through wise choices in the built environment. To accomplish this goal, existing structure at the Cooper Centre for Environmental Learning in Tucson, Arizona was re-designed into Net-Zero energy building. This paper describes the process of design and performance of two of the old buildings at Cooper Centre site and how they got converted into a Net-Zero stations that supply the whole campus with energy. The process was divided in two stages; Pre-Net-Zero and Net-Zero. After passively designing the existing cabins on-site, it was found that the required energy is approx 29,282 kW/hr, which was achieved by adding 58 PV panels on the Net-Zero station shading structure.*

*Keywords: Net Zero station, performance, energy generating*

## 1. INTRODUCTION

Cooper Centre for Environmental Learning is an environmental educational facility located in Tucson Arizona. In 1950s, Herbert Cooper, Tucson District Administrator, reserved a 10 acre site in order to building a new school. A decade later, a need for outdoor educational facility emerged and the site was utilized for nature study activities. The buildings consist of bathrooms, storage space, amphitheatre, large ramada, cook out grill and concrete slabs on which tents could be placed. The tents were built on those slabs in 1972 and the site was named "Camp Cooper". Now there is an intention for this project to expand learning scope to include built environment. The educational program for children at this site allows the overnight experience of nature and lasts 2-3 days. The Cooper Centre officials would also like to develop a facility that promotes adult education too (research groups, different ecological conferences, teachers courses, etc.).

Since the existing cabins were built in the 70s without any insulation, their thermal comfort is extremely poor. Therefore, one of the goals would be to maximize thermal comfort in the cabins. To reach these goals, different passive strategies were applied. This also became the basis to build a Net Zero station on the site.

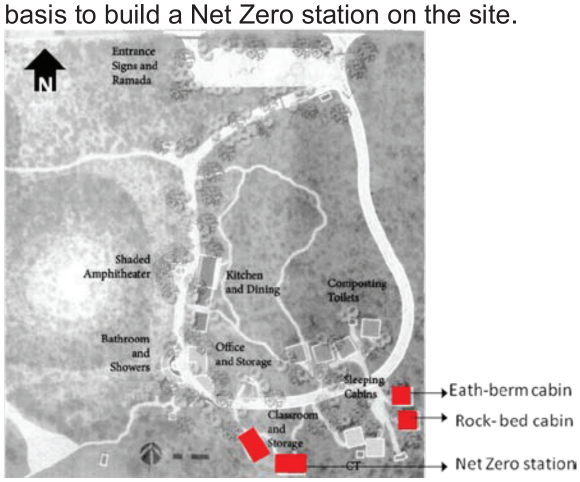
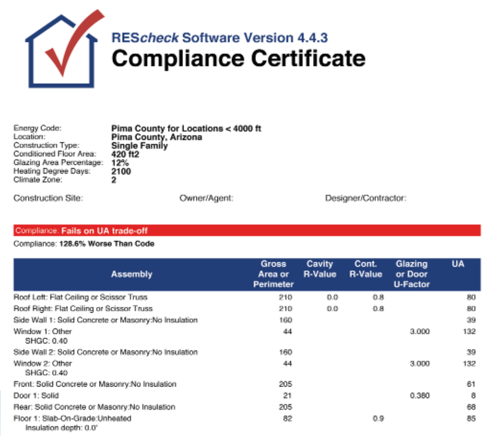



*Fig. 1: Cooper Center Site map*

In the figure above, location of Net-Zero station is shown, along with 2 cabin locations, in which passive design strategies were applied.

## 2. PROJECT DESCRIPTION

One of the steps of the site analysis was to check if buildings were in compliance with Pima County Energy Code. After entering all the required parameters, it was found that the buildings do not comply with the code. These calculations used Res*check* Software, developed by U.S. Department of Energy, as a tool to determine whether new residential projects or additions to existing structures meet the requirements of the Model Energy Code (MEC) or the International Energy Conservation Code (IECC). The buildings failed the RES*check* by 130%, as shown in the figure below.


RES*check* Software Version 4.4.3

**Compliance Certificate**

Energy Code: **Pima County for Locations < 4000 ft**
Location: **Pima County, Arizona**
Construction Type: **Single Family**
Conditioned Floor Area: **420 ft2**
Glazing Area Percentage: **12%**
Heating Degree Days: **2100**
Climate Zone: **2**

Construction Site: Owner/Agent: Designer/Contractor:

Compliance: **Fails on UA trade-off**

Compliance: **128.6% Worse Than Code**

| Assembly | Gross Area or Perimeter | Cavity R-Value | Cont. R-Value | Glazing or Door U-Factor | UA |
|---|---|---|---|---|---|
| Roof Left: Flat Ceiling or Scissor Truss | 210 | 0.0 | 0.8 | | 80 |
| Roof Right: Flat Ceiling or Scissor Truss | 210 | 0.0 | 0.8 | | 80 |
| Side Wall 1: Solid Concrete or Masonry:No Insulation | 160 | | | | 39 |
| Window 1: Other SHGC: 0.40 | 44 | | | 3.000 | 132 |
| Side Wall 2: Solid Concrete or Masonry:No Insulation | 160 | | | | 39 |
| Window 2: Other SHGC: 0.40 | 44 | | | 3.000 | 132 |
| Front: Solid Concrete or Masonry:No Insulation | 205 | | | | 61 |
| Door 1: Solid | 21 | | | 0.380 | 8 |
| Rear: Solid Concrete or Masonry:No Insulation | 205 | | | | 68 |
| Floor 1: Slab-On-Grade:Unheated Insulation depth: 0.0' | 82 | | 0.9 | | 85 |

*Fig. 1: Compliance Certification, generated using RES-check, shows that the cabins are not in compliance with the energy code of Pima County-Tucson*

In order to make buildings Net-Zero, we followed the two step strategy: 1. Pre Net Zero - all building performances were enhanced to meet the Pima County Energy code standards; 2. Net-Zero was achieved by adding PV panels to previously enhanced buildings.

1. Pre-Net-Zero Strategy

One of the project requirements was to try to maintain the existing structure, preserve existing vegetation, and minimize the negative impact of humans to existing land structure. Different passive strategies were applied such as, rock bed, solar chimney, sky-therm, and earth berm. These strategies were not only making the cabins more energy efficient and thermally comfortable, but were also valuable teaching tool for children about environmental systems while experiencing by an overnight stay in each cabin. As a part of educational process, one of the cabins was left without modifications so that children could compare it with enhanced cabins.

*Figure 1: Existing cabins on the South East part of the site*

*Figure 2: Proposed South East part of the site*

The cabins from the figure above are earth berm and rock bed cabin. In case of rock bed cabin, main elements are thermpsiphon and rock bed. The energy source is the sun, collector is thermosiphon, distribution system is fan and duct, storage is rock bed and back-up system is Samsung ductline split heating and cooling system.


*Figure 3: Proposed cabin design - rock bed*

After applying the passive strategies, a set of instructions was developed for each cabin as a part of interactive learning for children.

The sleeping cabin with the rockbed is 20 feet by 21 feet, gets heated in the winter day by direct gain. In the rock bed cabin, there is a hot air collector - thermosiphon (oriented south), that generates hot air that gets distributed to the cabin by fan. The air in the space gets cooled, then proceeds to the floor (as the cold air is always pressured downwards) through ductline where it gets heated again by the rockbed and gets distributed by fan.

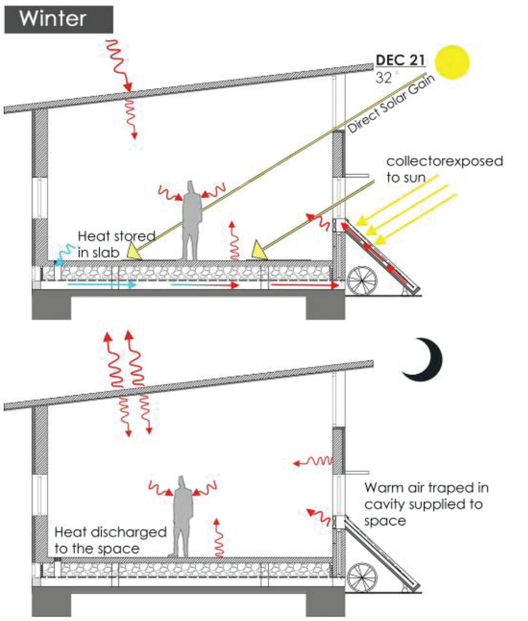



*Figure 4: Rock bed cabin environmental system diagram - winter day and night*

In the summer, the air collector (thermosiphon) is blocked. In the summer night, all the windows are opened allowing the night flush in the cabin while the envelope loses part of its heat to the night sky. In this process, coolth is stored in the rock bed and distributed using mechanically operated fan during summer day. During the day, all the windows are shaded by overhang not allowing the direct solar gain to the cabin.
One of the goals of the entire project is learning from built environment. This entire process would be explained to children and they would be involved in the process by operating the mechanical fan and opening and blocking thermosiphon depending on season.

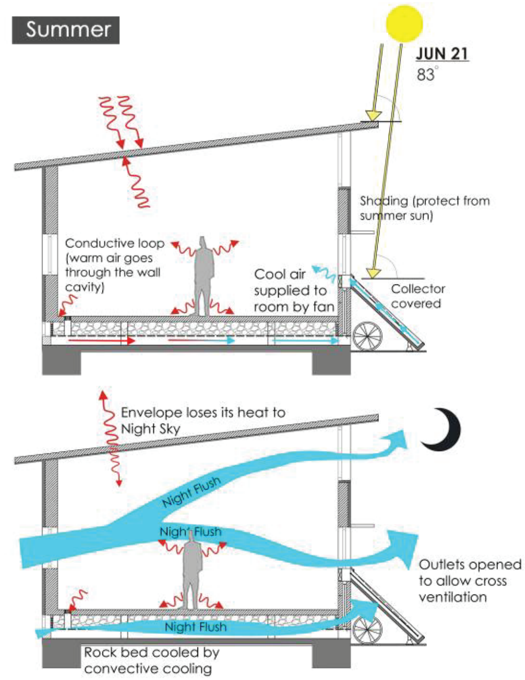



*Figure 5: Rock bed cabin environmental system diagram - summer day and night*

Another example of an applied passive environmental system is Earth berm cabin. Existing cabin was mostly preserved, and a new cabin was built on human scar land, which was earth bermed.

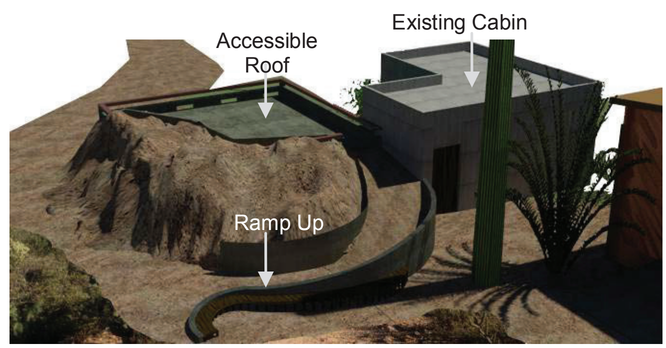



*Figure 6: Proposed cabin design - Earth Berm*

The earth-berm cabin is taking advantage of the earth as a thermal mass offering extra protection from the natural elements. In addition to that, earth shelter is known for its energy efficiency as it can save up to 80% on heating and cooling and it has low life-cycle cost (earth sheltered technology).

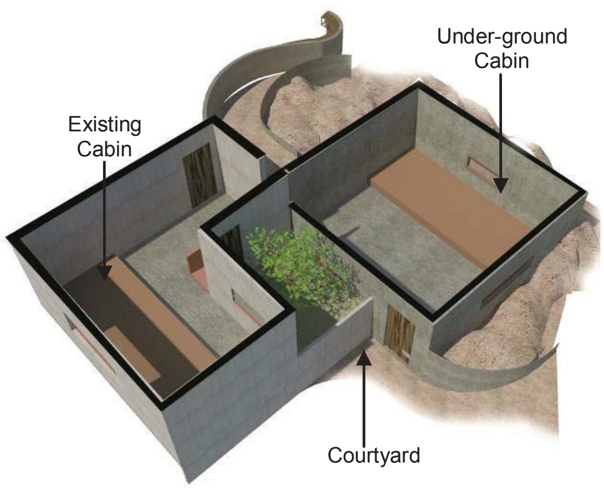



*Figure 7: Earth- berm cabin*

This cabin not only provides underground experience for children but it also allows for exquisite mountain and city views.

These strategies are just few of several applied to achieve Pre-Net-Zero path. The chosen Net-Zero station included two classrooms located in the Southwest portion of the site.
The Pre-Net-Zero strategy was not only applied on the sleeping cabins but it was also used on the Net-Zero station.
Since one of the requirements was to maintain the existing structure, it was decided to add a layer of adobe to the existing masonry wall leaving the gap of four inches between them instead of making a completely new wall. Adobe was used as thermal mass.
Since the idea was to represent different environmental strategies, adobe wall was used to create educational experience for children who could touch the surface of thermal mass and learn about heat transition.
Since adobe has low thermal resistance, it was shaded with self-standing wooden canopy which allowed night flush during summer nights and day heat during winter.
The roof profile was changed from pitched to flat roof to absorb less solar heat.

In summer night, the windows are open in order to allow the night flush which cools down the envelope for the morning. The coolth is stored in the Adobe thermal mass and since the envelope is shaded, it blocks additional heating.

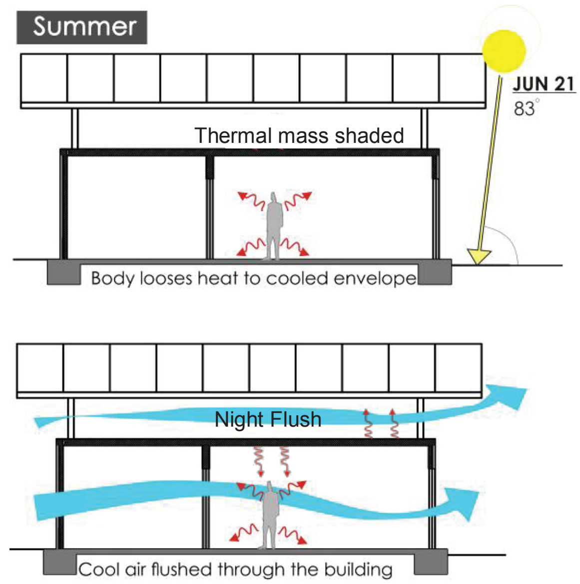
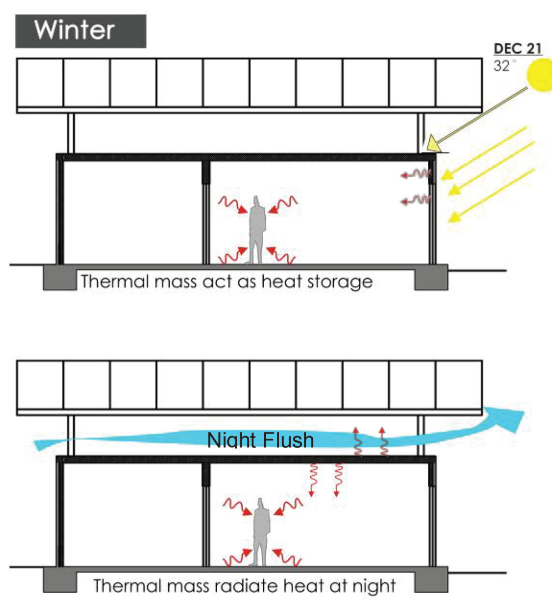



*Figure 8: Net zero station environmental system diagram - Summer day and night*

Whereas in winter day, the envelope is heated by direct solar gain and the heat is stored in Adobe thermal mass. During winter night, the envelope is closed to retain stored heat inside the space.




3. The Net-Zero Strategy

In the Net-Zero strategy, the energy requirements for the buildings on site were analyzed and number of required PV panels was calculated.

The most important consideration for sizing a PV system for a Net-Zero electrical energy building is the annual electrical load which PV system generates.

First step in calculating the needed number of PV panels was to calculate the total area of all the cabins on-site (5000 sqf). Then, the module of PV panel was chosen which was 300 W_MC_48V.

Entire cabin area of the site 5000 $ft^2$ x20Kbtu/$ft^2$/3413=29282 kW/hr – Total annual electrical load needed.
The Capacity Factor Method: In a sunny climate like Tucson, we might expect an annual capacity factor of 20%.
Initial decision was to choose south-facing array tilted at the latitude of the site.
The 285 W modules will produce: 0.2 x 8760 x 285 x / 1000 =499 kWh
29282kW/hr / 499 kW/h = 58 panels
So the number of PV panels required to produce energy for the cabins on-site is 58 panels.
Dimension of selected modules are 4.2' width x 6.2 '' height = 26.04 sq. ft. (1.28m x 1.89m = 2.42 meters sq.),
This means that the area required for placing 58 panels, is around 1,511 sq. ft.
The PV panels were placed on self-standing shading device with an angle equal to latitude of Tucson facing South (32$^o$). Addition of PV panels contributed in shading of the roof, hence reduction of absorbed solar heat through the roof.

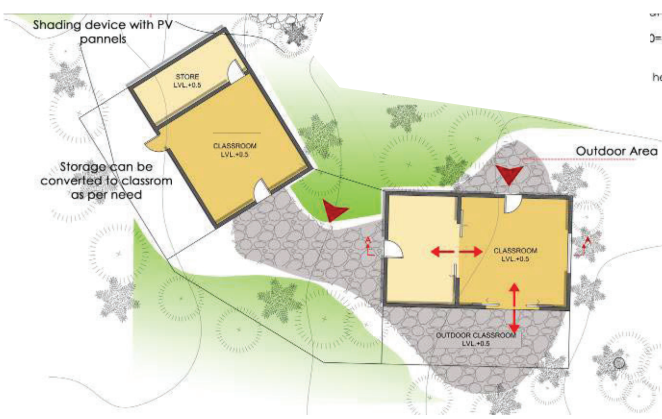



*Fig. 1: Proposed cabin design*

The figure above shows the proposed plan of the classrooms along with outdoor teaching area and the outline of the PV panel canopy.

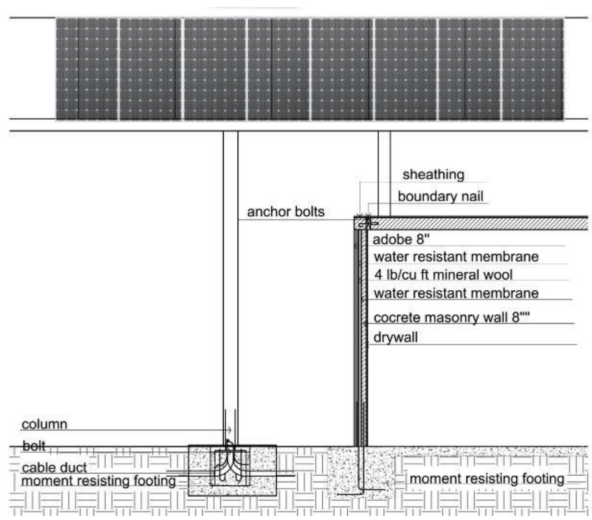



*Fig. 1: Cabin wall and shading device Detailing*

The canopy which holds the PV panels allowed additional shaded space that can be used for outdoor activities.

*Fig. 1: Visualization of proposed cabin design*

## 4. CONCLUSION

The strategy of Net-Zero was applied after the entire site was designed passively, which is considered to be an important aspect for any Net-Zero project. It was found that energy required for the cabins is approx. 29,282 kW/hr which was achieved by adding 58 PV panels on the shading structure.
The final outcome of this project is not only energy efficiency but also educating children at young age about environmental systems and energy generation.

## 5. ACKNOWLEDGEMENTS.

The authors would like to thank Mr. Mike Meyers from Cooper Center for his support and input during the project.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# Ventilated Façades: A strategy for improving the energy efficiency of buildings in warm and humid climate like Maracaibo, Venezuela

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*ABSTRACT: This paper is the result of a study conducted by H. González (2012) for his dissertation toward a master's degree in "Renewable energy, architecture and urban planning: the sustainable city". Its aim is to study the reduction of the heat flow into building interiors in Maracaibo, Venezuela, afforded by ventilated façades with a naturally ventilated air gap through the calculation of heat flow in a steady state regarding diverse materials of the building envelope. A number of ventilated façade configurations are proposed and the steady state thermal performance is analyzed to determine their efficiency. Intensely ventilated double-skin façades are found to lower heat flow by up to 53 % and, ventilated double skin green façades by up to 84 %.*

*Keywords: ventilated façade, warm and humid climate, energy rehabilitation.*

## 1. INTRODUCTION

One of today's major challenges in connection with climate change is high energy consumption in buildings, which in some countries accounts for up to 50 % of all the energy used, with a substantial share going to environmental control: heating and cooling.

The electric power consumed to cool buildings in warm and humid tropical places such as Maracaibo, Venezuela, may amount to over 70 % of the total. Located on the shores of Lake Maracaibo (10º40 N latitude, 71º37 W longitude), the city is characterized by high levels of solar radiation and high relative humidity. With a population of approximately 1 900 000, it boasts the highest rate of electric power consumption in Latin America, at 4 103 kWh per capita per year in 2007 (CORPOELEC, 2012). Air conditioning units account for 75 % of the total. (González, S. 2010). Sixty-two percent of Venezuela's installed capacity is produced at hydroelectric stations, while the remaining 38 % is supplied by steam plants and distributed generation. In all, the country has an installed capacity of 24 000 megawatts (CORPOELEC, 2012).

Most buildings in Maracaibo were built "traditionally", i.e., with reinforced concrete superstructures and hollow clay block enclosures rough-coated on the inner and outer faces with cement and sand mortar and painted or sided with stone or tile cladding. Such enclosures absorb huge amounts of incident solar radiation, rapidly transferring the heat to building interiors and raising the indoor temperature (Bravo, 1994). This induces users to resort to power hungry mechanical air conditioning systems.

A ventilated façade system for existing buildings is put forward here as a way of lowering the heat flow into buildings and with it the electric power needed to handle their cooling loads, while at the same time renovating the appearance of the façades in question. Although ventilated façades are not a new solution in many parts of the world, no specific proposals involving such systems exist for high-rises in the city of Maracaibo. By analyzing steady state thermal behavior, the present study shows that Maracaibo's present buildings would benefit to varying degrees from the thermal insulation afforded by opaque ventilated façade (OVF) systems. Nine (9) ventilated façade case studies are conducted, analyzing the materials and their ability to lower heat flows into buildings. These proposals are compared to ascertain the most suitable options, bearing in mind factors such as system construction and maintenance. The working hypothesis is that the cooling load in existing buildings in places with warm and humid climates such as Maracaibo, Venezuela, can be lowered by retrofitting building enclosures with a second skin and a ventilated air gap (ventilated façade).

## 2. CLIMATIC DATA FOR MARACAIBO, VENEZUELA

Maracaibo is a city with a warm, humid climate. Neither temperature nor relative humidity varies significantly throughout the year, with mean values of 27 to 28.6 ºC (with a total range of 7 to 9 ºC) and 70 to 80 %, respectively. Two clearly defined wind seasons are observed. In the first, from December to April, trade winds prevail, with mean speeds of 3 to 5 m/s. In the second, from May to November, the air is predominantly still, with only gentle winds that vary in direction. Yearly rainfall ranges from 450 to 550 mm and mean total daily radiation is 4.2 kWh/m$^2$.

## 3. VENTILATED FACADES

A ventilated façade constitutes an "obstacle" to heat flow toward the inside of a building thanks to its capacity to reflect solar radiation and to the lowering of the air temperature via heat exchange in its naturally ventilated air gap (Figure 1).

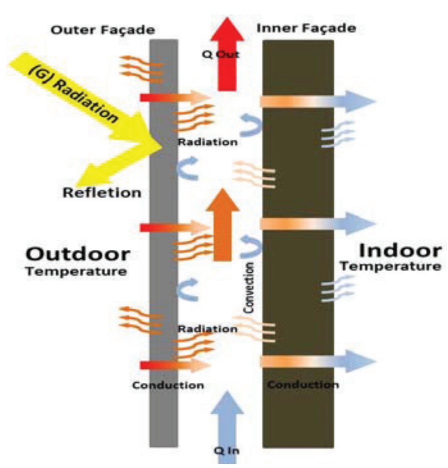



*Fig. 1: Opaque ventilated façade: working principles.*

The most prominent factors in double-skin systems include incident solar radiation on the outer side, wind speed and the velocity of air circulation in the ventilated gap. (Marinosci, 2011).

Basically there are two strategies that must be applied to ventilated facades in places where the outdoor temperature is higher than the indoor temperature; the first one is to reduce the solar gain with the use of shading devices, with this strategy it can be reduced the cooling charge of the building; the second strategy, is to use the air flow of the chamber to improve the air flow that goes through the interior of the building.

## 4. TYPOLOGY OF BUILDINGS STUDIED.

Residential buildings, built in Maracaibo, Venezuela until 2005, as well as their opaque vertical skin, constituted the object of study of this paper.


*Fig. 2: Examples of buildings in Maracaibo, Venezuela, constituting the object of study.*

4.1. Present enclosures

The present enclosures consist of "traditional" walls comprising 15 cm thick hollow clay block, rough-coated with 1.5 cm of sand and cement mortar on both sides and painted. Theses façades are occasionally sided with materials such as clay panels, granite spray or ceramic cladding (Figure 3). The thermal properties of the materials used are given in Table 1.

**TABLE 1: THERMAL PROPERTIES OF CONSTRUCTION AND SIDING MATERIALS ON ENCLOSURE WALLS (SOURCE: González, E. 1992 cited by Bravo, 1994)**

| Material | Thermal property | | |
|---|---|---|---|
| Type | Conductivity W/mºc | Specific heat J/kgk | Density Kg/m$^3$ |
| Clay block | $\lambda$e = 0.236 | pCp=4.06e5 j/m$^3$k | $\rho$e = 461.6 |
| Base rough-coating | 0.698 | 1 005 | 1 800 |

The characteristics of typical residential building enclosures in Maracaibo, Venezuela, are listed below.

15x20x30 cm (9 hole) clay block, rough-coated on both sides:
U: 1.75 W/m2K (where Rse = 0.04 W/m²K and Rsi = 0.14 W/m²K)

Equivalent thermal conductivity ($\lambda$e): 0.438 W/mK
Equivalent density ($\rho$): 785 kg/m$^3$
Equivalent specific heat (Cp): 899 J/kgKls comprising.

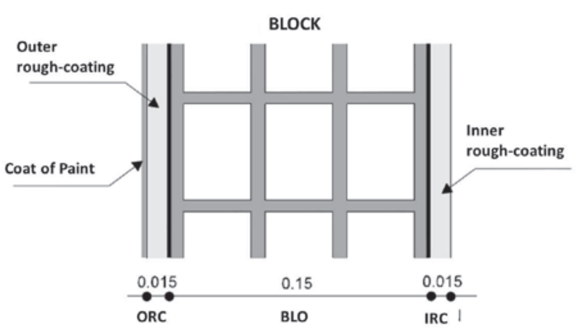



*Fig. 3: Cross-section of outer wall. Traditional enclosure, case 1 (Source: Bravo, G. (1995).*

4.2. Proposed façade materials and systems
A multi-layer panel is proposed, in which stiff phenolic resin foam, mineral wool foam (not mentioned) or wood wool thermal insulation would account for a substantial proportion of the total volume. This core material would be sandwiched between two layers of fiberglass or galvanized sheet steel.

In addition, a wide variety of commercial prefabricated materials and systems are specifically designed for use as ventilated façade panels. One of the options considered for this study was Alucobond® paneling (plastic interior sandwiched between two layers of aluminum). Another material that could be used for ventilated façade panels, although not formalized, is 50-mm thick cellular concrete.

## 5. RESEARCH METHODOLOGY

This study applies a descriptive research, which is defined by Gómez (2006) as one that "looks to specify the properties, characteristics and most important aspects of the phenomenon that is up to analysis", which means how it is and how it manifest that phenomenon to know its trends with the purpose to improve their knowledge and be able to control them.

The study with steady state models allows to know the thermal performance of the system, even though it leaves behind the dynamic aspect of the thermal phenomenon. With this kind of models it can be calculated the heat loss and gain, though the indoor and outdoor temperature and the solar radiation; measuring in that way the quality of the construction and the system's design (Giancola, 2010).

## 6. CASE STUDIES

The first step was to find thermal transmittance in the present (traditional) enclosure under three conditions: a) wall exposed to outdoor air; b) wall protected by a second skin with a non-ventilated air gap; and c) wall protected by a second skin with an intensely ventilated air gap. While the technical codes and standards in place establish no specific method for calculating thermal transmittance (U) in double-skin façades, in case c), the enclosure was assumed to lack an outer skin (ventilated façade panel) and to have equal outer and inner surface resistance values, as provided in the Spanish technical building code.
Case 1: present (traditional) building enclosure (see Figure 3) with no outer skin, painted white.

a) U = 1.75 W/m2K (traditional enclosure)
b) U=1.30 W/m2K (enclosure protected by a fibre cement outer skin and non-ventilated air gap)
c) U=1.49 W/m2K (as in the preceding case, but with an intensely ventilated air gap)

The U value is greater in the intensely ventilated than in the non-ventilated double-skin façade because in the calculation method recommended by the Spanish Technical Building Code for such cases, the layers of material on the outer side of the air gap are disregarded and the outer and inner thermal resistance values for the enclosure are assumed to be equal. Consequently, total thermal resistance is higher is case 1b) than in case 1c).

6.1. Incident solar radiation

The incident solar radiation on the east façade at 10:00 AM and on the west façade from 1:00 to 4:00 PM in the least favorable months, i.e. the months with the highest solar radiation values (April and August) are shown in Table 2 below.

**TABLE 2: IRRADIANCE ($I_B$) AND OVERALL INCIDENT RADIATION ($I_T$) VALUES ($W/M^2$) ON THE EAST (10:00 AM) AND WEST FAÇADES (1:00-4:00 PM) IN APRIL AND AUGUST.**

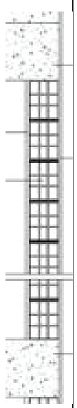
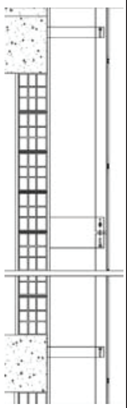
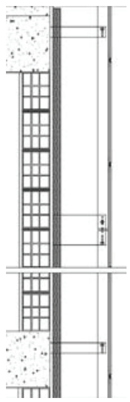
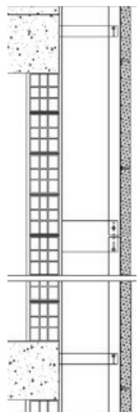
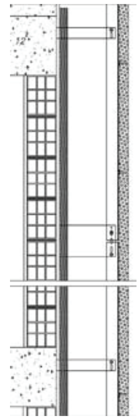
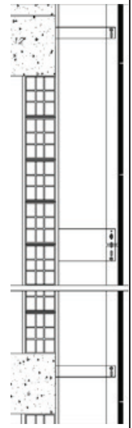
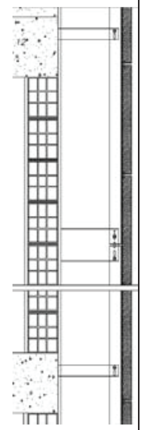
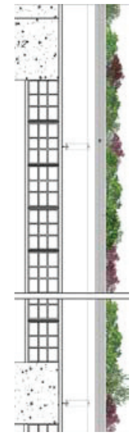
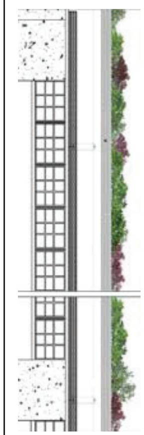
| Month/time | 10:00 AM | | 1:00 PM | | 4:00 PM | |
|---|---|---|---|---|---|---|
| | $I_B$ | $I_T$ | $I_B$ | $I_T$ | $I_B$ | $I_T$ |
| April | 637.1 | 564 | 656.2 | 248.6 | 663.1 | 623.8 |
| August | 511.1 | 447.3 | 461 | 155 | 804.3 | 734.4 |

6.2. Heat flow

For heat flow calculations in opaque ventilated façade systems that shade the building enclosure and protect it from direct solar radiation, the equation used is $q=UA\Delta T$, in a area of $1M^2$, the highest temperature to which the façade is exposed is assumed to be equal to the outdoor temperature, whereas the temperature assumed for the ventilated façade panels is the sol-air temperature ($42.2^0C$), calculated with the equation $T_{sa}=T_e+(G*\alpha*R_{se})$.

**TABLE 3: SUMMARY OF THE INTENSELY VENTILATED AIR GAP* SYSTEMS ANALYZED**

| Component | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 | Case 8 | Case 9 |
|---|---|---|---|---|---|---|---|---|---|
| Enclosure | Clay block | | | | | | | | |
| insulation (EPS) | ------- | ----------- | 50 mm | ----------- | 50 mm | ----------- | ----------- | -------- | 50 mm |
| Air gap | ------- | 300mm | | | | | | 150 mm | 150 mm |
| Structural support | ------- | Sheet steel or aluminum | | | | | | | |
| VF panel | ------- | Alucobond (6 mm) | Alucobond (6 mm) | Cellular concrete (50 mm) | Cellular concrete (50 mm) | Fbrgls & phenolic res. (20 mm) | Galvanized sheet steel & wood wool (40 mm) | Green façade | Green façade |
| Growth material | ------- | ----------- | ----------- | ----------- | ----------- | ----------- | ----------- | Wool panel (120 mm) | Wool panel (120 mm) |
| Damp Open Foil | ------- | ----------- | ----------- | ----------- | ----------- | ----------- | ----------- | PS panel | PS panel |
| Outer sheet | ------- | ----------- | ----------- | ----------- | ----------- | ----------- | ----------- | Black panel | Black panel |
| Plant type | ------- | ----------- | ----------- | ----------- | ----------- | ----------- | ----------- | Ferns | Ferns |
| Panel thermal res. ($m^2K/W$) | ------- | 0.018 | 0.018 | 0.55 | 0.55 | 1.057 | 1.11 | 3 | 3 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Enclosure thermal res. ($m^2K/W$) | 0.571 | 0.671 | 1.96 | 0.671 | 1.96 | 0.671 | 0.671 | 0.671 | 1.96 |
| Heat transfer, $q_n$, ($W/m^2$), ventil. gap | 30.1 | 24.01 | 8.22 | 15.1 | 5.19 | 14.03 | 13.97 | 13.08 | 4.82 |
| **Diagram** (2:clay block, 3-4: Roof and Mezzanine slab, 6:Insulation EPS) |  |  |  |  |  |  |  |  |  |

The outdoor temperature used here was 33.4 ºC (mean high temperature in the warmest month, as per readings), while the indoor temperature adopted was 25 ºC. The sol-air temperature was calculated to be 42.2 ºC.

Case 1: the control for all subsequent comparisons consists of the present building enclosure. The heat flow was calculated for conditions a), b) and c) described above pursuant to the Spanish Technical Building Code (CTE, 2010). These values were then used to ascertain whether the ventilated façades proposed would raise or lower the heat flow into the building.
Condition a): outside wall exposed to direct radiation and outdoor temperature (present state): q1a = 30.1 W/m2.
Condition b): outside wall retrofitted with a second (fibre cement) skin and a non-ventilated air gap: q1b = 22.3 W/m2.
Condition c): outside wall retrofitted with a second skin and an intensely ventilated air gap: q1c = 12.5 W/m2.

The results of the heat flow calculations for each type of ventilated façade are given in Table 3. All these façades were assumed to have an intensely ventilated air gap, as defined in the Spanish Technical Building Code (2010).

## 7. CONCLUSION

An analysis of the thermal transmittance (U) of the existing (traditional) enclosures on buildings in Maracaibo revealed that they provide poor thermal insulation. The daytime heat gain through the wall is exacerbated when the outer surface is sided with highly absorptive materials, as is presently the case.

This study confirmed that the use of double-skin ventilated façades contributes to improving the thermal efficiency of building enclosures in places with warm and humid tropical climates such as Maracaibo. Retrofitted second skins with intensely ventilated air gaps would reduce heat flow by up to 53 % and by up to 83 % when such skins have green façade.

The calculation of heat transfer in steady conditions on ventilated facades presents several unknowns factors, including the temperature of the ventilated air. However, to determine this temperature is necessary to know the surface heat transfers coefficients, surface temperature and air velocity in the ventilated chamber. To get these factors is required to perform numerical simulations, or develop an experimental model subjected to measurements with specific equipment, in order to get an answer closer to reality. The methodology used in this study does not allow a more detailed understanding of the thermal efficiency of the systems studied.

The findings are based on an analysis of steady state thermal performance, to which the study was confined for want of precise information on parameters such as air temperature, convection heat transfer coefficients, surface temperature and the velocity of air circulation in the ventilation cavity.

With respect to the foregoing, one of the key factors in heat transfer in ventilated façade systems is the amount of long wave heat emitted by each side of the outer skin. The inference is that the long wave heat flow toward the outer surface of the building enclosure is more effectively reduced by skins with low inner surface emissivity.

Case 9 (ventilated double skin green façades with thermal insulation retrofitted to the outer surface of the enclosure) proved to lower heat flow more effectively than any of the other configurations, with an 84 % reduction. This was followed by case 5 with 83% decline, case 3 with 73%, cases 8, 7, 6 and 4 with 57%, 54%, 53% and 50% and lastly case 2 with a 20 % reduction in heat flow into the building interior.

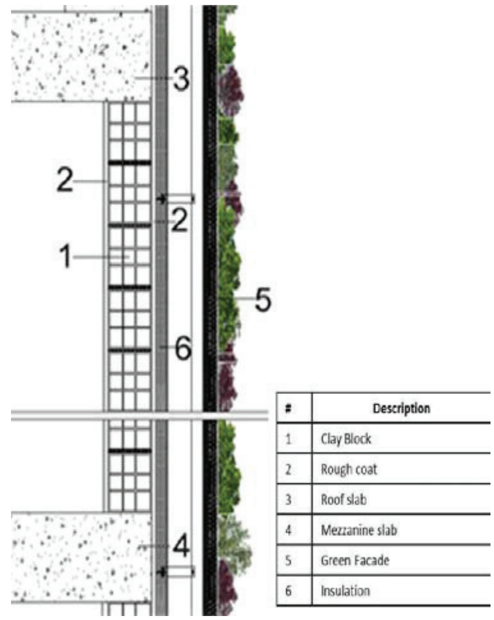
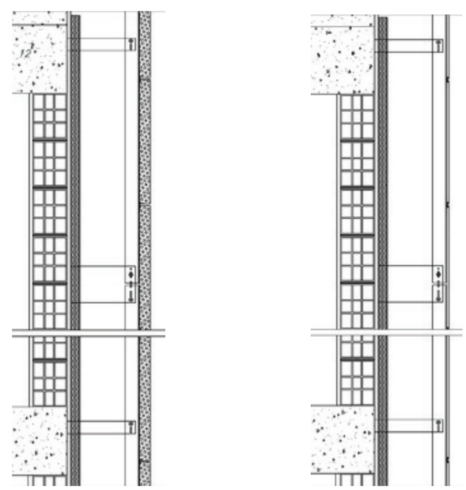



*Fig. 4: Case 9 (84% reduction of the heat flow).*



*Case 5* *Case 3*

*Fig. 5: Case 5 - Cellular concrete panel + insulation- and Case 3-Alucobond Panel + insulation- (83% and 73% reduction of the heat flow successively)*

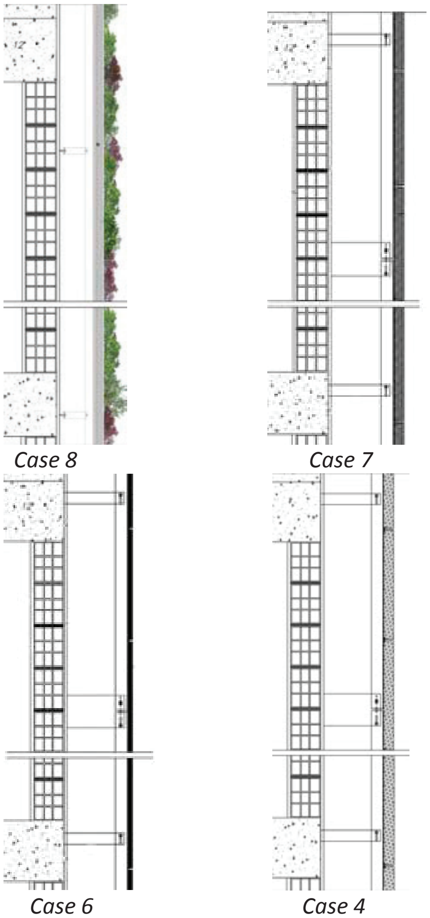



*Fig. 6: Case 8 –green wall-, Case 7- Galvanized sheet steel & wood wool panel-, Case 6 – Fiberglas & phenolic resin panel-, Case 4 - Cellular concrete panel- (57%, 54%, 53% and 50% reduction of the heat flow successively)*

These findings infer that applying thermal insulation directly to the outer surface of the building enclosure enhanced efficiency, and combining this strategy with a ventilated façade system raised thermal efficiency even further.

### 6.1. Recommendations

A detailed study of power consumption in existing buildings must be conducted prior to undertaking any manner of energy rehabilitation.

In Maracaibo, one of the most suitable alternatives for façade rehabilitation in general and energy rehabilitation in particular is retrofitted ventilated façades. Systems with low thermal conductivity panels, low inner surface emissivity, high outer surface reflectivity and a naturally ventilated air gap constitute the most efficient options for lowering heat flow toward building interiors.

The installation of vertical gardens with naturally ventilated air gaps is also recommended. In addition, cladding the outer side of the existing enclosure with expanded polystyrene (EPS) thermal insulation panels is an advisable procedure to reduce thermal transmittance (U).

A dynamic state heat flow analysis in the cases proposed here is recommended to acquire a deeper understanding of the thermal performance and efficiency of these systems. Experimental studies with physical models in real environmental conditions are likewise recommended.

Cost and (private + public) financing are essential parameters in residential building rehabilitation. Resident occupation of buildings during rehabilitation works is another consideration to be borne in mind.

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# Zero Net Energy Education Manifesto:
## The core strategies essential for market transformation

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*ABSTRACT: This paper proposes a manifesto for ZNE building education for professionals and building trades. The core issues for educating the workforce to achieve ZNE buildings are relatively few and rely not on new technologies but on changes in our building industry culture. Correctly identifying ZNE education needs can greatly accelerate our progress to ZNE goals while at the same time dramatically reducing the associated costs. All we need is an industry-wide shift in mindset, supported by the adoption of relatively uncommon (but tried-and-true) design and construction processes, related tools, and available communication technologies to facilitate the new processes. The necessary shift in mindset is twofold, comprising a new understanding about the design approach and cost thinking surrounding ZNE, and a new focus on building organizations' capacity to deliver higher-performing buildings, supplanting the current focus on features and technologies of the buildings themselves. This paper addresses each of these topics, providing a framework for ZNE education.*

*Keywords: education, integrated project delivery, mindset, process, tools*

### 1. INTRODUCTION: THE MANIFESTO

Zero net energy (ZNE) homes and buildings are achievable today. There are many built and documented examples. We have the technologies and the know-how, yet we don't see the rapid change in our industry – widespread achievement of ZNE – that should follow from this knowledge.

In fact, the principal challenges to achieving ZNE are not technological, but cultural – we face lack of experience among both design teams and building trades in incorporating energy-saving features, siloed rather than integrated approaches to project delivery, and a misplaced focus on the physical artifacts we are producing, rather than on building our organizational capacity to deliver higher performance.

Hence this manifesto: The primary requirement for whole-scale implementation of ZNE building is industry-wide education. Specifically, that education needs to focus on shifts in mindset and on adoption of integrated project delivery.

["*A manifesto is a published verbal declaration of the intentions, motives, or views of the issuer … [It] usually … promotes a new idea with prescriptive notions for carrying out changes the author believes should be made."* (Wikipedia) This paper, therefore, is not scientific, but instead expresses matters of opinion, albeit based on direct empirical observation.]

Education is the primary need, because education is our principal means of cultivating understanding among industry stakeholders – understanding of both why change is needed, and how to create change effectively within our organizations. As to why change is needed, Albert Einstein tells us, "Insanity is doing the same thing over and over again and expecting different results." If we hope to create a higher standard for our buildings, we had better stop doing the same thing over and over again.

The remainder of this paper is devoted to a more detailed discussion of the ZNE-focused education needs for the building industry, as this author views them.

### 2. BACKGROUND

The bulk of education and research in the arena of zero net energy design and construction tends to focus on new technologies as the sine qua non that will make ZNE buildings achievable. And yet we have enough built examples of ZNE – both residential and non-residential – to demonstrate that new technologies are not always necessary to achieve zero net energy.

We also know, despite the nascence of this field, that there are circumstances that will preclude some individual buildings ever from achieving ZNE; for example, in many cases there is insufficient opportunity for the production of renewable onsite energy. There are also many existing buildings that will be quite costly to retrofit sufficiently to achieve ZNE; that cost will prove an impediment to achieving zero net energy where otherwise it might technically be feasible.

Notwithstanding these scenarios where ZNE is impossible or improbable, there is a wide and largely untapped opportunity to create ZNE buildings *now*, with current technology, and at zero cost premium. The only impediment is the mindset with which project teams approach the goal of creating ZNE buildings.

## 3. REQUIREMENTS FOR WIDESPREAD ZNE IMPLEMENTATION

Three major foci are needed for education aimed at widespread ZNE implementation:

- A shift in mindset regarding design approaches and costs;
- A shift in mindset regarding the need to build organizational capacity to deliver ZNE (high-performance) buildings;
- Integrated project delivery (IPD).

### 3.1 Mindset Shift #1: Design Approaches

The prevalent mindset regarding ZNE is most readily illustrated by research findings about ZNE. For example, research from California's PIER (Public Interest Energy Research) program concluded that:

- The cost premium for ZNE homes is $40,000 to $70,000;
- In order to meet ZNE goals at neutral cost in all climates, a number of technologies and strategies that do not yet exist are needed; and
- A number of existing technologies will require further research and development to bring their costs down. (Navigant, 2008)

And yet ZNE projects already exist in virtually all North American climate zones, and have been reported as cost-effective by the owners, developers, and/or building operators. For example, Ryan Scott, president and CEO of Avalon Master Builder, states, "The [ZNE] Discovery Homes have taken us beyond energy savings. The learnings from these homes in the areas of indoor air quality, durability, and water conservation have improved all of our homes significantly. This has increased the saleability of our homes and improved our position in the Calgary market place." (Sankaran, 2013)

This disconnect between the research and some builders' reported experience is perhaps best explained by the "alternate reality" view of ZNE, as expressed by architect Bruce Coldham: "It is often presumed that 'green' resourceful building involves a cost premium. This is not a universal truth. Though it is reasonable to assume that a superior product should come at a premium, good performance enhancing design is more a matter of examining design goals and objectives with a view to redirecting investment. On this basis, a performance enhancement can be seen as favoring one option over another – a choice rather than a cost premium. Unfortunately, due to the rather extreme conservatism in the building industry, many choices are never made explicit. They are never discussed, never offered." (Coldham, 2008)

These observations are exactly on target. Implicit in the vast majority of analyses of ZNE is the presumption that no appreciable changes will be made to building design in order to achieve ZNE. And yet this is patently absurd; it assumes that:

- The design team has access to less than the full set of design tools;
- ZNE can (or should) be achieved without a fundamental shift in architectural design; and
- We can change the direction of North American building energy performance without redirecting investment priorities.

There is no sound basis for these assumptions, and to accept them is a disservice to the planet, the design professions, and the communities and movements that are attempting to further ZNE goals. We need to have the full design palette at our disposal, and we absolutely should anticipate a fundamental shift in architectural design in order to achieve ZNE goals. Otherwise (if we are to believe Einstein), we are in fact insane.

Therefore, the first and foremost educational need in the arena of ZNE buildings is to shift the mindset to that of redirecting investment to better achieve our ZNE goals. Instead of asking, “How much extra will a ZNE building cost?” we need to ask, “What design changes do we need to make in order to create a ZNE building?” This shift in mindset yields a very fundamental change in approach. From a perspective of constraint (we can’t afford this, or the right gizmos aren’t yet available), we shift to a perspective of opportunity (what strategies are available to us to accomplish this compelling goal?).

Two of the most obvious opportunities that come to light when the inquiry is thus shifted are (1) reduce the size of the building; and (2) simplify the building. Either change would allow investment to be redirected from more floor area or more complex geometries and/or finishes to energy efficiencies and renewable energy.

Let’s review the implications for these approaches in the housing market.

3.1.1 Size. U.S. Census Bureau statistics show median home size, after peaking in 2006, fell in 2007, 2008 and 2009; it has risen each year since 2009, reportedly due to limited credit leading to more of the purchases being made by wealthier buyers. (NAHB, 2013) These shifts indicate that buyers’ preferences for homes of a given size are not immutable, but rather influenced by market forces. And in fact, most decisions about housing options available to buyers are made several years before buyers are seeking to make a purchase, so buyers’ options are limited by the crystal ball-gazing efforts of developers and builders (often referred to as “market research”).

Let’s imagine that home size decreases by 5 to 10 percent (100 to 200 square feet, or more) in the ZNE market sector in order to redirect investment (a few to tens of thousands of dollars, depending on locale) toward a higher-performing product. Buyers will make their choices from among the available offerings. Such a minor size reduction is unlikely to affect their interest in a ZNE home, *assuming a ZNE home is the goal*.

This is a critical assumption. Notwithstanding the intention that we shift the industry whole-scale to producing ZNE buildings, the transition to ZNE will occur in stages. Shilpa Sankaran (principal of Alpha Group SF and co-founder of ZETA Communities) says, “At the current stage – essentially, we are now in research and development (R&D) – consumers who purchase ZNE homes are not doing so as an incidental benefit; they are doing so largely driven by emotion, a personal philosophy and commitment, not by a dispassionate view to return on investment, any more than their desire for a granite countertop is driven by ROI.” (Sankaran, 2013)

3.1.2 Simplicity. Any good architect knows that adding complexity to a building does not necessarily add to its appeal; conversely, working with a simpler geometry does not necessarily detract from its appeal. In fact, the opposite can be true. A recently completed ZNE demonstration project sponsored by Southern California Edison, the “ABC Green Home,” applies the principles of simplicity in a holistic, comprehensive manner.

*Fig. 1: ABC Green Home ZNE demonstration project*

Architect Manny Gonzales describes the design approach: “The footprint of the home is a very efficient, almost square house plan that allows for the shortest mechanical runs possible … whole feet measurements are used throughout to allow for modular construction with minimal waste.

“Additionally, the interior dimensions have been programmed to minimize construction waste, with measurements in inches of zero, four, six or eight. The exterior walls are constructed of two-by-six boards to provide room for added insulation, yet at the same time, since the studs are stronger than the conventional two-by-four exterior, they can be placed at 24 inches on center, thus using less lumber compared to the way homes are traditionally being built today. These are all simple practices that require just a little more discipline on the part of the architect to incorporate.

"Production homebuilding has not changed much in its means and methods since the industry began, and the ABC Green Home uses the same means and methods that any of today's home builders would, it just uses them in a more affordable, buildable and certifiable way. The simple footprint and roof form keep it affordable, yet [with] the simple architectural detailing the design can be quite aesthetically appealing to the broadest buyer market." (Gonzales, 2013)

As an architect to production builders including Shea, Lennar, Toll Brothers, KB Home, and others, Gonzales (of KTGY Architecture & Planning, Inc.) speaks – and designs – from a firm grounding in the realities of the industry. Greater simplicity carries with it a multitude of benefits, and zero liability.

3.2 Mindset Shift #2: Organizational Capacity

I have served as a green building/ZNE/LEED (etc.) consultant on numerous projects across a range of building sizes and types, over the course of 15+ years. Invariably, the project teams are targeting a higher performance goal than they have been accustomed to reaching in the past. Thus, they are implicitly facing change. Invariably, they focus almost entirely on what about the *building* needs to change – what new materials or equipment are needed, what different systems might be employed, perhaps even what changes in building configuration might be considered?

These are all legitimate areas of inquiry; however, as these projects unfold, they are not, at core, the source of the challenges the project teams face. And inevitably, challenges do arise. I give but one example of many in my own direct experience. Every one of my colleagues in this field can recount many more in similar vein.

The owner-developer of a large multifamily resort property called one day during the project's construction. All had gone well to date with the project's initial adoption of green performance goals and objectives; the team had been enthusiastic and cooperative. However, the call was to report that the plumber had installed fixtures that did not meet the flow/flush rates agreed upon during the early project meetings. I asked, "Were these performance specifications incorporated in your contract documents?" The answer: no.

This is a process failure. Not a technology failure, not a lack of availability, not a cost obstacle. Variants of this scenario have occurred countless times throughout North America – and no doubt beyond. It bears emphasizing that the developer was experienced and highly professional. Oversights such as this are not simply the province of novices. They are commonplace among teams at all levels of experience and sophistication, across building types. They are symptomatic of an industry that is change-averse and accustomed to operating in a comfortable, well-worn groove, *not* accustomed to innovation.

The fix for this process failure was to ensure that, for all future projects, all agreed-upon performance requirements would be incorporated into the contract documents. In other words, we use the standard means of communication and standard means of ensuring performance to address new performance requirements. I now routinely encourage clients to have my staff do this cross-check for them or to have another team member perform it for them. It's not a mistake I want to see other clients repeat. Incidentally, *every* time we have done this cross-check, we have found oversights and brought them to the client's attention.

After witnessing numerous process failures along similar lines, I began to recognize a larger pattern emerging. These project teams were all focusing on the *building*, while ignoring the implications regarding their organizations.

In order to create a changed product – one that is different from those produced before – the producing *organization* needs to change. I find many of my colleagues resonate with the following illustration.

Suppose you were in senior management at Hyundai, and the company decided to compete head-to-head with BMW in the production of high-performance automobiles. What would you do? This question typically produces a barrage of apt responses, including:

- Reverse engineer the competing product;
- Research new materials/methods;
- Establish new vendor relationships;
- Create new procedures;
- Redo the production line;
- Educate workers;
- Hire new staff.

Most practitioners in the building industry find it easy to envision how another industry, where product changes are more routine, would undertake these types of capacity-building. In our own industry, it's more common to focus on product changes than on organizational change. And yet, building the organization's capacity in these ways paves the way for much easier changes to the products themselves.

3.3 Integrated Project Delivery

The American Institute of Architects defines integrated project delivery (IPD) as, "a collaborative alliance of people, systems, business structures and practices into a process that harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction." (AIA-CC, 2007)

"Rather than each participant focusing exclusively on their part of construction without considering the implications on the whole process, the IPD method brings all participants together early with collaborative incentives to maximize value for the owner. This collaborative approach allows informed decision making early in the project where the most value can be created." (Wikipedia, 2013)

Nowhere is this collaborative approach more critical than in projects such as ZNE buildings, where innovation is essential, along with risk management and cost optimization.

IPD is distinguished from conventional projects – where the parties to design and construction operate in a sequential, hand-off model – by the early and ongoing collaboration of all parties, *including the general contractor*. There is an artificial divide between design and construction; in reality, to optimize a design, construction knowledge is needed from the inception of the design process. And design input is needed throughout construction – no design is absolutely complete and embodied in a set of construction documents before ground-breaking. The design continues to evolve.

Attorney Will Lichtig illustrates the different approaches to project delivery in the two graphs below.

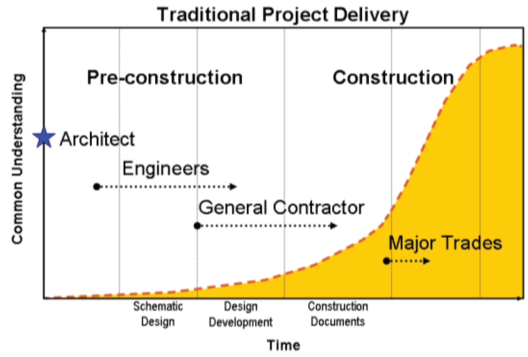


*Fig. 2: Traditional Project Delivery*

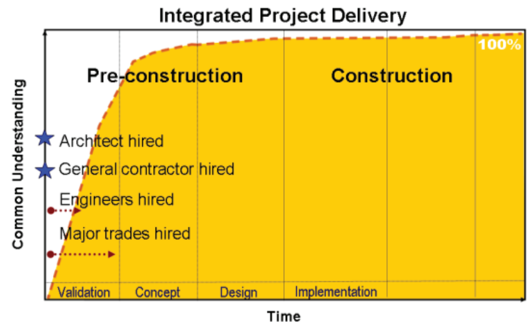


*Fig. 3: Integrated Project Delivery*

As these figures clearly convey, common understanding develops and peaks among project team members very early during IPD. By contrast, in a traditional project, common understanding is not achieved by all team members until after the project is complete.

Particularly for projects that depart from business as usual, as ZNE projects must, a common understanding among all contributors to the project is crucial to achieving the desired level of performance.

Collateral benefits of IPD that result from early-and-ongoing collaboration include:

- Shared sense of purpose;
- Collegial work environment, with reduced adversarial behaviors and attitudes;
- Shared responsibility for outcomes;
- Improved ability to identify synergies based on the team's collective knowledge and experience.

Numerous tools exist to support IPD processes. In the ideal implementation of IPD, teams adopt contractual structures that support the goals of collaboration. There are several contract forms available for this purpose, including:

- AIA A195/B195/A295 Standard Form of Agreement Between Owner and Contractor/ Owner and Architect for Integrated Project Delivery
- AIA C195 Standard Form Single Purpose Entity Agreement for Integrated Project Delivery
- ConsensusDOCS 300 Standard Form of Tri-Party Agreement for Collaborative Project Delivery

A single insurance carrier sometimes covers all the parties to an IPD contract. This also reduces the potential for adversarial situations to develop.

Cloud-based software also fulfills key functions for IPD teams, which frequently operate from geographically dispersed locations. There is an ever-expanding array of supportive software offerings, a few of which are described below.

- Scheduling. Especially for large teams, the logistics of scheduling meetings or calls can be a major barrier to collaboration. Online utilities such as Doodle can greatly simplify this task.
- Note-taking. The leader in this category is Evernote, available in a free individual version and a low-cost team version.
- Virtual meetings. In-person meetings can be supplemented with virtual meetings held via audio and video platforms – many of them free or low-cost –e.g., GoToMeeting, Join.me, Google Hangout.
- File sharing and collaboration. Platforms such as Google Drive, Dropbox, Basecamp, Central Desktop, and All-In, at the most basic level ensure that all team members have access to the same versions of key files. Platforms with collaboration and communications features range from relatively generic and user-friendly sites (Basecamp) to more powerful, comprehensive, and customizable offerings, such as All-In.
- Image libraries. Early entries (e.g., Flickr, Snapfish) allow photo-sharing. Houzz and Pinterest offer more sophisticated evolutions of this genre.
- Brainstorming, data mapping, etc. There are a host of cloud-based applications that enable remotely-located team members to work more visually – and sometimes in real time. Two examples are MindJet, a “mind mapping” package, and Gliffy, a diagramming tool that includes several standard symbol sets.

Collaboration software represents a vast and growing resource for IPD teams. New entries are continually emerging, many with great potential to improve communications and productivity, and facilitate higher-performing projects.

## CONCLUSION

Industry-wide education of both building professionals (architects, engineers, developers, et al.) and trades is the key to scaling up ZNE building. Education efforts need to target two shifts in mindset:

- Instead of asking, “How much extra will a ZNE building cost?” we need to ask, “What design changes do we need to make in order to create a ZNE building?”
- Instead of focusing on changes needed in our buildings, we need to focus on building organizational capacity to deliver ZNE buildings.

Finally, we need all parties engaged in the adoption of integrated project delivery.

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# SECTION 3

## AFFORDABLE SUSTAINABILITY & EMPOWERING THE USER

# A Simplified Approach Towards Net Zero Energy Buildings:
## The Early Stage Primary Energy Estimation Tool

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*ABSTRACT: The economic impacts of energy production and usage and its detrimental environmental effects have instigated a great interest in net zero energy buildings and their future usage within the built environment. In this article a simplified calculation tool is presented aimed at stakeholders, policy makers and decision-makers. This tool makes use of user input parameters in order to determine the primary energy usage within a net zero energy building. The simplistic methodology presented herein, allows for a first step energy analysis of a net zero building based on its energy demand and expected usage and provides an overview of the renewable energy ratio and building energy use patterns.*

*Keywords: net zero energy building, primary energy calculation, renewable energy ratio*

## 1. INTRODUCTION

Amid the economic challenges, one vision shared by the majority of the building community is to develop buildings that produce the same amount of energy as they utilize. These buildings are called net zero energy buildings (NZEBs). In the U.S. only, the energy usage within the commercial sector is expected to grow by 1.6% annually. In addition, buildings are responsible for 40% and 70% consumption of primary energy and electrical energy, respectively. These factors all contribute to energy conservation measures which include both energy conservation and refurbishment. ASHRAE has a vision of implementing market-viable NZEBs by 2030. This measure calls for implementation of the NZEB strategies in existing and new buildings (ASHRAE, 2008).

## 2. THE EARLY STAGE PRIMARY ENERGY ESTIMATION TOOL (ESPEET)

While numerous articles have been devoted to the definition of NZEBs (Torcellini et al., 2006), there has been a paucity of articles with focus on exemplified calculations of the primary energy of a NZEB. Therefore, this article seeks to outline a few of these calculations with focus on obtaining the primary energy for NZEBs. Recently Kurnitski et al., (2011) presented a number of equations pertaining to calculation of primary energy in NZEBs. The methodology is partially based on user input data and with additional modules added for estimation of different parameters. In order to analyze whether or not a building will qualify under the net zero energy building categorization, the Early Stage Primary Energy Estimation Tool henceforth referred to as ESPEET, has been developed. The model is based on two different metrics for net zero energy buildings: the primary energy and the renewable energy ratio. A complete overview of the different inputs and outputs of a NZEB and an insight into calculation of the primary energy has been provided by the REHVA team (Kurnitski et al, 2011; Voss et al., 2012).

The developed ESPEET in this study is based on four distinct modules. These provide data about on-site resources, the delivered energy, the exported energy and the required net energy, for the NZEB. The flow of data for ESPEET is shown in Fig. 1.

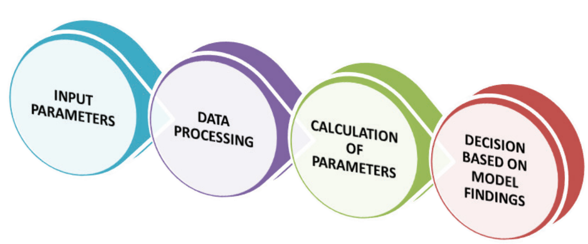


*Fig. 1: Flow of data within the Early Stage Primary Energy Estimation Tool (ESPEET).*

The main purpose of the developed tool is to provide the user with an overview of the influences of the different factors based on a limited number of input parameters. The full methodology of ESPEET is shown in Fig. 2.

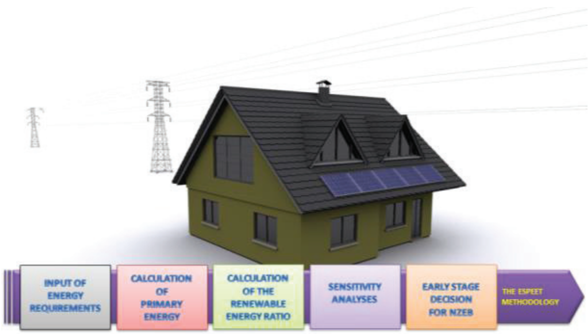


*Fig. 2: Flow of data within the Early Stage Primary Energy Estimation Tool (ESPEET).*

Initially the methodology utilizes a limited number of input parameters whereupon the primary energy can be calculated. In addition, the methodology establishes the renewable energy ratio and enables sensitivity analyses based on a parameter of interest. Based on the findings from each simulation, a primary early stage decision can be made concerning whether or not a building may qualify for a NZEB or not.

2.1. Input parameters

An exemplary overview of some of the input parameters to ESPEET is shown in Table 1. It should be noted that the extent of these parameters may very well extend beyond those presented in the table, as each added module may require additional inputs to that specific model.

**TABLE 1: EXAMPLE OF ESPEET INPUT PARAMETERS**

| Parameter | Parameter description |
|---|---|
| $A_{Net}$ | Building area [m$^2$] |
| $E_{N,H}$ | Net energy need for heating and ventilation [kWh] |
| $E_{N,C}$ | Net energy need for cooling and ventilation [kWh] |
| $E_A$ | Electricity for appliances [kWh] |
| $E_L$ | Electricity for lighting [kWh] |
| $E_{S,T}$ | Energy, solar thermal [kWh] |
| $\alpha_{SPF}$ | Ground source heat pump, seasonal performance factor |
| $\beta_{SPF}$ | Free cooling, seasonal performance factor |
| $\gamma_{SPF}$ | Seasonal energy performance factor (fans) |
| $\delta_{SPF}$ | Seasonal energy performance factor (ventilation) |
| $\chi_{SPF}$ | Gas boiler performance factor |
| $f_{Del,Exp,i}$ | Primary factor delivered or exported (i=1, fuel) (i=2, electricity) where i is the specific type of carrier |

2.2 Calculation of primary energy

The primary energy can be calculated based on processing of the input data. In particular the calculation of primary energy is actualized by utilizing Eqn. 1:

$$E \equiv \frac{\{\sum_i E_{Del,i} \cdot f_{Del,i}\} - \{\sum_i E_{Exp,i} \cdot f_{Exp,i}\}}{A_{Net}} \quad (1)$$

In Equation (1), $E_{Del,i}$ and $E_{Exp,i}$ denote the delivered and exported energy for carrier *i*, respectively. Moreover, the equation considers the primary energy factor for delivered energy $f_{Del,i}$ and exported energy $f_{Exp,i}$ and the useful floor area $A_{Net}$.

2.3 Calculation of the renewable energy ratio

The renewable energy ratio $\tilde{R}$ can further be defined as

$$\tilde{R} \equiv \frac{\psi}{\psi + (N_{C,Off} - N_{C,Exp})} \quad (2)$$

with

$$\psi \equiv (R_{C,On} - R_{C,Exp}) + R_{C,Off}$$

In the context of Equation (2) $R_{C,On}$ and $R_{C,Exp}$ refer to the collection of renewable energy produced on site and collection of renewable energy produced on site and exported, respectively. Further, $R_{C,Off}$ denotes the collection of imported non-renewable energy produced off-site, $N_{C,Off}$ the collection of delivered non-renewable energy carriers, and $N_{C,Exp}$ the collection of exported non-renewable energy carriers. The amount of $R_{C,On}$ in Equation (2), captured by the heat pump from ambient heat sources is given by

$$E_{Rc,on} \equiv Q_u \cdot \left(1 - \frac{1}{f_{SP,h}}\right) \quad (3)$$

where $Q_u$ is the estimated total heat delivered by the heat pump and $f_{SP,h}$ the estimated average seasonal performance factor. In this context the condition imposed on the performance parameter according to Szabó (2012), is that it needs to fulfill $f_{SP,h} > 1.15 \cdot \eta^{-1}$, where the parameter $\boldsymbol{\eta}$ is the ratio between total gross production of electricity and the primary energy consumption for electricity consumption.

An alternative representation of defining a net zero energy building, NZEB (Kilkis, 2007), is

$$NZEB \equiv \left(\sum_i E_{f,i} - \sum_i E_{t,i}\right) + \left(\sum_i H_{f,i} - \sum_i H_{t,i}\right)$$

where $E_{f,i}$ and $E_{t,i}$ is the electrical energy received from and returned to the district, during the time increment *i*. Similarly, $H_{f,i}$ and $H_{f,i}$ represent the thermal energy from and returned to the district, respectively. With this designation $NZEB \leq 0$, identifies a zero energy building. The caveat however with utilizing Equation (4) stems from its indifference to exergy levels between electrical and thermal energy.

In order to introduce exergy analysis, the net zero exergy building factor $XZEB$ is defined as

$$XZEB \equiv \left(\sum_i \epsilon_{Ef,i} - \sum_i \epsilon_{Et,i}\right) + \left(\sum_i \epsilon_{Hf,i} - \sum_i \epsilon_{Ht,i}\right) \quad (5)$$

designating the building as a net zero exergy building if $XZEB \leq 0$. In this article however, solely the primary energy analysis and renewable energy ratios for a detached dwelling and an office building with different energy demands will be discussed.

## 3. CHOICE OF OBJECTS FOR ANALYSIS

In order to determine the usefulness of ESPEET, at least two different categories of dwellings have been chosen, namely single detached dwellings and office buildings. The choice of these two building types stems from the interest in obtaining different initial requirements for each building. Moreover, the combination of different on-site resources and their respective influence on the resulting primary energy can be determined. The single detached building, in this context refers to a building with a useful floor area less than that of an office building. This type of building usually features solar thermal energy and a ground source heat pump.

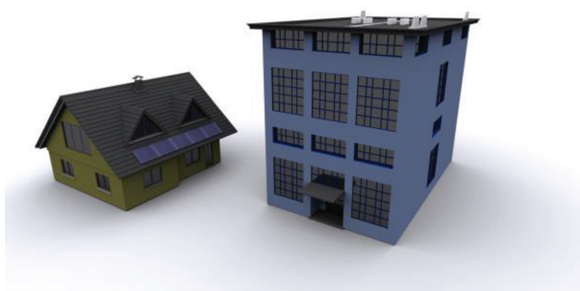

*Fig. 3: Example of a detached dwelling and an office building.*

An office building is designated by its larger useful floor area, in comparison to the detached building. As a baseline in this study, a useful floor area for an office building was considered to be 500 m$^2$. Heating is in this context often provided by means of a gas boiler, although the presence of solar energy also is possible.

### 3.2. Choice of locations

In order to fully assess the capabilities of ESPEET, different countries at different geographical locations in the world were chosen. This choice was based on their latitudinal global placement and attention was also devoted to whether the specific building was situated in the Northern Hemisphere, Southern Hemisphere and Western and Eastern Hemispheres. The different considered locations and their corresponding energy parameters are shown in Table 2.

**TABLE 2: EXAMPLE OF ESPEET INPUT PARAMETERS FOR DIFFERENT COUNTRIES (European Environment Agency, 2013; Swedish Energy Agency, 2013; BBC; 2013)**

| Country | $A_{Net}$ [m$^2$] | $\bar{E}_{N,H}$ [kWh/m$^2$] | $\bar{E}_{N,C}$ [kWh/m$^2$] | $\bar{E}_{S,T}$ [kWh/m$^2$] |
|---|---|---|---|---|
| Australia | 206 | 58 | 13 | 18 |
| Denmark | 137 | 51 | 6.4 | 8.4 |
| France | 113 | 35 | 8.0 | 9.4 |
| Ireland | 88 | 24 | 5.5 | 4.0 |
| Spain | 97 | 9.8 | 4.2 | 3.6 |
| Sweden | 149 | 43 | 5.4 | 7.1 |
| UK | 76 | 24 | 4.2 | 3.9 |
| USA | 214 | 64 | 21 | 20 |

## 4. RESULTS AND DISCUSSION

The presented results herein have solely been based upon the outputs from the developed tool. In essence, two different studies have been carried out in which a detached building and an office building in different countries have been subjected to analyses, with the input parameters presented in the preceding section.

### 4.1. Detached dwelling

Based on the findings of the developed tool, Fig. 4, depicts the primary energy usage within the considered countries.

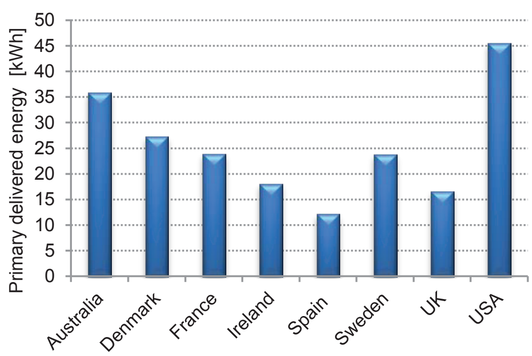


*Fig. 4: Primary energy usage for the considered detached dwellings in the given countries simulated by ESPEET.*

Similarly, the ratio of the renewable energy is shown in Fig. 5.

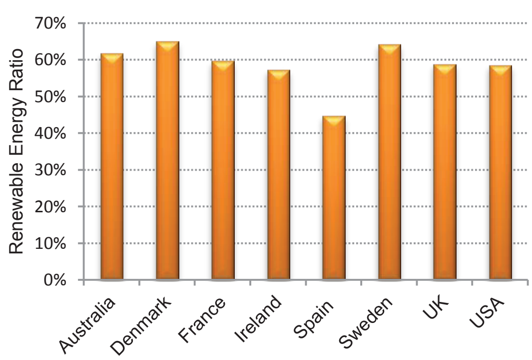


*Fig. 5: Ratio of the renewable energy for the considered detached dwellings.*

The findings of the simulation results based on ESPEET stem from the choice of input parameters in Table 2. It is noteworthy that the chosen parameters are partially based on retrieved data from the literature. The large area of some of the considered countries in the study made the choice of input parameters convoluted. For the United States, the chosen value was an estimated averaged value chosen for the entire country. Given the vast areal extent from the east coast to the west coast, a single chosen parameter cannot incorporate the entire spectra of encountered energy conditions across the nation. Hence, the findings of the primary delivered energy for the United States do not necessarily entail that the detached building is less of a NZEB, in comparison to other countries.

In Fig. 4, the least value of the primary delivered energy is indicative as the building which serves as the most NZEB. With the given input parameters, the simulated values suggest that the primary energy usage for Spain closely resembles NZEBs. The most NZEBs as determined by the simulation results are encountered in the following countries: Spain, UK, Ireland, Sweden, France, Denmark, Australia, and U.S.A.

From Figure 5, the ranking of the highest value of the ratio of the renewable energy is encountered for Denmark, followed by Sweden, Australia, France, U.K., U.S.A., and Spain.

An interesting analysis pertaining to usage of the developed tool is a sensitivity analysis based on a single specific parameter. These parameters have been considered in order to analyze the impact of the different parameters on the overall primary energy and renewable energy ratio.

In particular the sensitivity analysis presented herein explores the influence of the building area. Hence the remaining parameters have been kept constant. For the building area, a minimum and maximum building area of 150 $m^2$ and 500 $m^2$ has been considered, based on possible existing building area values of detached dwellings for the considered countries.

As shown in Fig. 6, it is evident that in the case of the detached building, a change in useful floor area for the same heat input values renders the building as more prone towards the net zero energy building definition, as a comparatively less energy input is utilized in the analysis.

Nevertheless, this statement should be viewed against the simple fact of whether or not the utilized input parameters indeed are sufficient for the energy demand of a large building with the building area of 500 $m^2$. From a net zero energy building viewpoint, utilizing a combination of large building area in conjunction with a limited energy input, renders the building as more NZEB friendly.

Explicitly for the given range and extension of the useful floor area, corresponding to a 233% increase, the building becomes 61.3% more NZEB-friendly. For the same increase in the useful floor area, a decrease of 11.7% is experienced concerning the renewable energy ratio.

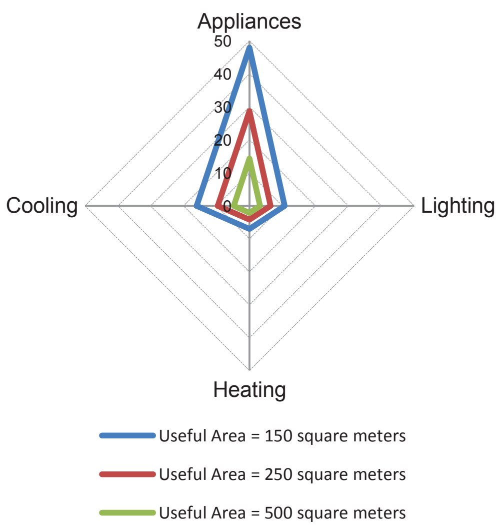


*Fig. 6: Sensitivity analysis conducted on the building area with all other input parameters remaining constant using ESPEET.*

This simple example illustrates that there are certain limitations with utilizing the primary energy equation without devoting attention to the input parameters and realistic energy demands of the building. Therefore, although the literature indicates that the primary energy can be viewed as a single metric for NZEBs, consideration has to be taken in order to ensure that realistic heat demands are utilized in ESPEET.

Although the geographical location of the building is considered in the developed methodology, ESPEET does not account for advanced site specific weather analysis and temperature ranges, in its current state. Hence, this fact places more emphasis on adequate input data provided by the user for a more accurate analysis. Despite this limitation, it should be emphasized that ESPEET is not intended as a detailed assessment tool, which incorporates advanced calculations of the heat transfer, occurring in NZEBs. Instead it is intended as a first analysis tool which provides a baseline for NZEBs. The usefulness of ESPEET can be placed in its simplistic nature and its adaptation to incorporate other relevant analyses pertaining to NZEBs, such as exergy and $CO_2$-analysis.

For the considered office building, a sensitivity analysis was conducted based on the gas boiler and seasonal performance factor $\chi_{SPF} \in [0.5,0.9]$. A decrease of the aforementioned performance factor with 44% yields that an increase of 18% is evident in the primary energy factor. The corresponding decrease in the renewable energy factor is 36%.

By utilizing ESPEET, stakeholders, policy makers and decision-makers can robustly obtain a preliminary platform for decision making based on specific criteria. Upon calculation of the primary energy and the renewable energy ratio, a sensitivity analysis can be carried out in order to enhance the net zero energy aspect of a new or existing building.

The findings of this study have highlighted the manner in which ESPEET can be utilized in order to assess NZEBs based on a simple yet effective methodology.

## 5. CONCLUSION

In light of the findings of this study, it has been shown that the developed tool is able to provide a preliminary overview of the primary energy usage and the ratio of renewable energy based on a limited number of input parameters. A number of limitations pertaining to a mere energy difference and large influence of input parameters of the developed model are also addressed in this study.

It should be noted that the tool is intended solely as a first approach analysis tool, for determining whether or not a building can be considered as a NZEB and in order for the user to perform simple analyses on both existing and new developed buildings, at an early stage. The tool is therefore not intended as a comprehensive tool for analysis of NZEBs, due to its simple nature. The full potential of ESPEET can be realized upon its usage by the aforementioned users. This approach will provide a prospect of developing NZEBs in a broad range of the existing building stock.

More in-depth NZEB calculations are referenced to commercial codes as they will account for both the influence of climate, geographical location and other relevant factors for a more precise analysis.

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# Designing an energy efficient and comfortable building

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*ABSTRACT: The building has a gross area of 182,000 sq. ft. The building will contain a basement with 4 levels above grade. The spaces are distributed in general in the following manor:*

- *Server room, classrooms, a parking garage and mechanical and electrical rooms in the basement,*
- *The 1st and 2nd floors contain a mix of classrooms studios as well as office and support facilities;*
- *The 3rd and 4th floor contains the main administrative offices, faculty offices and ancillary support spaces.*

*It was decided at an early stage in the design that occupant comfort would be a priority as well as energy conservation. The goal was to provide comfort levels of 10% PPD (Percentage of Person Dissatisfied) or less for each space and at the same time consume the least amount of energy against both California's Title 24 requirements and ASHRAE 90.1-2007 for LEED points.*

*The first step in creating comfortable spaces is with the architecture and not the conditioning systems. IBE spent considerable time working with the architects, analyzing different glazing alternatives and investigating the inside surface temperature for the glass as this drives the mean radiant temperature (MRT) in the occupied spaces. A dynamic comfort simulator was used that could analyze space conditions for a single day, month or year. Having a better understanding of the building shade characteristics and thermal conditions, the overall thermal comfort was improved in addition to reducing energy consumption by implementing some or all of the investigated strategies.*

*Occupant spaces are conditioned by active beams and classrooms are conditions by radiant ceilings together with a variable volume ventilation system.*
*The building includes the following features to increase the performance of the building to exceed Title 24 minimum standards by 37.9 percent:*

- *High performance lighting systems in classrooms, seminar rooms, meeting room and offices, with occupancy sensors and daylight harvesting sensors.*
- *High performance glazing*
- *High efficiency frictionless chillers*
- *Wall insulation increased to R-19 and roof insulation increased to R-30.*
- *Daylight harvesting sensors.*

*For the LEED submittal the percentage of Energy savings was 63.5% and the cost savings were 46.7%, which was good for 10 LEED points*

*Keywords: energy, comfort*

## 1. INTRODUCTION

The building has a gross area of 182,000 sq. ft. The building will contain a basement with 4 levels above grade. The spaces are distributed in general in the following manor:

- Server room, classrooms, a parking garage and mechanical and electrical rooms in the basement,
- The 1st and 2nd floors contain a mix of classrooms studios as well as office and support facilities;
- The 3rd and 4th floor contains the main administrative offices, faculty offices and ancillary support spaces.

It was decided at an early stage in the design that occupant comfort would be a priority as well as energy conservation. The goal was to provide comfort levels of 10% PPD (Percentage of Person Dissatisfied) or less for each space and at the same time consume the least amount of energy against both California's Title 24 requirements and ASHRAE 90.1-2007 for LEED points.

## 2. ENGINEERING THE ARCHITECTURE

The first step in creating comfortable spaces is with the architecture and not the conditioning systems. IBE spent considerable time working with the architects, analyzing different glazing alternatives and investigating the inside surface temperature for the glass as this drives the mean radiant temperature (MRT) in the occupied spaces. A dynamic comfort simulator was used that could analyze space conditions for a single day, month or year. Having a better understanding of the building shade characteristics and thermal conditions, the overall thermal comfort was improved in addition to reducing energy consumption by implementing some or all of the investigated strategies.

Claremont McKenna College is located in Claremont, California at 34.1 degrees Latitude. Using a software program, a sun path diagram was created to show the total solar radiation on south and west facing surfaces of a 90 degree structure. The sun path diagram reveals the maximum solar radiation potential for September and July are 144 Btu/h $ft^2$, and 168 Btu/h $ft^2$ respectively. The design peak days selected for the analysis were July 30th for the western facing windows and September 24th for the southern facing windows.

On the fourth floor of the southern façade of the college there are 1.5 ft. long fins protruding from both sides of the windows. There is also a 1.5 ft. overhang above the windows.

The material characteristics of the fins are very important. The material should have a high reflective factor to reflect solar radiation from being absorbed into the shade. In Claremont California the peak solar intensity is 168 Btu/h $ft^2$. By allowing only minimal radiation to hit the windows, the solar gain to the space is reduced significantly. At the same time, the solar radiation penetrating the fins must be utilized to enhance the natural day lighting of the spaces.

The inside surface of the fins must also be carefully selected., If the surface has a higher reflectance than any radiation reflected from the glass, after being allowed to hit the glass, could be reflected back into the building from the shade. If the inside surface of the fins is not reflective, the solar radiation reflected from the glass will be absorbed by the fins.

A representation of the exterior fins attached to the fourth floor offices was developed in the simulation program for the analysis. (Figure 1)

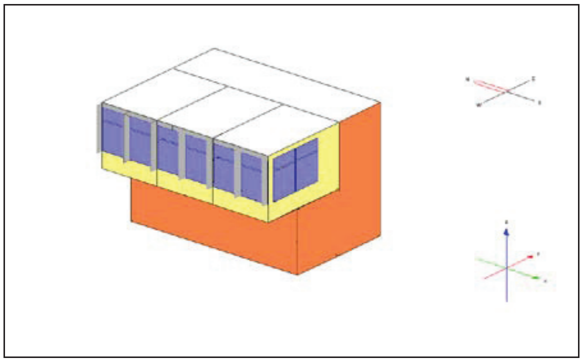

Figure 1 illustrates the representation of the exterior shades that were developed in the simulation program for the fourth floor offices.

The glazed surfaces of the college were carefully selected as the glass had to perform to reduce solar loads yet permit natural day light to enter the spaces. During the winter the glazing must have a low U value to reduce heat losses. A low U value is most often obtained by having a coating on either the second or third surface of the double glazed construction. The ideal glazing is one with a balance between a high visible light transmittance and low shading coefficient. This is often a difficult compromise to maintain a clear appearance yet achieving the required shading performance.

The glazing type used in the analysis for the College was an insulating glass with a low shading coefficient of 0.32 and high visible transmittance of 62%, a winter nighttime U value of 0.29 BTU/h.sf and a summer U value of 0.25 BTU/h.sf

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**3. SYSTEM CHOICE**

The choice of an appropriate conditioning system was based upon the required comfort compliance requirements. But the different characteristics of classrooms and offices would lead to two different conditioning systems.

Classrooms

Based upon previous design for academic buildings such as Cooper Union we had some excellent operational feedback that would help us select a system for CMC. Each classroom was designed for 30 students, with and without computers. Experience in designing academic buildings over the years requires a flexible solution, will all the students be present and at what time of the day will the classes be held. The basis of the design is a variable volume ventilation air supply; we chose to provide 20 CFM of outside air for each person present. By providing 20CFM the ventilation rate qualifies for the LEED point for extra ventilation. The cooling provided by supplying 20CFM per student and with a maximum of 30 students in the room is nearly sufficient to maintain a space temperature of 74F. But we were looking for comfort compliance so a radiant ceiling was introduced mainly for heating during the brief and relatively mild winters in California. The choice of a radiant ceiling was based upon the system being able to control radiant temperatures in the space, especially for the first lesson of the day and with only a minimum of students present. The radiant ceiling would provide heat to the space and control space radiant temperatures and the ventilation air would be supplied in amounts determined by individual space CO2 sensors. Another spin off from this methodology is the reduction in fan power for the ASHRAE 90.1

energy performance. Once the choice for a radiant ceiling was made, investigations then took place to look at the utilization of cooling from the radiant ceiling. It was basically the same scenario as heating, if the class was partially occupied the ventilation air would be reduced and the cooling and radiant temperature control would be performed by the radiant ceiling.

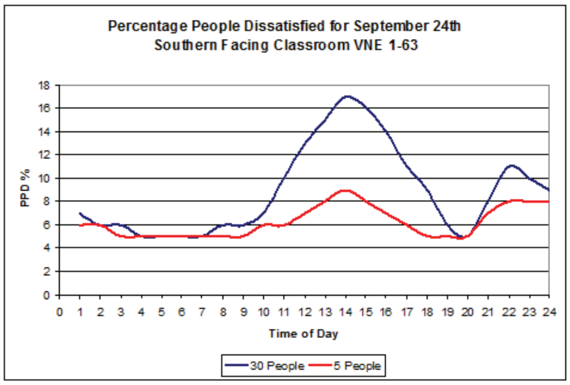



Figure 2 shows the PPD levels in a classroom when conditioned by a traditional overhead VAV system for a variation in occupants.

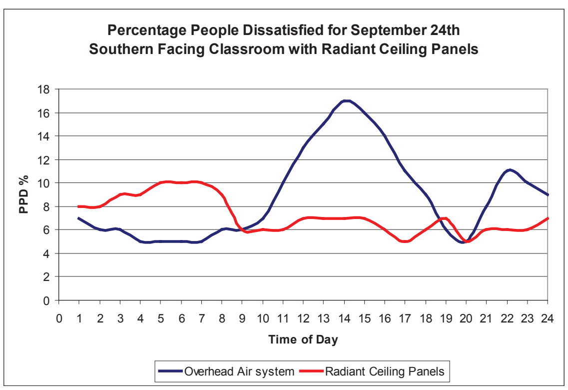



Figure 3 shows the percentage of people dissatisfied for different air conditioning methods for the classroom

The results show that comfort conditions comply with ASHRAE standard 55 when a radiant ceiling is introduced as part of the conditioning system for the classrooms.

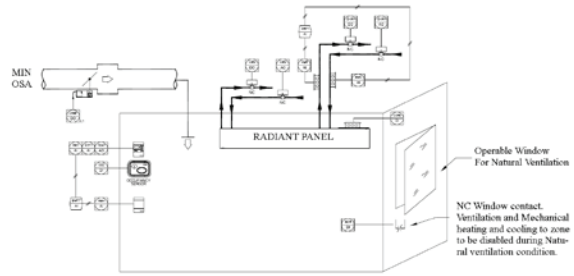



Figure 4 shows the controls for the classrooms and meeting rooms at CMC

Figure 5 shows one of the meeting rooms at CMC which is conditioned in the same manner as the classrooms.

## 4. OFFICES

It was decided to use active beams to conditions the offices and administrative spaces at CMC. The choice was based upon our quest for occupant comfort and individual control in each space. Constant volume primary air is supplied to each beam; the sensible cooling from the primary supply air is only about 15-20% of the space sensible cooling load. The larger portion of the cooling load is provided by the control of cooled water flowing through the beam. By putting the control emphasis on the water side control of the system, the response time is improved and this increases the efficiency of the system.

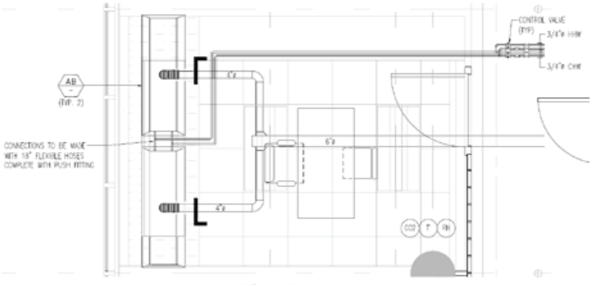


Figure 6 shows a plan view of the active beams and primary air connections for each space. The temperature, humidity and CO2 sensors are also shown for each space.

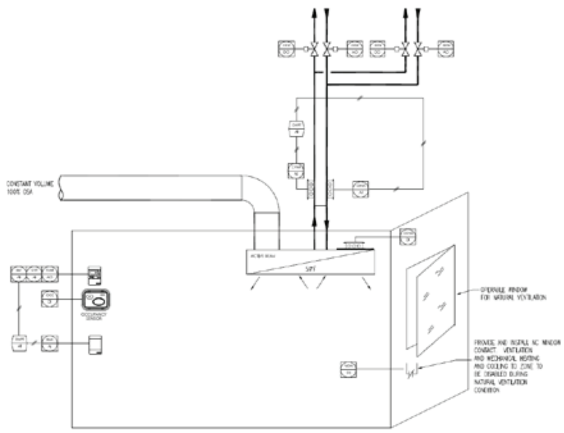


Figure 7 shows the control systems for offices conditioned by active beams.

Figure 8 shows a typical office space with floor to ceiling glass

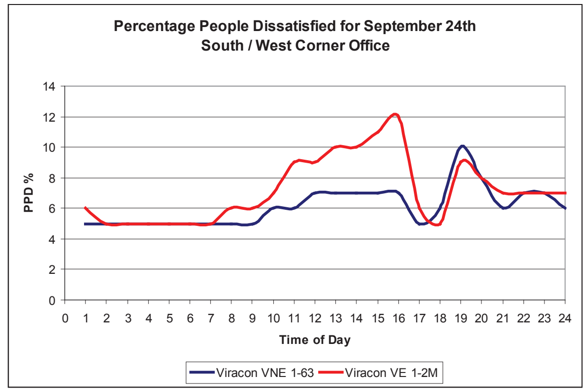



Figure 9 shows the percentage of people dissatisfied for two different glass types for the corner office

## 5. ENERGY EFFICIENCY

A central cooling and heating plant was provided to serve this building. The central plant is located at the basement level to the north of the building. The chiller plant will consist of two 160 ton frictionless chillers. Each chiller will have a variable speed primary pump. The chillers also have the capability of having their speed varied to improve efficiency. Condenser water for the chillers is cooled by a single cooling tower having variable speed fans. The condenser water loop is constant volume.
There are two variable volume chilled water loops:

1. There is a 42F loop that transports water to the air handling units, CRAC units and fan coils in the IDF rooms.
2. The second loop has a variable supply temperature from 55F to 58F for the active beams and the radiant ceiling panels.

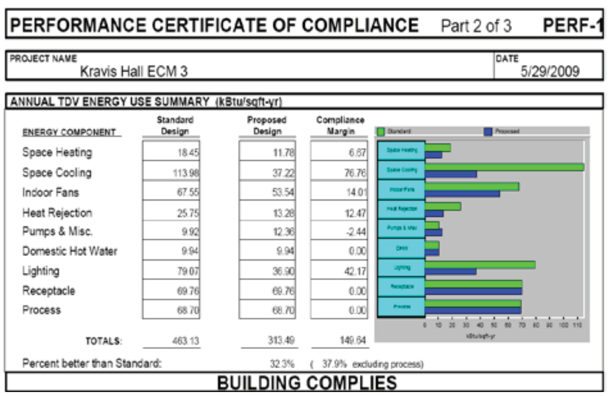
Two boilers each with a 2MBH capacity provide water at a constant volume to a common header. There are two variable volume heating hot water loops:

1. There is an 180F loop that transports water to the air handling units.
2. The second loop has a variable supply temperature for the active beams and the radiant ceiling panels.

## 6. ENERGY ANALYSIS

An energy model was constructed to explore the building's performance against the California Energy Code (Title 24). This code provides a measuring stick based upon the size and use of a building.

The Reference Baseline building shell is comprised of metal frame wall with R-13 batt insulation, insulated glazing with a T-24 maximum shading coefficient and roofing with a R-19 insulation.
Lighting systems were specified to meet Title 24 allowances of 1.2 Watts/square foot.
The Reference Baseline mechanical system was an overhead VAV system and a central heating and cooling plant as allowed by Title 24 standards.


PERFORMANCE CERTIFICATE OF COMPLIANCE Part 2 of 3 PERF-1

PROJECT NAME: Kravis Hall ECM 3 — DATE: 5/29/2009

ANNUAL TDV ENERGY USE SUMMARY (kBtu/sqft-yr)

| ENERGY COMPONENT | Standard Design | Proposed Design | Compliance Margin |
|---|---|---|---|
| Space Heating | 18.45 | 11.78 | 6.67 |
| Space Cooling | 113.98 | 37.22 | 76.76 |
| Indoor Fans | 67.55 | 53.54 | 14.01 |
| Heat Rejection | 25.75 | 13.28 | 12.47 |
| Pumps & Misc. | 9.92 | 12.36 | -2.44 |
| Domestic Hot Water | 9.94 | 9.94 | 0.00 |
| Lighting | 79.07 | 36.90 | 42.17 |
| Receptacle | 69.76 | 69.76 | 0.00 |
| Process | 68.70 | 68.70 | 0.00 |
| TOTALS: | 463.13 | 313.49 | 149.64 |

Percent better than Standard: 32.3% ( 37.9% excluding process)

BUILDING COMPLIES



Figure 10 Annual TDV Energy Use Summary (kBtu/sqft-yr)

Figure 10, above, shows the EnergyPro output for the energy analysis. The reference Standard Design is a building of the same size and usage built in accordance with the prescriptive requirements of Title 24. By taking the performance approach, we do not need to follow the prescriptive requirements as long as our proposed building out performs the standard building.

Based on the preliminary model, the proposed building is performing 32.3% better than the standard model, although the value of 37.9% better than Title 24 is used for Savings by Design as this excludes process loads.

## 7. CONCLUSION

The building includes the following features to increase the performance of the building to exceed Title 24 minimum standards by 37.9 percent:

- High performance lighting systems in classrooms, seminar rooms, meeting room and offices, with occupancy sensors and daylight harvesting sensors.
- High performance glazing
- High efficiency frictionless chillers
- Wall insulation increased to R-19 and roof insulation increased to R-30.
- Daylight harvesting sensors.

For the LEED submittal the percentage of Energy savings was 63.5% and the cost savings were 46.7%, which was good for 10 LEED points

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# Gypsum - Rubber from pipe foam insulation waste recycling: Thermal performance

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*ABSTRACT: The aim of this research work is to study the effect of different percentages of waste rubber coming from pipe foam insulation addition in the thermal performance of a gypsum matrix.*
*Four particle size waste rubber: 1-2 mm, 2-4 mm, 4-6 mm and 20-25 mm, and different rates of waste rubber addition: 1.25%; 2.50%; 5.00% and 7.50% were analyzed. After deciding the optimal size and percentage of waste rubber, two combinations were chosen to carry out the thermal test.*
*Furthermore, in order to characterize its mechanical behavior, an experimental plan was elaborated to study its density, flexure strength and compression strength.*
*This addition contributes to obtain a low density, lightweight, environmentally friendly material with improved thermal performance.*

*Keywords: thermal performance, waste rubber, low density.*

## 1. INTRODUCTION

Under the 2020 objectives on energy efficiency, all new buildings shall be nearly zero-energy consumption by 31 December 2020 and new materials with improved thermal behaviour are a key tool in order to obtain this target.
For this reason, the development of research studies in this field has experienced a strong growth in recent years and many works are focusing on cement - concrete - gypsum matrixes incorporating different additions to improve their thermal conductivity. Recently, Bouvard et al (2007) characterized and simulated an expanded polystyrene (EPS) lightweight concrete and Vejmelková et al (2012) analyzed the improved thermal properties of concrete containing fine-ground ceramics, among other examples.
Moreover, due to the concern about the high rate of waste disposal in landfill, the recycling of industrial wastes in new materials would contribute to valorise certain types of waste, forming part of new materials with improved thermal properties: Bederina et al (2007) studied the effect of the addition of wood shavings on thermal conductivity of sand concretes, Corinaldesi et al (2011) tested the mechanical behavior and thermal conductivity of mortars containing waste rubber from used tires and Panesar and Shindman (2012) analyzed the mechanical and thermal properties of concrete containing waste cork.
However, no previous experience about the addition of pipe foam insulation waste rubber in any matrix has been found. Only in Spain about 400 tons of this foam insulation are yearly sent to landfill for only one manufacturer, meaning a great amount of waste in volume due to its low density.
This new material would contribute to pursue the European Union targets set out for waste recycling. (European Parliament and the Council of the European Union, 2008)

## 2. MATERIALS AND METHODS

- Gypsum matrix E-35 plaster, Type B1 according to UNE-EN 13279-2 Standard, and certified by N mark from AENOR. (Fig.1)

**TABLE 1: MATERIALS**

| Materials | Thermal conductivity | Size (mm) |
|---|---|---|
| E-35 Plaster | 0.30 | >0.2 |
| Pipe foam insulation | ≤ 0.036 | 1 - 25 |

AFFORDABLE SUSTAINABILITY & EMPOWERING THE USER

- Ground waste rubber coming from pipe foam insulation, received from a Spanish manufacturing plant as material rejected during its production process. It is listed in the European List of Waste (ELW) as 07 02 13: Waste Plastic. (Fig. 1)

Its initial ground size, after being shredded by the manufacturer, varies from 20 mm to 25 mm, being subsequently mechanically shredded in laboratory, to sizes from 25 mm to 1 mm.

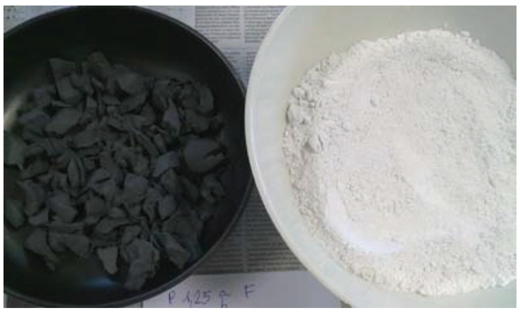

*Fig. 1: Waste rubber 20-25mm and plaster under study*

## 3. TEST PIECES ELABORATION AND METHODOLOGY

Test pieces series of 40 mm x 40 mm x 160 mm (three per series) were produced in order to assess the mechanical behavior. Furthermore, 230 mm x 230 mm x 25 mm wall test pieces were prepared to assess thermal performance.

Sizes of crumbed rubber, 1-2 mm, 2-4 mm, 4-6 mm and 20-25 mm and percentages of 1.25%, 2.50%, 5.00% and 7.50% added by plaster weight were studied.

The water/plaster (w/p) ratio was assessed according to UNE-EN 13279-2 Standard, being 0.76 the value obtained.

Wet weight was recorded after the test pieces were unmolded, then they were kept for 6 days in laboratory atmosphere and later stored for 24 hours in a stove (CENTERM 150 model), at 40 ± 2 ºC (313 ± 279 K), to reach a constant mass and in order to obtain the dry weight value.

Seven days later, the test pieces were cooled in the desiccators in order to achieve the room temperature and being subsequently mechanically and physically tested. The reference standard for this process has been the UNE-EN 13279-2.

In order to determine the thermal behavior a simplified method was used, which allowed obtaining a first approximation of the composite heat conductivity.

To assess the heat conductivity rough value a model house-box with replaceable side walls (Fig. 2 and Fig 3) was used. The box had an inside heat source and a temperature sensor connected to the thermal control thermostat.

Three NiCr-Ni thermocouples connected to temperature measurement tools and the software *Measure,* to program the box and to export the results, were used.

The temperatures were measured in the steady state, at a constant interior and outer air temperature. (Phywe Systeme GmbH & Co. KG, 2008)

*Fig. 2. Model house to study the heat conduction.*

*Fig.3. Interior of the model house: NiCr-Ni thermocouples and rubber-gypsum wall test piece*

An EPS board with known thermal conductivity was fixed to the gypsum-rubber test piece, in order to obtain the plaster-rubber λ value.

The heat flow (Q) through the wall was considered constant. The plaster-rubber λ value was obtained according to a simplified Fourier Equation:

$$\frac{\lambda_1 \cdot S \cdot (T_1 - T_2)}{h_1} = \frac{\lambda_2 \cdot S \cdot (T_2 - T_3)}{h_2}$$

Where:
$\lambda_1$ is the plaster-rubber composite thermal conductivity (W/m·K)

$\lambda_2$ is the EPS thermal conductivity (known value): 0.041 W/m·K

S is the wall surface (known value): 0.0441 $m^2$

$T_1$, $T_2$ and $T_3$ are the layers' temperature (ºC)

h is each material thickness, being $h_1$ 0.035 m and $h_2$ 0.019 m.

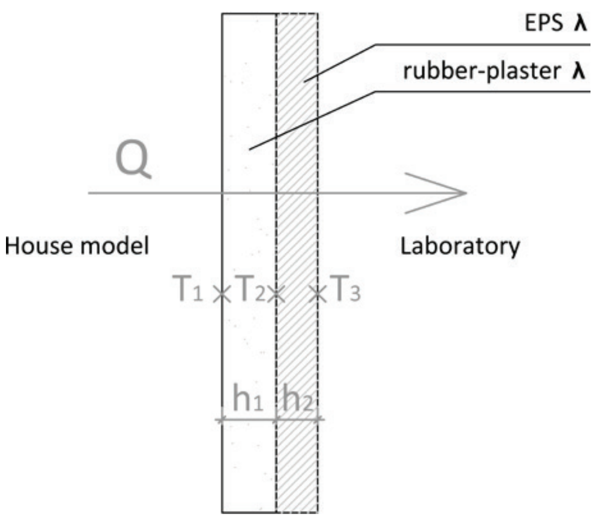


*Fig. 4. Experiment scheme.*

## 4. RESULTS AND DISCUSSION

### 4.1. Density

Waste rubber addition entails a density decrease in the test pieces. The values obtained with 1-2 mm, 2-4 mm and 4-6 mm particle sizes, resulted very similar varying between 0.90 and 1.00 $g/cm^3$. Up to 48% of density lost is obtained in 20-25 mm test pieces, compared to reference plaster, turning into a highly lightweight composite. (Fig. 5)

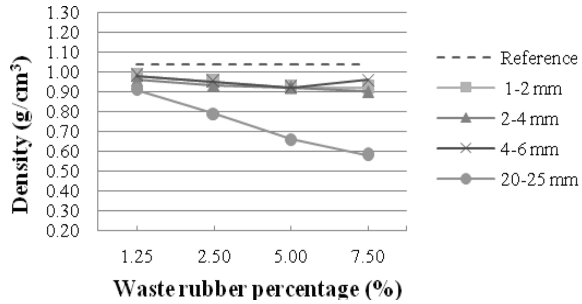


*Fig. 5. Waste rubber percentage –density*

### 4.2. Flexural strength test

It can be stated that the waste rubber addition increases the composite plastic period: once the breaking load is achieved there isn't a division between both sides, remaining strongly joined in most of the cases. (Fig.6). However, an important strength loss is observed when increasing rubber addition and as larger its size is. (Fig. 7)

*Fig. 6. Waste rubber percentage -density*

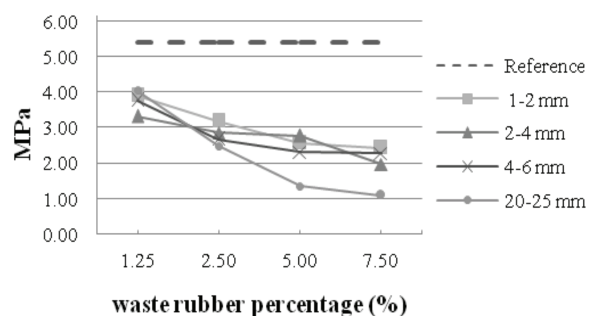


*Fig. 7. Flexural strength - waste rubber addition*

### 4.3. Compressive strength

Once the breaking load is reached, the different fragments are still linked, allowing the material being deformed after exceeding its breaking load. (Fig. 8)
The results are much smaller than the reference ones, being under UNE-EN 13279 standard the 20-25 mm size from 5.00% percentage addition: meaning a decrease of around 88% under the reference results. (Fig.9)

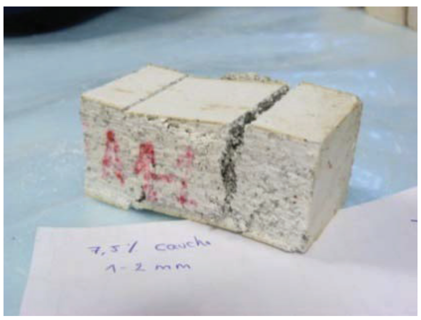


*Fig. 8. Test piece after exceeding its breaking load.*

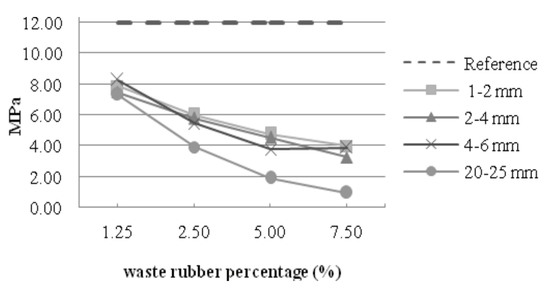


*Fig. 9. Compressive strength - waste rubber content*

### 4.4. Thermal behavior

Two rubber-gypsum composites were selected to be tested in order to assess its thermal behavior:
- The 7.5% of 4-6 mm waste amount: because its size is easy to obtain and its mechanical performance fulfills the UNE-EN 13279-2 standard.
- The 1.25% of 1-2 mm waste amount: for being the minimum content of waste in the series studied meeting high mechanical strengths.

The average results are shown in the following table (Table 3):

**TABLE 2. THERMAL TEST RESULTS**

| Wall test piece | Thermal conductivity, λ (W/m·K) |
|---|---|
| Reference | 0.30 |
| 1.25% 1-2 mm | 0.25 |
| 7.5% 4-6 mm | 0.20 |

The minimum presence of rubber leads to an increase of 17% of the thermal performance, being 33% higher the improvement obtained with 7.5% of waste.
Due to the low density of both materials and the low thermal conductivity of waste foam rubber, an improvement in the thermal performance was expected.

## 5. CONCLUSION

This paper presents the results of an investigation on the use of waste ground rubber, from pipe insulation production, as addition in gypsum-plaster matrix. Based on the results of this study, the following conclusions can be drawn:

1. The maximum waste weight percentage accepted by the mixture, to make it workable, is 7.50%

2. There is a good compatibility between waste rubber coming from pipe foam insulation and the plaster matrix. Despite the low density waste particles present, the ground rubber is distributed in a proper way inside the test pieces: they don't float in the mixture and therefore an homogenous paste is obtained.

3. Plaster-rubber composite is a lightweight construction material: 48% weight reduction is reached compared to the reference samples.

4. Mechanical strength decreases with an increase in waste rubber addition, highlighting a higher decrease with the larger size and waste amount added, this happens because the matrix pores compromise its strength. All the flexural strength values obtained meet the UNE-EN 13279 requirements. However, there are two series which don't meet the

compressive requirements: 5.00 and 7.50% with 20-25 mm rubber size.

5. An improved thermal behavior is obtained, decreasing the new composite thermal conductivity as far as the rubber content increases.

For all these reasons, waste foam rubber could be used forming part of core plasterboards, achieving an environmental benefit as well as an improved thermal performance. On the other hand, the resulting lightweight drywall would be easier to handle, making it easy to install too.

## 6. ACKNOWLEDGEMENTS

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# Low Energy Design:
# An Evaluation of a Vacation Home in Panama

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*ABSTRACT: This paper will discuss a low impact and low energy vacation home in the surfing capital of the world, Venao Panama, using the standards for zero site energy as well as other performance factors as the basis for the analysis. The home was designed to achieve net zero energy use, but given the climate and irregular occupancy, its design and systems are unique. The focus of this paper is to highlight the construction type, energy use, active and renewable systems, and other features of this particular zero energy building. The objective is to facilitate a better understanding of efficient and sustainable residential design for tropical climates. This understanding is critical to bringing Net Zero Energy to the public.*

*Keywords: low energy construction, residential, tropics, Panama*

## 1. INTRODUCTION

The construction and operation of residential and commercial buildings have a significant environmental impact. In the last quarter century, global temperatures and $CO_2$ emissions have increased dramatically, increasing both the risk and reality of catastrophic environmental disasters (RMI, 2002). Analysts estimate that global carbon emissions will more than double by 2050 if changes are not made in the way we build and live.

There is a growing global awareness of the need for energy conservation and this awareness is increasingly reflected in the way we design and build. Efficient HVAC equipment, better insulation, smarter design, and occupant awareness of energy efficiency and renewable energy are now bringing the concept of Net Zero Energy Buildings to the mainstream (Farhar & Coburn, 2008). Net Zero Energy Buildings, or NZEB, are buildings that produce as much energy as they consume on an annual basis. A Net Zero Energy Building is capable of producing, at minimum, an annual output of renewable energy that is equal to the total amount of its annual consumed/purchased energy from energy utilities (Fortmeyer 2006).

This paper describes the design process and specific characteristics of a vacation home in Panama that is intended to be net zero energy. The project illustrates opportunities and challenges of designing and building low-energy structures in a different climate and cultural context. The discussion highlights design parameters, construction techniques, and supporting environmental (mechanical, plumbing, and lighting) systems that were specified for the house with the intention of achieving net zero site energy. It will also describe additional efforts by the designers and owners to not only meet the criteria for zero site energy use, but also to be locally rooted, resource efficient, and healthy. The intent is to show how construction practices, technologies, sustainable materials, innovative mechanical, electrical, and plumbing systems, and lifestyle choices impact home energy performance in a tropical climate.

## 2. BACKGROUND

Panama borders the Caribbean Sea and the North Pacific Ocean, between Colombia and Costa Rica. The country occupies the southeastern end of the isthmus forming the land bridge between North and South America. The climate is described as tropical maritime- hot, humid, and cloudy (Ward and Ostbo, 2010). Panama has an average of 3600 cooling degree days and its seasonal variations are marked by hot and wet in the dry season and hotter and wetter in the rainy season. Lowlands line both the Caribbean and Pacific coasts. Venao is situated on the easterly tip of Panama's Azuero Peninsula in the province of Los Santos. The world-famous Playa Venao, a 2-mile long beach, is a half-moon bay facing south towards the Pacific Ocean (Fig. 1).

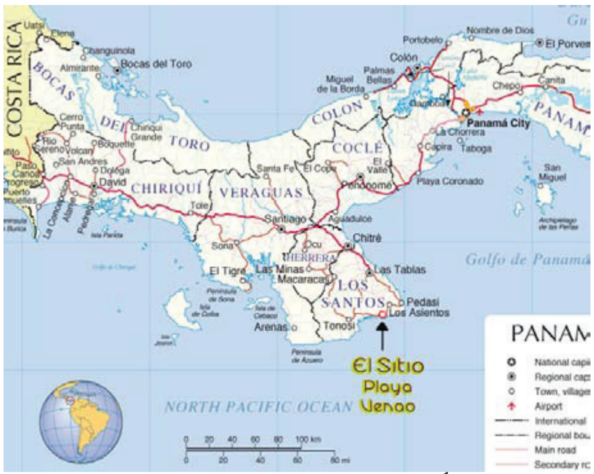


*Fig. 1: Map of Panama with the site (El Sitio).[1]*

In a cooling dependent climate like that of coastal Panama, reducing a building's annual cooling load is vital to energy efficient design. The prevailing design strategies include a well-ventilated and light building envelope, high-efficiency windows, controlled shading, and passive solar considerations. Net Zero Buildings further minimize cooling and electrical consumption loads by using high-efficiency mechanical ventilation and air conditioning (MVAC) equipment and solar powered lighting. Solar thermal systems are used to satisfy domestic hot water demands.

Zero Energy Buildings mean freedom from variable energy prices, a reduced cost of living, and higher resale values as demand increases for high-efficiency homes. In a remote region like Venao, where the supply of energy from the grid can be unstable and vulnerable to tropical storms, the importance of zero energy is magnified. Potential barriers include higher initial costs of construction and renovation, lack of reliable technology for installation, the lack of builder experience, and the reality that building occupants need to become more involved in daily maintenance and operation of the buildings in which they live and play (Tobias & Vavaroutsos, 2012).

This paper focuses on the Espave House, which is adjacent to a 140 hectare (346 acre) reforestation project in Eco Venao, Panama. The home is one of several 'low impact' accommodations in the region that supports activities at Playa Venao, Panama's best beach break (Fig. 2).

*Fig. 2: Playa Venao Beach Break.[1]*

### 3. METHOD AND ANALYSIS

The Espave House is a 2-story 125 square meter post-and-beam structure on an 11-acre lot (4.5 hectares). The site is located between two hills and overlooks the Pacific Ocean to the south and south-east (Fig. 3).

*Fig. 3: View to the south-east from site, Playa Venao.[2]*

The house has an open floor plan, 3 bedrooms, 3-1/2 bathrooms, living room, dining room, and kitchen (Fig. 4). The home maximizes passive ventilation and daylighting, uses photovoltaic panels to provide for 90% of the electrical load, supplies 100% of the domestic hot water load with a solar hot water system, and is equipped with energy efficient appliances.

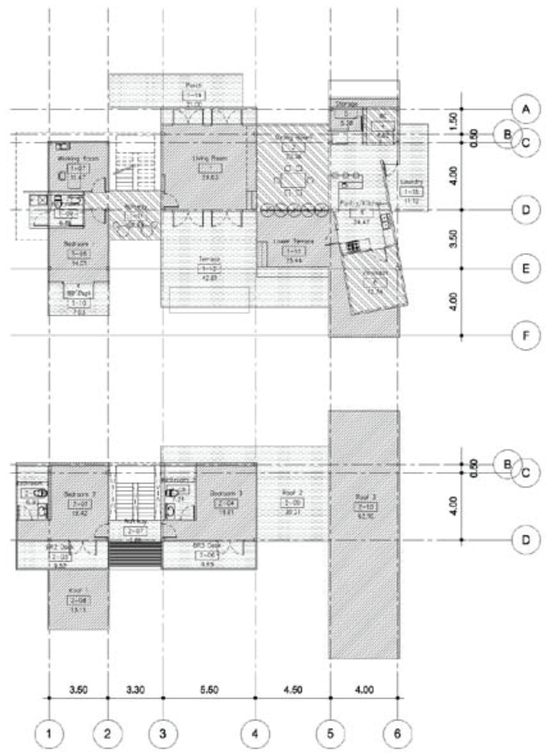


*Fig. 4: Plan of first and second floor.*

There are three analytical metrics that were adopted for this research: an examination of the home's overall massing, spatial organization, and orientation, an evaluation of the materials and resources needed for its construction, and analysis of its predicted MVAC system performance. The data was based on the narrative documents submitted by the owners during pre-design, design documents created during the design/build phase, and emails/telephone conversations with the contractors and owners.

## 4. RESULTS AND DISCUSSION

Panama is booming. It has the highest economic growth rate in the hemisphere. Manufacturing, mining, utilities, and construction together account for 19 percent of GDP. Private construction is one of the key growth areas in Panama and new condominiums, hotels, and office towers are being built across the country (CIA, 1995). These buildings consume natural resources and energy.

Despite the positive outlook for Panama's construction-related economic activities, very little has been done to define provisions for conservation and sustainability in the built environment. Building codes for private construction are based on minimum design requirements for safety, focusing only on fire prevention and egress. Durability, energy conservation, and minimum performance are not considered a high priority. In this paper, the Espave House is presented as a case study on how local attitudes towards sustainable design can be influenced.

The Espave House focused on site and climate as a starting point for low energy design. We mapped the site with regard to wind, sun, and rain to define building orientation, layout, massing, and footprint (Fig. 5).

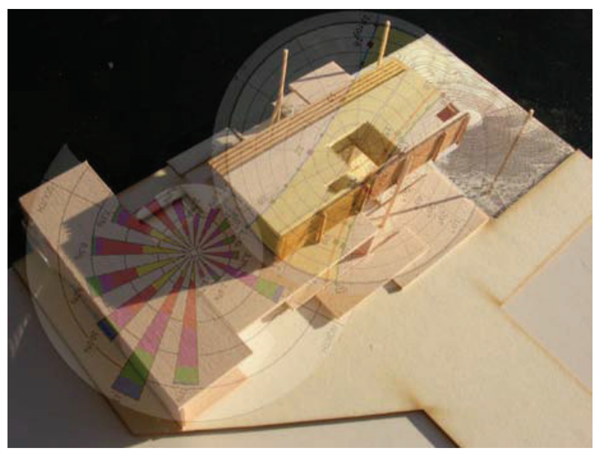

*Fig. 5: Site Planning and Analysis.*

Site mapping was an important first step in the design process given the sloping topography and wind conditions. Building footprint as well as the relative usable area of the home was an equally important issue as size is one of the most significant contributing factors to the resource efficiency and the environmental impact of building construction activities (Wilson & Boehland, 2005). The main difference between Espave House and other vacation homes in the region is that the Espave House is almost 30% smaller, which accounts for significantly less materials and resources, both in construction and operation.

The spatial organization of the Espave House is optimized working daylight and passive cooling and ventilation. The home has an open floor plan with permeable walls along a long south-facing axis that is mostly open to views of the ocean below. The house also utilizes very deep thresholds on the southern face that act as sun shades, allowing primarily indirect and diffuse light to the interior. The deep overhangs prevent direct solar radiation from raising interior temperatures during the day (Fig. 6). The shallow width of the house allows diffuse light to penetrate all the way to the north side. This eliminates the need for artificial lighting during daylight hours.

*Fig. 6: South-eastern elevation, deep overhangs.*

The eastern side of the house is subject to very strong and gusty winds, which we harnessed to create cross-currents within the house for passive cooling. We designed slit windows with slated shades that can be adjusted according to ventilation needs. Because of this, the house does not need air conditioning except for the very hottest and most humid days in the year (Fig. 7).

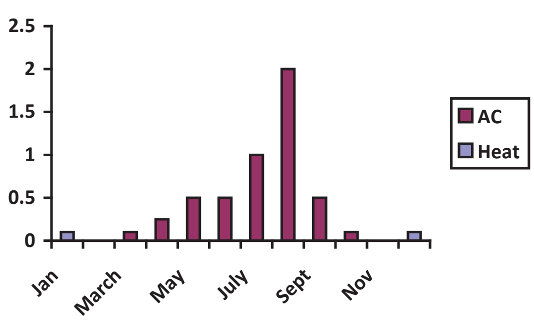


*Fig. 7: Average space conditioning kW.*

We also worked with the reforestation program at Eco-Venao and mapped out a solution involving tree and shrub plantings to create a shelter belt along the entire eastern façade. The reforestation efforts have been on-going for the past twenty years, converting degraded and abandoned agriculture and pasture lands back into the tropical forests that used to flourish in this region. Studies of shelter belts have shown that trees can provide wind breaks to reduce wind speed and alter the characteristics of air flow around them. It is well-known that the structural characteristics of shelterbelts and the individual tree are important factors influencing their effectiveness (Vigiak et al. 2003). The shelterbelt we designed on the eastern side of the Espave House was composed of Acacia, Macano, Balo, Guácimo, Teak and Balsa trees. These are known to rapidly develop large, dense crowns and attained canopy closure after just two years (Wishnie et al., 2007). We also hope that these species can stabilize soils in what has now become eroded and infertile land.

In general, maintaining comfortable temperatures with passive strategies is difficult, because there are no controls to ensure the interior spaces do not overheat or over-ventilate. To prevent overheating, a simple massing technique is employed along with second floor overhangs and a light colored exterior to prevent mitigate heat gains. We designed deep thresholds with the flooring as a thermal mass element. The thermal mass in the threshold is locally sourced stone tiles that absorb heat during the day, creating a thermal break between the interior floor system and the exterior shaded space. The thermal mass absorbs the heat from the sun during the day – like a heat storage battery – and at night, radiates the heat back to the atmosphere. This 12” (305 mm) stone slab helps to regulate the temperature of the house at around 78°F (25°C) with little need for air conditioning (Fig. 8).

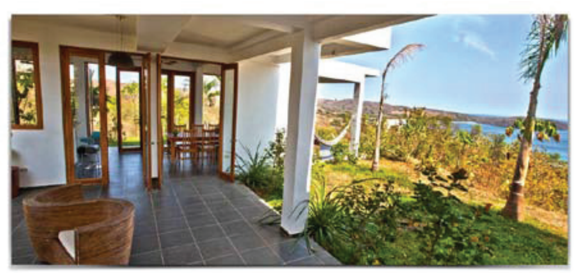

*Fig. 8: Thermal mass stone slab in threshold.*

In the Espave House, using locally sourced and sustainably harvested materials and products was an imperative for minimizing embodied energy. Building and construction activities worldwide consume three billion tons of raw materials each year (Roodman & Lenssen, 1995) and sustainable building materials can help reduce the environmental impacts associated with extraction, transport, processing, fabrication, installation, reuse, recycling, and disposal. Furthermore, due to the close proximity of the Eco-resort which would provide an additional source of rent income for the owners, we considered how the building could promote the basic principles of those who vacation at Eco Venao- conservation and durability.

The Espave House walls are post-and-beam construction using sustainably harvested teak pressure-treated wood. In general, it is unusual in Panama to construct walls out of wood, rather than concrete. But not only are wood walls cheaper to build, they have less embedded energy than concrete. Furthermore, teak is grown within 10 kilometers from the site, whereas concrete would have to be transported from a town 300 km away. Other local materials such as glass countertops and sustainably harvested clay tiling further reduce embodied energy. In addition, all paints and finishes are low/no VOC, and the white-painted reflective metal roof is highly durable.

The Espave home's exterior walls are constructed with light-colored materials that are punctuated with ventilation and/or window gaps to allow the interior to be passively daylit and ventilated. The mostly opaque walls on the north, east, and western facades are insulated with straw in the stud cavities, with a mixture of plasterboard and clay for sheathing. The entire wall assembly has an R-value of 3 °C-m$^2$/W (17 °F-ft$^2$-hr/BTU). The ceiling is insulated with fiberglass batts and has an R-value of 4 °C-m$^2$/W (23 °F-ft$^2$-hr/BTU). The roof is a metal deck that is painted white and reflective to help block radiative heat transfer. The roofing element is also from below ventilated to prevent heat transfer from its surface to the interior spaces. Double pane, low-e windows are used for additional energy efficiency. Whereas most homes in the area do not have any insulation and use jalousie windows that have no insulative or air sealing capacity at all, the Espave House outperforms its neighbors simply due to its construction specifications.

Moisture control is particularly important in the Panamanian climate and has a significant effect on building durability and occupant comfort. Bulk water (rain) penetration is controlled with well-placed down spouts and gutters to drain water away from the building, deep overhangs to keep water off the walls and windows, and free-draining building materials around the building perimeter. Free-draining materials such as crushed stone permits the flow of groundwater downwards and when properly installed, prevents water from collecting at the foundation walls and slab.

Due to an innovative passive dehumidification system, the Espave House can mainatain the level of relative humidity around 50-60% year-round. In conventional houses the relative humidity rises to about 70-90% during the summer season. The side effects of higher humidity are reduced comfort and the energy it takes to cool and dehumidify interior spaces. Furthermore, a typical house absorbs hundreds of gallons of water during the summer months and cooling system has to do more work to dry the interior at considerable energy expense (2254 KJ/kg or 970 BTU/lb of water).

The passive dehumidification system for the Espave House is a cold water plunge pool in a small covered pavilion connected to the southern-eastern part of the house. The plunge pool is a bi-level four square meter outdoor 'tub' that is designed to be like an outdoor hot tub (with cold water) for relaxation and play (Fig. 9). The water from the plunge pool is significantly colder than the surrounding air temperature, and serves a surface against which moisture from the humid air can condense. Ceiling fans and prevailing eastern winds help to circulate the cooled dehumidified air through open windows into the house.

*Fig. 9: Plunge pool passive dehumidification system.*

The final design strategy towards net zero energy in the Espave House are the energy systems. This includes energy consuming equipment as well as the energy generation systems. The first consideration is to size the major equipment in the home correctly and select systems that are very efficient. That includes the air-conditioner and water heater as well as the duct and piping systems that deliver air and water to the outlets. The next opportunity to reduce energy loads is to use higher efficiency lighting and appliances. Once the home's energy demand is reduced, a renewable energy production system (PV, in this case) is installed to provide the electricity used in the home and offset electricity supplied by the utility when averaged over the course of one year.

In the Espave House, the owners worked to eliminate or find less energy intensive alternatives for major household appliances. For example, they also choose to use a solar-thermal hot water system rather than an electric hot water heater, as is common in the area. Appliances like the wall-mounted air conditioning unit, refrigerator, laundry machine, and dishwasher were all Energy Star-rated top-of-the-line American products. Almost all lighting in the house is florescent and plug loads are unplugged or put on a switched outlet strip.

The energy production system is a 2 KW PV system that generates all the home’s electrical power. The PV is oriented due south to maximize yearly power output and achieve the lowest cost per watt. A 100-amp hour 48 volt battery pack can power the critical loads during a power outage when the sun is not shining. For the home’s domestic water load, a solar hot water system using 110 evacuated glass tube collectors (112 square feet; 10 square meters), coupled with a stainless steel hot water tank, and a circulator pump was installed. Once the tank has met the set point temperature, excess hot water from the collectors is used for the plunge pool.

## 5. CONCLUSION

Every building, no matter how well-conceived, designed, and operated, loses and gains heat, moisture, and air as a result of differences between indoor and outdoor conditions. These factors, to a large extent, determine the amount of energy a building will consume. There is a growing interest, driven by changes in the global climate, rising fuel prices, and attitudes of the public, in the design and construction of buildings that consume less energy. The house analyzed in this study illustrates that there are numerous strategies to achieve net zero energy for homes in tropical climates. The significance of this analysis, showing a wide range of possible strategies, indicate that there are a variety of different ways to reduce energy demand even in remote regions around the world.

There are no standard designs for zero energy homes. Shape, size, orientation, climate, equipment, occupancy behavior, and energy production systems are part of the range of decisions that must be considered. There are three primary areas that must be considered for *any* building that strives towards net zero site energy use. The first step is to focus on the overall architectural organization, size, orientation, massing, roof forms, and location, and to assess their contributions to overall building loads. Second, the building envelope must be characterized – in terms of its construction type, materials, insulation, and air and moisture barriers – to ensure reduced energy use and well as improved comfort for the building’s users. Only when these first two steps have been optimized can the building’s operational costs be lowered – by selecting efficient systems, appliances, and lighting. For each one of these areas of consideration, there are a variety of approaches – and much of it depends on the aesthetics, budget, and expertise of the design team and its ability to work closely together to optimize the functioning of the whole building as a system. In this case study, the owners and designers worked closely with the builders to ensure that site design, lighting, window fenestration, energy delivery systems, etc., were considered *together*, rather than discrete parts of the project. The results of such coordination (called integrated design) contributed to lowered first costs (PV system was sized smaller than originally estimated) and produced long term benefits (better humidity control due to efficient thermal envelope).

Future improvements in residential energy efficiency can be made by better modeling and monitoring of energy consumption data to determine where to make changes and how these decisions impact the environment. Simply accounting for net zero site energy use does not fully encompass the scope of the sustainable building movement. Other categories for concern, such as occupancy patterns and behavior, site selection and building location, water efficiency, indoor air quality, and construction resources, must be addressed. The development of accurate energy models that are dynamic and can calculate the complex interactions between various components ought to be used to propose energy conservation measures (ECMs). The process is iterative and necessary at all stages of design to inform the development of energy efficient housing and the systems within them. In the coming years, providing examples of successful net zero energy buildings and an accurate means to evaluate their environmental impact will help to facilitate the widespread acceptance of and enthusiasm about Net Zero Energy.

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# REPURPOSING RETORT POUCHES AS A RADIANT BARRIER:

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ABSTRACT: *We tested ways of repurposing food-grade retort pouches as a radiant barrier on corrugated steel roofs. The test barrier was fabricated by sewing together empty retort pouches. The test barrier was then fastened to corrugated steel roofs using three varied methods of application. Each assembly was tested as the roof of a 2' x 2' x 2' oriented strand board (OSB) model, constructed with nails and wood stakes. The testing surface was a 26" x 26" corrugated steel roof on each of the volumes. The test barrier was applied using the following methods: 1) clipped directly to the exterior surface of the corrugated steel, following the contours of the corrugation; 2) clipped to the roof's exterior leaving an air gap between the test barrier and the metal roof; and 3) clipped to the underside of the roof leaving an air gap between the test barrier and the metal roof. HOBO dataloggers were then placed inside each volume, resting on insulated platforms to avoid contact with the dirt floor.*

*Keywords: retort pouch, radiant barrier, shantytown*

## 1. INTRODUCTION

Shantytowns are a common solution for affordable housing throughout much of the world. They share a common problem of wide fluctuations in internal temperature, making them thermally uncomfortable. We wanted to investigate a way of improving the thermal comfort of the shanty houses using inexpensive, readily available materials. Another goal was also to reuse materials that would otherwise enter the waste stream. Retort pouches are widely used in Latin America, Asia, and Europe for food packaging, automotive fluids, detergents, and personal care products. In the U.S. Capri Sun®, Inc. was the first large volume commercial user. The U.S. military uses retort pouches to package meals-ready-to-eat (MREs) for soldiers in the field. They are used to a limited extent in the United States because the pouches and related machinery are not available from a domestic source.

Retort pouches are not recyclable because they are made by fusing metal and plastic together in such a way that they cannot be separated. Our goal was to repurpose retort packaging, an unrecyclable material, into something that would make the dwellings thermally comfortable. Most shantytown houses are constructed out of corrugated sheet metal and plywood or oriented strand board. (Silva, 2012) We are conjecturing that these small dwellings get too hot during high temperature days because the corrugated sheet metal conducts heat into the interior spaces. Thus, we hope to develop a type of barrier that will protect the dwellings from extreme thermal fluctuations.

We experimented using Capri Sun® retort pouches to form a durable sheet to test as a radiant barrier. We sewed their edges together using cotton thread and a zigzag stitch. We tested the sheet as part of the roof assembly in the following three ways. (1) The test sheet was applied as an exterior radiant barrier to the corrugated steel roof. We placed the sheet on top of the corrugations and did not press it into the valleys, so there was an air gap between the test sheet and every other corrugation ridge.

This meant that the test sheet, in this application, did not touch all of the surface area of the roof. (2) We tested the sheet as part of the interior assembly of the roof, leaving an air gap as mentioned before. (3) We also tested the sheet as an exterior radiant barrier in direct contact with all the surface area of the roof.

We predicted that the water resistance of the retort pouch, as well as the aluminium component, would make the pouch the optimal candidate for repurposing it as a radiant barrier. Retort pouches are unrecyclable, typically made of a material of four layers of polyester PET, nylon bi-oriented polyamide, aluminium, food-grade case polypropylene or CPP bonded together in a lamination machine. (Selke, 1997)

*Fig. 1: Shantytown in Lima, Peru*

The data for this study was collected over the course of one week in February and early March in Eugene, Oregon. The weather at the time was above freezing temperature, moderately rainy and cloud covered.

## 2. PROBLEM AND HYPOTHESIS

Problem: Corrugated steel roofs are insufficient radiant barriers in hot climates where the interior temperature falls well outside of the thermal comfort zone.

Hypothesis: Repurposing retort packaging pouches into a sewn sheet will prove to be an effective and economical radiant barrier. The interior thermal comfort achieved due to the retort pouch radiant barrier will meet or exceed the performance of a commercially available radiant barrier.

## 3. METHODOLOGY AND EQUIPMENT

3.1 Glossary

*peak hours:* hours of greatest heat gain and solar radiation, from 10 a.m. to 5 p.m.

*retort packaging:* a pouch consisting of four layers bonded in a lamination machine, polyester PET, nylon bi-oriented polyamide, aluminium, food-grade case polypropylene or CPP (Selke, 1997)

*radiant barrier:* material that is a poor re-transmitter of radiant energy


*Fig. 2: Capri Sun® retort pouch*

3.2 Construction of Test Shanty Houses

We constructed five models of shanty houses to test different ways of using the test radiant barrier as part of the roof assembly. Each model was a box assembled using four 2' x 2' sheets of oriented strand board leaving two sides open (top and bottom). We nailed the sides to wooden stakes at the four corners of the box, using 1-1/2" nails. A 26" x 26" sheet of corrugated metal with one of the radiant barriers being tested was then nailed to the oriented strand board box (OSB) opening to simulate a shanty house roof (Fig. 3). The bottom opening of the box was placed on bare earth in a raised planter bed.

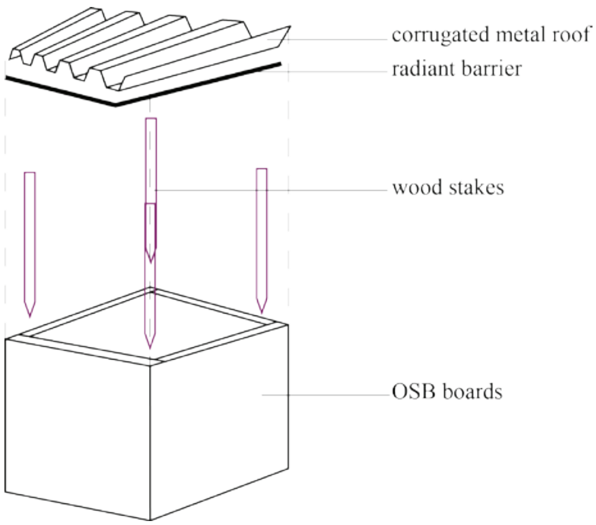


*Fig. 3: Diagram of model shanty house construction*

3.3 Testing Five Roof Assemblies of Shanty Houses

We constructed five model shanty houses to measure the thermal conditions caused by different application methods of retort packaging radiant barrier. The five different shanty houses were as follows:

1) Control Shanty: oriented strand board box with a corrugated sheet metal nailed on top (Fig.4)

2) Direct Contact Shanty: Retort pouch radiant barrier clipped directly onto the corrugated sheet metal, following the contours of the corrugation (Fig. 5)

3) Exterior Barrier Shanty: Retort pouch radiant barrier, clipped flat across the exterior of the metal roof, leaving an air space in the corrugated voids (Fig. 6)

4) Interior Barrier Shanty: Retort pouch barrier, clipped flat across the interior of the metal roof, leaving an air space in the corrugated voids (Fig. 7)

5) Commercial Brand Radiant Barrier Shanty: *Reflectix®* radiant barrier is installed, per instructions, flat across the interior of the metal roof (Fig. 8)

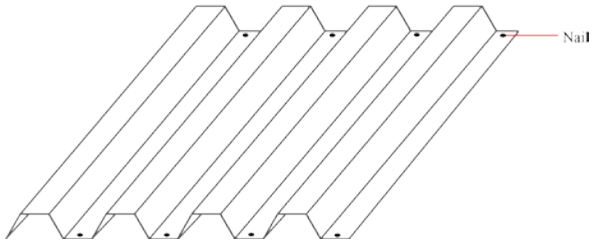


*Fig. 4 Control roof: corrugated sheet metal only*

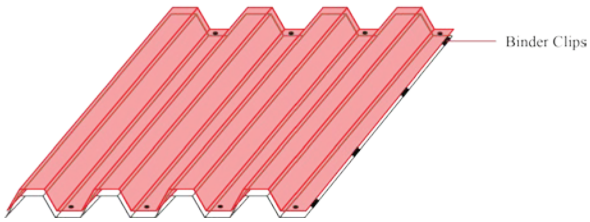


*Fig. 5 Direct contact: Retort pouch barrier placed in direct contact with sheet metal, following corrugations*

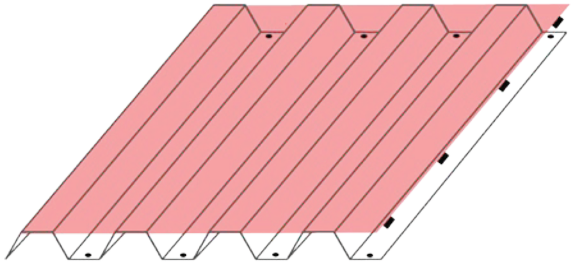

*Fig. 6 Exterior radiant barrier: Retort pouch barrier placed flat against sheet metal, with air gap*

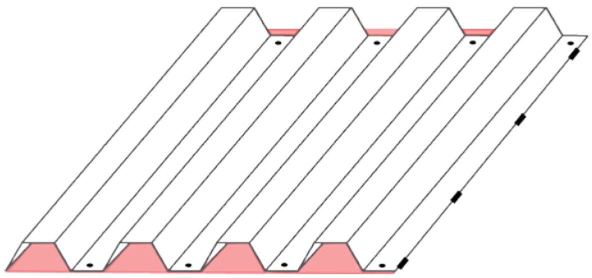

*Fig. 7 Interior radiant barrier: Retort pouch barrier placed flat against sheet metal, with air gap*

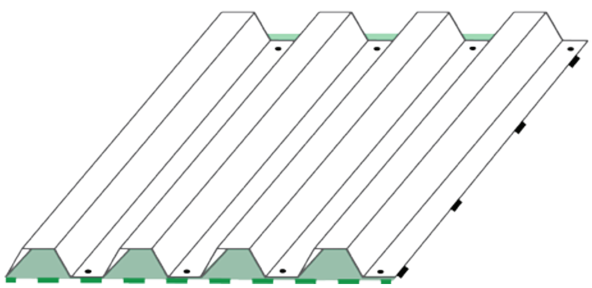

*Fig. 8 Commercial radiant barrier: Installed on the underside of metal roof, as per manufacturer instructions*

3.4 Construction of Test Radiant Barrier
To form the test radiant barrier, we emptied, washed, and dried Capri Sun® retort pouches. We taped seven pouches together horizontally and sewed them with black cotton thread in a zigzag. Five horizontal rows were then sewed together to create a 26"x26" sheet of retort pouch test radiant barrier. All sewing was done by a sewing machine to ensure a consistent connection throughout all the sheets. Each radiant barrier to be tested was then clipped to the metal roof in the ways described in the previous section.

3.5 Data Collection Method
Inside each of the five shanties we placed a HOBO data collector sitting on a corrugated cardboard box, which was wrapped in a plastic bag. These plastic covered cardboard boxes were used to prevent the HOBOs' data from being affected by the moisture and temperature of the dirt floor. Additionally, one HOBO was hung from a tree in the vicinity of the shanties to record the outside temperature.

We set the HOBOs to collect data at 30-minute intervals for 13 days. We assumed that the shanties with the retort pouch radiant barrier would have a greater difference in temperature (interior to exterior) compared to the Control Shanty.

3.6 Equipment and Usage Conditions
Equipment:
- 20 – 2'x2' oriented strand board boards
- 5 – 26"x26" Corrugated metal roofs
- 3 – 26" x26" Sheets of Retort Pouch Test Radiant Barrier
- 3 – 26"x26" Sheets of *Reflectix*® Radiant Barrier
- 6 – HOBO data collectors
- 1 – Spool of 100% cotton thread

Factors that might affect results:
- Geographic location
- Wintertime conditions
- Individual shanty's location at test site (wind, shade, weather changes, moisture in air, moisture in ground)

## 4. RESULTS

The HOBO dataloggers recorded temperature data over 13 days, with an average outside peak temperature of 59.1° F. The Control Shanty held an average temperature of 53.2˚F during the peak hours. Interior Retort Barrier and Exterior Retort Barrier had similar results. Their increase in temperature was 2˚F less than the Control.

The Commercial Radiant Barrier kept the interior temperature an average of 3°F cooler than the control. The Direct Contact Retort Barrier, where the sheet was in direct contact with all the exterior surface area of the roof, had the best performance out of the retort test group. It kept the interior temperature an average of 3°F cooler than the control. Because of its direct application to the peaks and valleys of the corrugated steel, we believe that it provided a more effective radiant protection, blocking the sun's heat before it had the opportunity to enter the volume of the shack. The retort pouch radiant barrier that we constructed was as effective as the commercially available product.

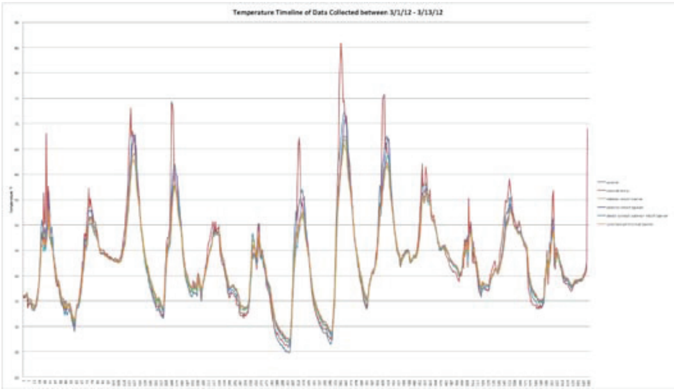


*Fig. 9 Temperature fluctuations during testing period, March 1-13, 2012*

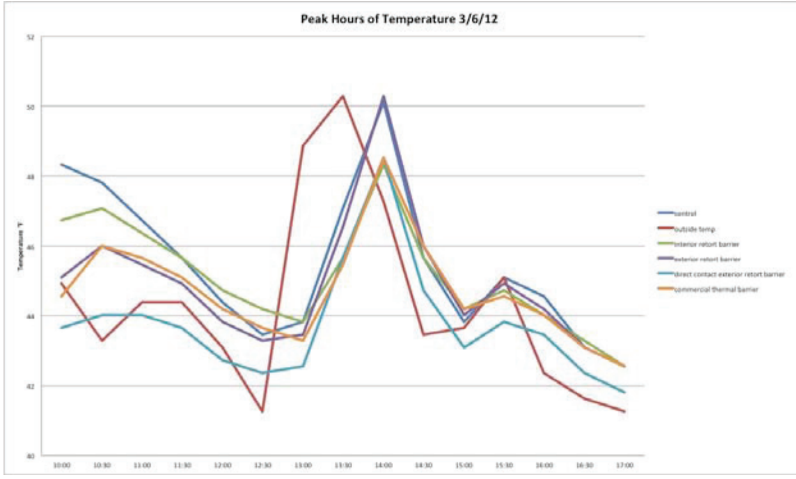


*Fig. 10 Peak hours of temperature on March 6, 2012, lowest temperature day during testing period*

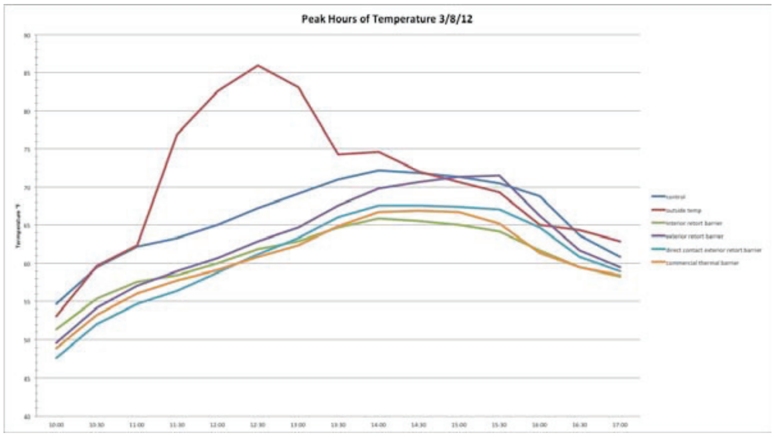


*Fig. 11 Peak hours of temperature on March 8, 2012, highest temperature day during testing period*

## 5. DESIGN LESSONS LEARNED

This research project provided us with information on the construction and thermal qualities of shantytowns as well as the conditions that make thermal stability possible. We wanted to experiment with a material that currently cannot be recycled. Choosing to repurpose a non-recyclable material into a radiant barrier would have positive thermal and environmental effects. We also learned that the width of streets and proximity of shanties affects the temperatures of shanties throughout the year.

Further research could be done with the material as a form of insulation on the walls of the shantytowns. Since we looked to simplified our study we did not test the radiant barrier with other materials like brick and concrete as the materials of the structure. It is possible that these materials may alter the effectiveness of the retort pouch radiant barrier.

Due to our test location in Eugene, Oregon our thermal comparison with less temperate climates is limited. We would like to continue our study by testing the radiant barrier's effectiveness in places with more extreme temperatures.

## 6. ACKNOWLEDGEMENTS.

Thank you to Professor Alison Kwok for her inspiring instruction in ECS1 at the University of Oregon. We are also extremely grateful to the Society of Building Science Educators (SBSE) for their support of our travel to the BESS 2013 conference.

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# **Towards Zero Energy House Integrated Design**: Simulation for Optimum Thermal Mass

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*ABSTRACT: This paper investigates current research in the design of an insulated geopolymer system that was used on walls and floors of a net zero energy house. The house design is fuelled completely by solar power designed for humid southern US climate to promote high performance building while using the traditional passive strategies. The study uses the Solar Decathlon Competition as a testbed to answer the questions raised by the idea of parametrically design the facade that is made out of zero carbon geopolymer concrete.*

*The house design employs a new material of precast carbon geopolymer concrete panel system, act as thermal mass and which is inlaid with a capillary system capable of circulating cooling and heating liquid to maintain a consistent interior temperature. The capillary tubes are connected to the heat exchangers on the roof. The thermal function of thermal mass was investigated using simulation program and dynamic thermal properties calculation program. The internal wall temperature changes more slowly than the conventional wall construction leading to more stable indoor temperature.*
*In an effort to improve the efficiency of the heat transfer in the thermal mass and capillary system by creating more volume and surface area, we have introduced a complex parametric analysis while maintaining the appropriate thicknesses for the capillary system to ideally function.*

*A one-dimensional model further verified these analyses, and the calculated results by thermal calculation program are in good agreement with the model. We conclude that the thermal mass wall does have the ability to store heat during the daytime and release it back at night, but in hot humid climates with high ambient temperature and intense sunlight, more heat will be stored than can be transferred back outside at night through capillary tubes and heat exchangers on the roof. As a result, an increased cooling energy will be required.*

*Keywords: energy, thermal mass, simulation, performance.*

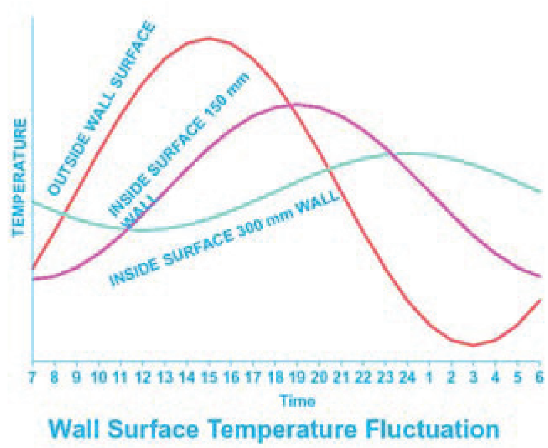
## 1. INTRODUCTION

Utilization of concrete as a major construction material is a worldwide phenomenon and the concrete industry is the largest user of natural resources in the world. This use of concrete is driving the massive global production of cement, estimated at over 2.8 billion tonnes according to recent industry data. Associated with this is the inevitable carbon dioxide emissions estimated to be responsible for 5 to 7% of the total global production of carbon dioxide.
Geopolymer concrete is concrete which does not utilize any Portland cement in its production. Rather, the binder is produced by the reaction of an alkaline liquid with a source material that is rich in silica and alumina. Geopolymer material properties are the same as cement concrete.

Thermal mass is a property that allows a material to absorb, store and release heat to surrounding space. Thermal mass can be used both for winter and summer and act as storage for both heat and cold as they heat up and cool down relatively slowly. Concrete is known to provide thermal mass but the time lag for dense concrete is not readily available. This study uses the simulation program and calculation program, dynamic thermal properties calculation to show the energy consumption of the Solar Decathlon house and the time lag of specific thickness of concrete on the façade. The study looks at how different interior concrete wall thicknesses affect the time lag of the material and deciding through the tests which thickness produces the greatest time lag for the house. It is used as a means to heat interior spaces during the winter months using the heat from the sun during the day, which is then released during the night, helping to keep the air temperature of space at a more constant level. The same procedure occurs in the summer as in the winter just a reverse of cool storage versus hot storage. The desired temperature fluctuation is represented by the yellow line in the graph below and stays at a more constant temperature.

*Fig. 1: Desired temperature for high and low thermal mass*

Not all material has good thermal mass and the material varies by region and climate as well as the location within the building. In diurnal climates, where there is a large temperature difference between the day and night. Throughout the night, when the outside temperature drops considerably, the heat from the walls radiate out into the surrounding air helping to keep the interior spaces from getting too cold, allowing the walls to absorb heat again the next day.



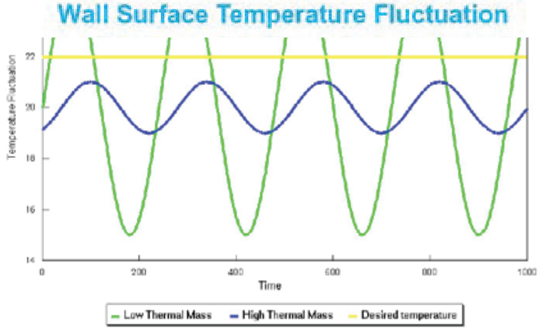




*Fig. 2: Wall Surface Temperature Fluctuation*

In humid climates where the temperature is more constant throughout a twenty-four period, the thermal mass like concrete can absorb low angle winter sunlight but is insulated from heat loss. In these instances, additional heating or cooling is needed to create a temperature range great enough.

A house for a young couple designed for solar decathlon needs to be able to regulate thermal control within each of its rooms. By using geopolymer concrete on the south facing walls of the house, it is taking advantage of the inherent properties of dense material in order to provide well-regulated rooms that work with environment.

## 2. METHODOLOGY

This approach began by recognizing which wall would affect the interior environment of the house the most and what thickness range needed to be tested for the testing. The four five, and six inch wall thicknesses of the interior concrete wall, the computer program Design Builder was utilized to run simulations in order to get the different energy usages. The information was then converted to charts, which were analyzed to determine which wall thickness performed best. The simulation used time lag for the concrete walls but did not specifically break down the date. To determine time lag within the system another program, the dynamic Thermal Property Calculator created by the concrete centre and Arup was used for each of the interior wall thickness chosen. The program permits for a number of inputs to be added to the system to determine lag time such as specific material type, material thickness, density and its properties.

Once these were inputted according to our material, location and individual thicknesses per test, the dynamic Thermal property calculator analyzed the data returned a graph and table of the lag time of the material over a specified time period of twenty-four hours. The graphs were studied and the individual time lags were put into a graph in order to study them more. After combining the information from Design builder and the results from the dynamic Thermal Property Calculator an analysis could be conducted and an idea wall could be determined.

## 3. FINDINGS AND RESULTS

The following tests were run for the building. The information consisted of three walls with differing interior dimensions of depth. Each wall was comprised of three inches of exterior concrete, six inches of insulation and an interior concrete wall. The interior wall depth tested were four, five and six inches. The following image show the three constants within each test, each of them were measured in kBtu.

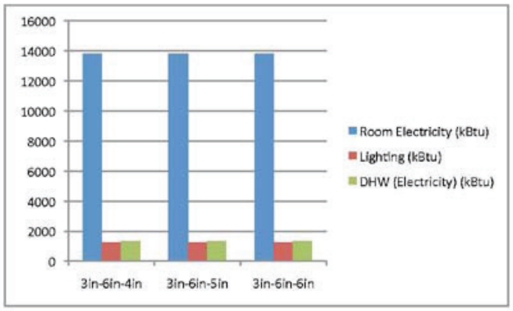



*Fig. 3 Energy analysis*

The results analyze the room electricity, lighting and DHW. These factors remain constant to allow a more precise evaluation of the overall calculated energy results of the solar decathlon house.

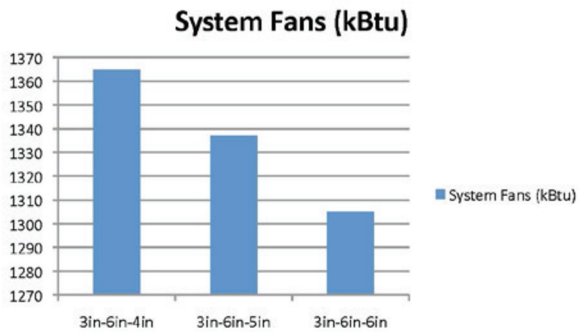



*Fig. 4: System fan results*

The image above was the anlysis of the system fans within the house. As the wall thickened from four to six inches the use of the fans decreased from 1,364 kBTU to 1,337 with five inch wall. There was a 2.1 percent drop in usage from the four to five inch wall and a 2.5 percent drop in usage from the five to six inch wall. Data from the chart shows the thickness of the wall was allowing either warmer or cooler air to remain in the space for a longer amount of time.

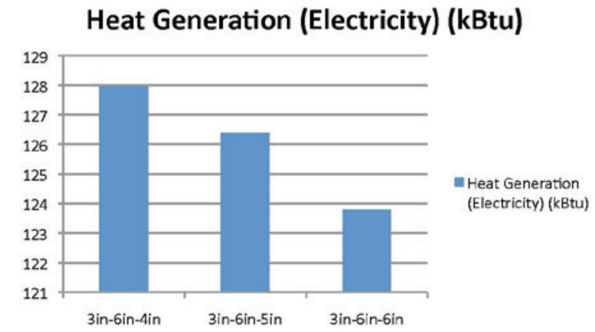



*Fig. 5: Heating load*

The image above analyzes the heat generation and was directly related to electricity usage and was also measured in kBtu. The usage of electricity was decreased with the added thickness of the interior wall. From the four to five inch wall there was a drop in kBtu from 127.98 to 126.38. That was a 1.3 % drop in usage. The six-inch wall drops to 123 kBtu annual usage, which was another 2.1% drop from the change of five to six inch wall thickness. The thickness of the wall allowed for warmer air to be kept within the house to reduce the amount of heating needed to keep the house at a comfortable temperature.

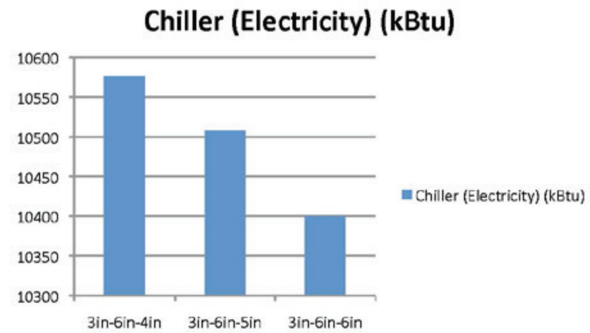



*Fig. 6: Cooling load*

The image shows that the thicker the wall becomes the less electricity was used. The four wall to five inch wall resulted in 1.1 percent drop of annual amount usage.

Dynamic Thermal Property Calculator
Design builder has time lag built into the program. The graphs below are the findings of the potential thermal time lags of the four, five, and six inch interior geopolymer wall. Each test was over a twenty four hour prior and an internal surface resistance of 0.13 m2 K/W, which is a default for ISO 6946. For the calculations, we used an exposed precast dense concrete with the following constants:

| Density [kg/m³] | Specific heat capacity [J/kg/K] | Thermal conductivity [W/m/K] |
|---|---|---|
| 2400 | 750 | 1.56 |

*Table 1: Geopolymer concrete properties*

for each of the calculations, the only changing factor was the wall thickness.

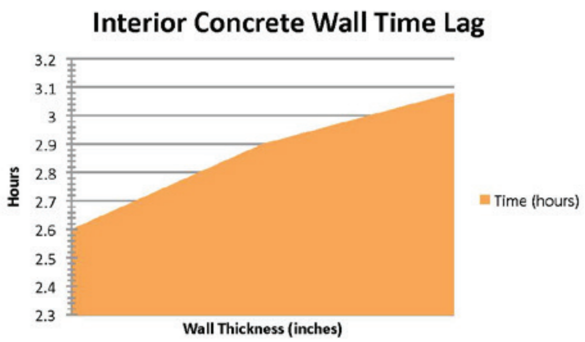
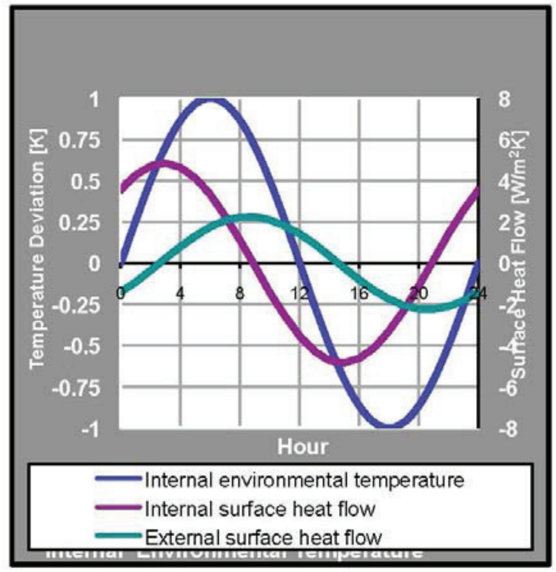



*Fig. 7: Time lag*

The image shows that a four inch thick concrete wall will have a time lag of 2.6 hours, a five inch concrete wall will have a time lag of 2.9 hours and a six inch thick concrete wall will have a 3.08 hour time lag. There was a 10.4% increase in time lag between the four and five inch thick walls while there was a 5.9% increase from the five inch wall to the six inch wall. There was a 15.6% increase in time lag between the four and six inch concrete walls.

The following image show the heat flow over a twenty-four hour period of time for each of the three wall thicknesses. Each image shows the internal temperature of the room in relation to the internal and external surface heat flow of the concrete wall over the twenty four hour time period.




4" Concrete Wall

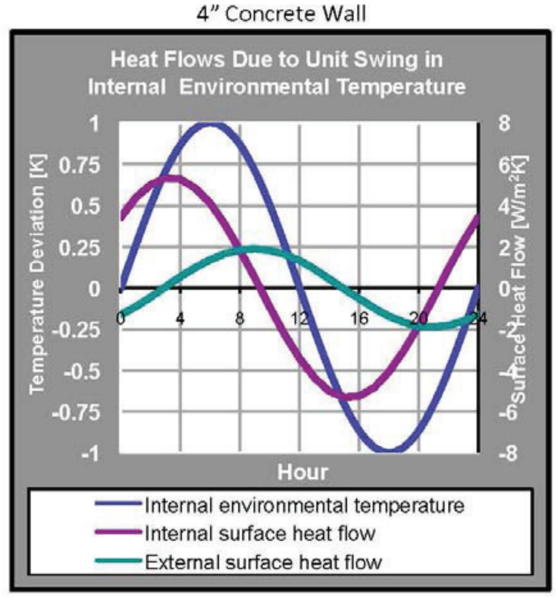



*Fig. 8: Four inch and five inch concrete wall time lag*

*Fig. 9: 6 inch concrete wall time lag*

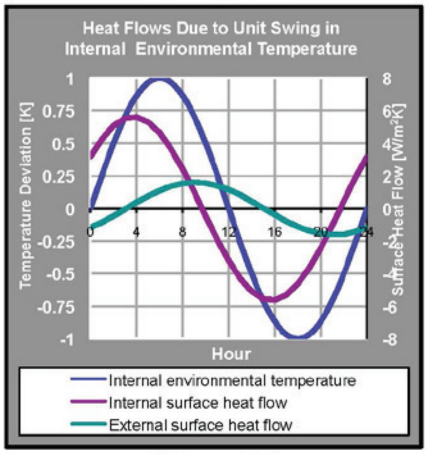
## 4. ANALYSIS

Through analysis the thicker wall required less energy usage by the heat generation and cooling loads.

Energy consumption:

The results that have been calculated for the hot humid climate have consistent information. Each offers the same ideas with respective information

5" Concrete Wall




6" Concrete Wall

about different data being collected within the house. Through analysis, the thicker interior wall required less energy

## 5. CONCLUSION

Our focus for this study was to see if by increasing the interior concrete wall thickness, energy consumption would be reduced, we then ran calculations to see how the time lag was affected by the thickness change and if it was significant enough to affect the energy consumption. While the study proved that an insulated wall systems work well as thermal storage, built wall testing proved the simulations to be not as accurate as the real world resting, requiring extra cooling energy to be used.

Our simulation shows a decrease in energy consumption from four inches to six inches in charlotte. Further testing proved that there is a maximum depth of concrete at which point energy consumption will increase due to an increased time lag that would require much time for heat transfer to occur over the twenty-four hour period.

For our purposes, the data above shows that a two-inch increase of the interior concrete wall will contribute to a reduction of energy usage for the Solar Decathlon House. Simultaneously, the dynamic Property Calculation test shows that the two-inch increase in concrete is a significant jump for the time lag. Combined this data shows that a six inch thick interior concrete would be more beneficial that a four or five inch interior concrete wall due to an increased time lag that would require too much time for heat transfer to occur over the twenty four hour period.

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# Value Management and Energy Management Corporation in Construction Projects to achieve Sustainable Architecture

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*ABSTRACT: Nowadays considering to the efficient use of funds and resources, on the one hand and improving the quality and performance of construction projects, especially in the energy sector on the other hand is one of the most challenging issues of the construction industry as one of the largest energy consumers in all industries ,so this paper expresses the importance of the use of value management as a method of comprehensive evaluation of projects in all sectors to choose the best performance alternative for efficiency and energy management systems throughout the project lifecycle. In order to achieve sustainable development and finally for clarifying and importance of this topic ,this paper presents how to use the analytical methods of value management during the three phases of design, construction and operation of the project along the construction project briefly.*

*Key-words: energy management, value management, construction phases, energy efficiency, cost, sustainability*

## 1. INTRODUCTION

Today limited energy resources, increasing the high energy consumption production and prevent the harmful effects of fossil energy consumption by optimizing the resources usage, have played essential role in maintaining sustainable development goals in world. So a variety of methods and patterns of work in optimal selection process have been caused.

One of them is related to improving the value of projects such as value analysis, value management and value engineering. Accordingly, the engineering and value management as a systematic and structured methodology determine functional implementation of projects by recognizing the value criteria. However, the management is a new concept in the construction industry, but the footprint of its concept can be seen in five roots (Avoid idleness, attention to people, Self-reliance, Static and Introversion) in original, traditional and vernacular Iranian architecture clearly which determine the importance of value management in construction projects. The proposals, after evaluation, are developed and became as the practical recommendations. However, the fact that management and energy efficiency is one of the concerns in order to sustainability development in all

parts of the energy industry, particularly in the construction industry, selection of management systems and energy efficiency tools in accordance with the project's requirements and specifications in the entire life of the project is one of the most considerable parts. This paper according to all weaknesses and shortcomings in the selection and implementation of energy management systems and optimization in construction projects expresses the necessity of energy management and value management integration throughout the project's life through the presentation the correct definition of value and performance management capabilities as a new tool includes a comprehensive data management, quality management, cost management and time management to select the best energy efficiency system and energy management and controlling comply with special features and requirements of every project.

## 2. CONSTRUCTION PROJECT PHASES

"A project is a series of tasks, arranged in a defined sequence or relationship that produces a pre-defined output or effect. A project always includes of start, middle and end" (William, 1999). Normally, whole life cycle of construction projects from start to demolition includes three phases:

| Design phase (D) | Construction Phase(C ) | Operations Phase(O) |
|---|---|---|
| D1:Project planning, feasibility study | C1: construction planning and construction detailing | O1: Sales |
| D2: conceptualization, programming and cost planning | C2: construction, manufacturing and procurement | O2: occupancy and operations |
| D3: architectural, structural and systems design | C3: commissioning, as-built and handover | O2: asset management and facility maintenance |
| D4: analysis, detailing, coordination and specification | C4: installation and testing and acceptance | O4: decommissioning and major re-programming |

*Table 1: Project Lifecycle Phases and sub-Phases, (William, 1999)*

## 3. VALUE MANAGEMENT IN CONSTRUCTION PROJECT

Value management is an organized and systematic process for decision-making based on team work. This process wants to reach the maximum value of the project by best solutions through minimal cost and resource consumption with consider to preservation the performance quality. In construction industry value management process consist of key factors groups (architects, engineers and construction managers) during the entire project (phases one, two and three) that pursue to review process, the creation of new ideas, does assessment and decision making.

3.1. Value Management Indicators & Process

Value management (VM) process consists of some consecutive steps as you can see in fig1 (Monavarian, 2001). At first, during the assessed step, value manager deals with the definition of standards and indicators with different importance degrees and the select the best and most appropriate action based on the criteria due to the nature and characteristics of the project and plan. Normally, most important value management criteria in construction project are shown in fig2.

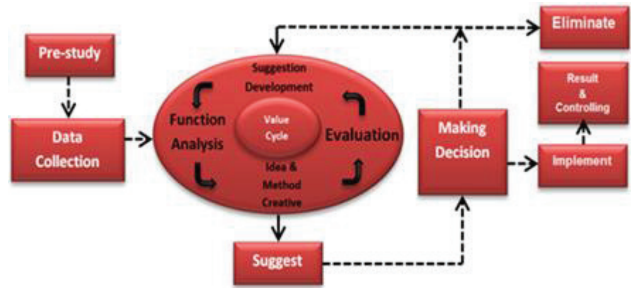



*Fig.1: VM Process, (Monavarian, 2001)*

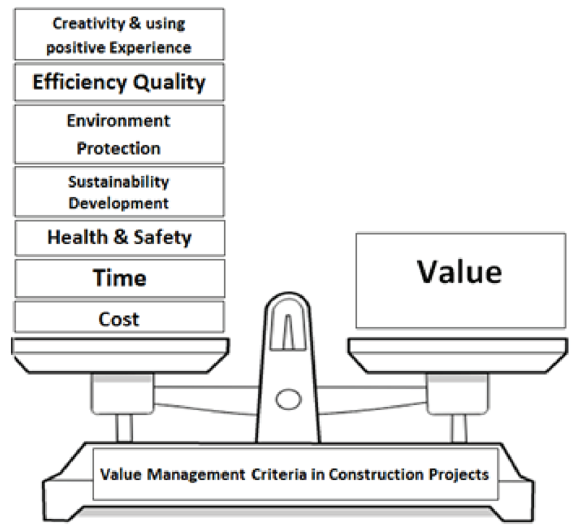



*Fig.2: VM Criteria*

## 4. ENERGY MANAGEMENT IN CONSTRUCTION PROJECT

Energy management (EM) refers to the set of methods and measures which are performed in the systems, processes and projects of the correct use of energy and maximize the benefits and minimize the costs or harmful environmental effects, without reducing the quality of products or service.

4.1. Energy Management Goals and Process

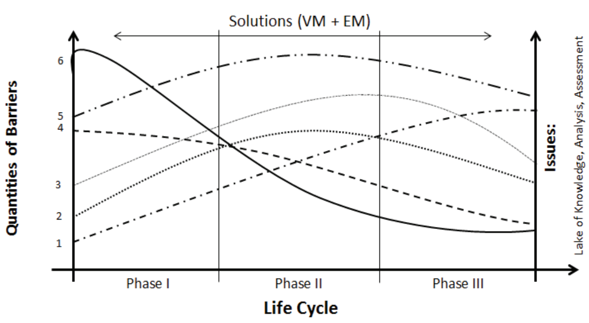
A. Improve energy efficiency, reduce energy consumption and therefore reduce costs.
B. Greater use of natural and green energy resources and fossil energy sources preservation.

Environmental pollution caused by energy consumption (Fig.3).


*Fig.3: EM Process (Department of Alternative Energy Development and Efficiency Energy Conservation Center Thailand, 2005)*

4.2. Barriers to Energy Management

Generally one of the main causes of the problems and obstacles in the implementation of management and energy efficiency is lack of knowledge and a comprehensive system of evaluation and analysis of opportunities and needs. Below the main barriers during project construction process and their value and quantity depends on the type of phase is shown (fig.4).




*1. Material & Equipment Problems, 2.Time Problems 3. Social Problems, 4. Problem of Knowledge 5.Economic Problems, 6. Lake of Motivation*

*Fig.4: barrier to EM*

## 5. VM + EM IN PROJECT PROCESS

In order to energy management system one of the measures is combining with the method of value management in whole of the project phases because the characteristics and capabilities of this process can have a positive impact on the obstacles and increasing energy efficiency.

5.1. VM +EM Indicators in Phases

In design phase process architects follow their design approaching to the interface point of environmental, economic and social impacts of decisions. There is an essential need for preparing a list of methods to outfit our buildings during the design, Also it is necessary to develop many appropriate methods for the assessment of energy efficiency in the construction industry.

Through this process we have some factors and indicators according the general surveys and specific surveys based on the specific area while they are coherence and having the same goals throughout the process, each one is applicable and practical in one of the project's phases (design, construction and operation) that the design team should be notice about all of them to access the best solutions and measures during the project's process. Some indicators are mentioned in following table which demonstrates that design phase is more important so all indicators must be considered in each phase according to other two phases (Table 2). (Kanagaraj & Ashwin, 2011, Yulan Yang & Baizhan, 2010, Zhou & Mark & Levine & Price, 2009, Western Cape Department of Environmental Affairs and Development Planning, 2008)

5.2. VM + EM Process in Phases

As you can see in Fig.5 the most important part of the process is evaluation step. As an example in a (VM + EM) process with mentione1d features in order to choosing a proper heating and cooling system, the implementation of the evaluation step is explained in following.

## 6. CASE-STUDY

Evaluation step in VM + EM process

In this project VM+EM team tries to choose the proper ventilation system for an official building according to the following features and conditions.

6.1. Data Collection

Area: 500 m2 (25*20m)

Location: Main Square of city, Yazd, Iran
Specification: developing city with traditional urban context
Climate: hot and dry in the desert region.
Owner demands: 1-symbolic design based on company's logo, 2-with third floors, 3- Function: official building some residential suite for staff

| Phase I. Design | Phase II. construction | Phase III. operation |
|---|---|---|
| cost & quality conservation | Implemented projects & plans by the low-energy's method | Operation & maintenance standards |
| Location& Infrastructure of building | Use the best insulation materials(walls, roofs, floors) | Standard for monitoring |
| Minimize the energy resources consumption | Providing time and resources program for the construction phase to reduce energy in the manufacturing process | Control of air conditioning system |
| use of renewable energy sources | | |
| Function of place | Use materials and resources near the site to waste less energy | Periodical Temperatures measurement |
| Using innovative techniques | Minimize the energy resources consumption in the construction site | Minimize the energy resources consumption during operation |
| Orientation and form of building | Transportation | Awareness of energy conservation |
| Density of residential building area | Lighting of the site | Monitoring of indoor co2 |
| Color of external building envelopes | Management of construction waste & Recycle of building materials | Controlling & monitoring energy systems in the building |
| Shading coefficient of external windows | Construction site specification | Property use of pumped systems |
| Outdoor plant covering area & roof | Safety | Residents training, social impact |
| Environment-friendly labeling of building facilities | Use of green building materials | Integrate facility upgrades & equipment replacement |
| Water conservation | Lift facilities | Emission of greenhouse gasses |
| Green power | Indirect use of renewable energy resources | Living specifications of resident |
| Thermal properties of building envelope | Use of solar energy in the site | Resident's health & safety |
| Use of ground heat | Renewable & low carbon energy sources in the site | Optimization of energy use, improvement of ventilation, Air conditioning facilities efficiency |
| Natural lighting & outdoor | Construction innovation techniques | Developing & enforcing |

| scenery | using | retrofitting |
|---|---|---|
| Use of solar energy | Hot water supply in the site | energy consumption auditing |
| Use of green building materials | Window double installing | Management of building operation |
| Improvement of ventilation efficiency | Use of glazing systems method | Energy-saving Retrofits for Existing Buildings |
| Humidity of the indoor thermal environment | | |
| Hourly heating & cooling load calculation | Natural ventilation in the site | Increase general energy awareness |

*Table 2: VM +EM indicators in phases*

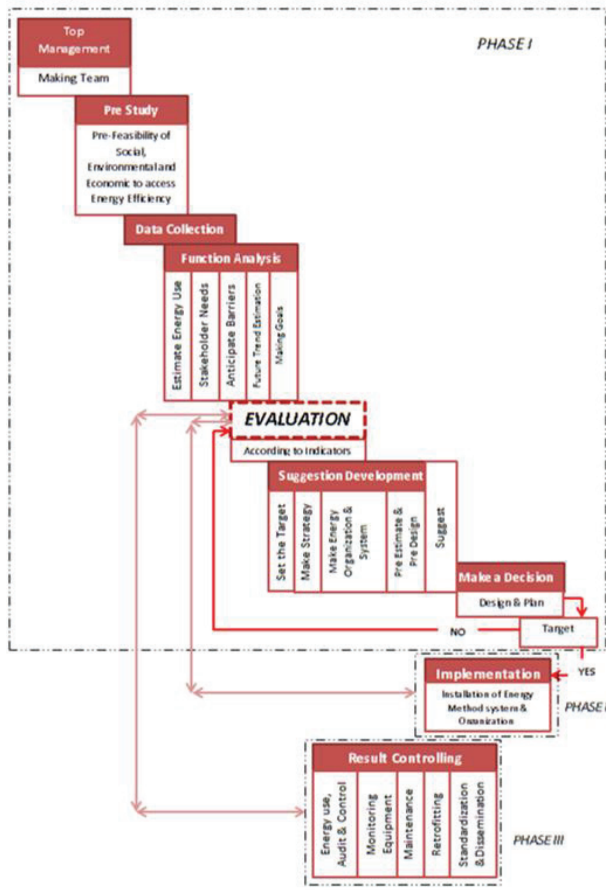



*Fig.5: VM+EM Process in Construction Project*

6.2. Suggest
Alternative 1-using climatic architecture - controlling temperature by dimension of window
Alternative 2- using smart Heating and cooling systems of building

6.3. Evaluation Step
The pervious Evaluation Step mentioned in Fig.5, show in detailing in table 3.

Although based on project's features and needs, the scores of the alternative "2" is more than alternative "1" , but since the weather is so suitable for the use of natural resources (solar energy), so in this step the team offer the combination of Solar Panel and Smart System according to the options assessment. This new alternative will be assessed and analyzed again to be implemented if it is through the project's aims.

| Phase | Criteria | Alternative 1 Criteria | Alternative 1 point | score | Alternative 2 Criteria | Alternative 2 point | score |
|---|---|---|---|---|---|---|---|
| I | Cost | 4 | 8 | 32 | 4 | 4 | 16 |
| | Energy efficiency | 6 | 5 | 30 | 6 | 7 | 42 |
| | Using natural energy | 4 | 8 | 32 | 4 | 1 | 4 |
| | Accesses to special façade | 6 | 4 | 24 | 6 | 10 | 60 |
| II | Construction time | 5 | 5 | 25 | 5 | 6 | 30 |
| | Easy performance | 3 | 6 | 18 | 3 | 4 | 12 |
| | Easy access to material | 3 | 4 | 12 | 3 | 7 | 21 |
| III | Friendly operation | 3 | 8 | 24 | 3 | 5 | 15 |
| | Energy measurement | 5 | 4 | 20 | 5 | 10 | 50 |
| | Training | 2 | 7 | 14 | 2 | 5 | 10 |
| Total score | | | | 231 | | | 260 |

*Table 3: Two alternatives Evaluation based on VM+EM Process Criteria*

## 7. CONCLUSION

According to the value management's importance in original, traditional and vernacular Iranian architecture and also this paper, the necessity of value management in energy management topic in order to achieve sustainable development is quite evident because in the design, construction and operation process of a project many criteria and indicators are discussed in energy management and efficiency topics leading to the creation of various options and alternatives which their assessment and Rating for priority and access to the best and most evaluative efficient solutions must be done by a group of respective professionals and managers as a value management team.

In order to achieve sustainable development, all options, including short-term, medium-term and long-term are assessed during the life cycle of project with a broad and comprehensive view by considering all details to get the optimal generalization. The effective tool of value management depends on its essence and function achieves to the best output and most performance through the design phase because this phase determines the project progress and the suitable method for the construction and operation phases.

By using (VM+EM) method we will receive following advantages:
Establishment of proper communication between the different phases throughout the project in the energy sector

a. Development of effective methods of notification, reporting and management for rational use of energy
b. Search optimization techniques to increase energy efficiency through investments in research and development
c. Increase the benefits and allocation them to energy management programs
d. Reduce the effects of shortages or interruptions in the energy supply on the system performance

Totally, according to mentioned example, project evaluation from the perspective of the management team is important role for choosing and performance the best method of energy management and efficiency and achieving to the sustainability development through the time from past till future.

## 8. ACKNOWLEDGEMENTS

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# SECTION 4

## EDUCATION

# Autodesk Building Performance Analysis Certificate

## Demonstrating Thought Leadership in Education

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*ABSTRACT: The Autodesk Building Performance Analysis Certificate is an educational program for architecture and engineering students who want to prove and improve their fluency in the strategies and tools of sustainable building design. The program is an online learning path with associated online tests and software exercises that is rigorous enough to have real merit, is synergistic with coursework, and can be done on a student's own time. Supported through the Autodesk Sustainability Workshop website, it is an online, open book series of questions and exercises that are design and workflow-oriented across multiple software platforms. This paper outlines the research and development of the program thus far in preparation for the global launch in August 2013. It also describes outcomes and future work gathered from test pilots conducted in the Summer and Fall of 2012.*

*Keywords: education, fundamentals, software, analysis, workflows*

## 1. INTRODUCTION

In the building science community, it is a well-known fact that buildings account for over 40% of energy consumption in the US. This attention grabbing fact often acts as a call to action for the building industry to reduce the energy consumption of buildings and contributions to global emissions and other environmental issues. Coupled with this plea are initiatives, legislation, and regulations like Architecture 2030, California Energy Commission's Title 24, and the US Green Building Council's LEED building rating system. The reduction of building energy consumption is quickly maturing from a want to a need. The problem is that many designers and engineers do not have the skills and experience to fill that need.

A recent survey of 448 American Institute of Architects (AIA) members found that 56 percent of the firms surveyed "reported difficulty finding employees with adequate green skills." For small firms, that number is even higher at 72 percent (Hanley, 2012). This skills gap must be filled in order for the building industry to be able to reduce its energy consumption and environmental impact, and it starts by filling a gap in building science education.

## 2. EDUCATION NEEDS

Current students have desires and intentions to make a positive impact and make the world a better place. For students interested in building design and construction, this desire aligns with sustainability and lessening the environmental impact of buildings (EDUCATE Project Partners, 2012).

Unfortunately, sustainable building design practices are usually not yet part of the mandatory curriculum for architecture and engineering students. The topic is still slowly being introduced into academia, if at all. Academia is falling behind industry practice and industry demand (Mazria, 2012). Sustainability should be a key component in the education of architects and engineers to meet industry demands (EDUCATE Project Partners, 2012).

Thus, students are often left to their own devices to teach themselves sustainable design tools and practices. Given that there are numerous resources, concepts, and analysis tools that need to be understood, this self-teaching process can be confusing, cumbersome, and discouraging. Educators often want to incorporate building performance and energy analysis into their courses, however they too frequently run short of accessible and reliable resources, or become overwhelmed at the amount of material.

An additional roadblock to understanding sustainable building design is current educational models, where theoretical knowledge is taught separately from practical application. This leads to a good base foundation of fundamental knowledge, but no clear path on how to utilize the information to impact design decisions (EDUCATE Project Partners, 2012).

2.1 Fundamental Knowledge

A basic understanding of how buildings are designed and constructed is the first requirement for learning about sustainable building practices. This need is met by the universities educating the students, or through professional experience gathered by students.

However, building upon this basic understanding with sustainable building design concepts is where academia often falls short (Rügemer, 2009). For example, students need to understand dependencies like: utilizing natural daylight for interior spaces can decrease the demand for electric lighting, but can also increase the heat gain inside a space and require more mechanical cooling efforts.

These fundamental concepts can be enough to encourage students to effectively improve their design, but it is also important to give students the case studies and references to go further. Information such as material properties, metrics, and practical applications can provide a deeper understanding of sustainable building practices (Rügemer, 2009).

2.2 Software Fluency

Computer modeling, and more specifically Building Information Modeling (BIM), is becoming standard in architecture and engineering courses. Quite often students know how to do basic simulations and analyses in these software programs, but do not always have the full knowledge to do them correctly (including understanding common errors and pitfalls).

A study conducted by Diego Ibarra and Christoph Reinhart compared daylight factor measurements of undergraduate architecture student models to best practice models. Conclusions from the study included "dramatic errors" when instructors provided no simulation guidelines; as a remedy, they suggested an "emphasis on the importance of high quality teaching material to complement simulation workflows" (Ibarra and Reinhart, 2009).

Perhaps more importantly, if students do not understand the concepts behind the simulations and analyses they are conducting, the results can become meaningless. An accurately simulated daylight factor serves no use if the student does not understand what it is indicating, and how it should influence their design.

The need for simulation guidelines, best practice tips, workflows, and software transparency is reiterated not only through Ibarra and Reinhart's study, but also through student and educator interviews. The starting place for this information should come from the software company. It is their responsibility to provide accurate documentation and explanation of how their tools work.

2.3 Synthesis

To fill the current void in education, students need to be supported in learning building science fundamentals, and how to put these fundamentals into practice through software simulation. Educating students about fundamental design concepts and software practices together, instead of treating them as separate entities, will increase the student's understanding and make them more fluent in putting these ideas into practice. The union of fundamental knowledge and practical application is essential for pushing the building industry forward.

## 3. A COHESIVE EDUCATIONAL PROGRAM

The Autodesk Building Performance Analysis Certificate (BPAC) is designed to meet the current education needs in sustainable building design. In the bigger picture, the program tries to provide students with the skills and knowledge required to drive an industry-wide transition to performance-based sustainable design.

The program ties building science fundamentals to Autodesk building performance analysis tools through an online course. It has been designed for architecture and engineering university students seeking to improve their ability to design and optimize high-performance buildings.

Learning is supported by text articles, videos, case studies, software workflow tutorials, and links to external content for more detailed information. This online learning content is freely available on the Autodesk Sustainability Workshop website.

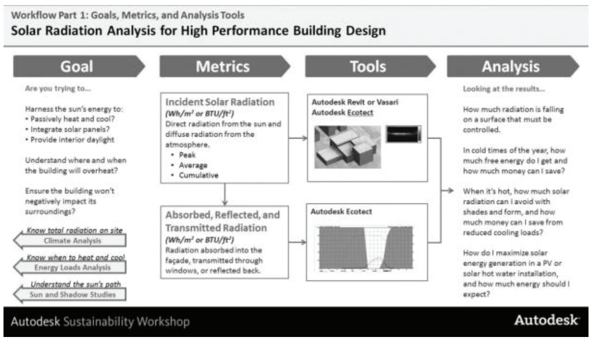


*Fig. 1: Software workflows provide students with an actionable path, with ties to fundamental design concepts.*

Software exercises give students practice using the concepts and software in realistic workflows, and then online quizzes assess the students' understanding and ability to synthesize these concepts.

While the program is self-paced and allows students to complete it on their own, the BPAC program has also been designed to be synergistic and supplemental to coursework such as studio projects or design competitions like the Solar Decathlon.

The topics currently covered are:

1. Climate & Weather Analysis
2. Sun & Shadow Studies
3. Conceptual Energy Analysis
4. Energy Loads
5. Wind & Airflow Analysis
6. Solar Loads Analysis
7. Daylighting Analysis.

For each topic, there are two quizzes: a fundamentals quiz and a software exercise quiz.

The fundamentals quiz is meant to test students on the basic concepts of the topics such as terminology, common practices, and case study interpretations. Questions are designed to require the students to synthesize and interpret the concepts, not just locate and regurgitate information.

The software exercises feature two to three evaluations of the student's proficiency in Autodesk software, and their ability to apply the fundamental concepts to design optimization. With datasets provided and instructions given as to what specific analyses to perform in the software, the questions ask students to interpret the results and make conclusions about design decisions. All the software exercises were designed to be "machine gradable."

## 4. DEVELOPMENT METHODOLOGY

To test the design and robustness of the BPAC program before a planned global launch in August 2013, three controlled pilot programs were planned. Two pilots have already been conducted in the Summer and Fall of 2012, and as of this writing, the third and final pilot is occurring in Spring 2013.

The Summer pilot included 31 participants who were already members of the Autodesk Student Expert Program. The students were asked to complete the program in an aggressive timeline of one topic each week, for seven weeks (both the concept-based multiple choice quiz and software exercises). After completing each topic, students completed a feedback survey with detailed questions pertaining to their learning experience, previous knowledge, question usefulness, and effectiveness of the supporting content. Additionally, a conference call was conducted with these students in which they voiced questions, concerns, and suggestions for program improvement.

The Fall pilot ran in alignment with the traditional college semester and lasted 12 weeks. Two groups of students participated in the pilot: 1) Independent students signed up to complete the certificate on their own, and 2) Instructor-led students were participating as part of an academic course. The pilot included 6 educators, who offered the certificate in their course as either a requirement or as extra credit.

In total, 222 students signed up for the Fall pilot, 88 of whom independently signed up. The feedback process was similar to that of the

Summer pilot in that students were required to fill out a feedback form after they completed each topic. A conference call with the educators was held at the end of the pilot.

During each pilot, a help-line was offered and open lines of email communications were kept with participants in the program.

In the interim periods between pilots, the feedback that was collected was evaluated and analysed to improve the program. Questions were changed, content was added, platforms were updated, and learning paths were made clearer in preparations for the global launch in August 2013. Additionally, industry professionals were also asked to review the content.

Even though it is still in its pilot phase, the BPAC program is quickly gaining popularity. The first pilot group from Summer 2012 had 8 out of 31 students earn a certificate. Round two, Fall 2012, had 91 out of 222 students earn the certificate. For the Spring 2013 pilot, over 20 educators and over 600 students participated. These numbers were achieved with no formal marketing efforts. All BPAC graduates are featured on an online roster.

## 5. CONCLUSIONS & DISCUSSION

Both the Summer and Fall pilot programs provided valuable insights about student learning patterns, educator needs, and software applications. These insights have been, and are currently being used to revise the content and user experience of the program.

**Provide linear learning paths and consistent frameworks**

At the beginning of the Summer pilot, students were only provided with one content link that served as a launching page for all the content pertaining to topic. While the link was straight forward, it was not always clear which concepts were pertinent to the topic and the site navigation made it difficult to follow the progression of the quizzes.

Towards the end of the summer pilot and throughout the fall pilot, playlists were introduced that helped make the student's learning path more scoped and linear. The playlist hosts all of the content and videos that are already on the Sustainability Workshop website, but guides students through the content in a sequence that not only builds upon concepts and software practices, but also follows the flow of the quizzes.

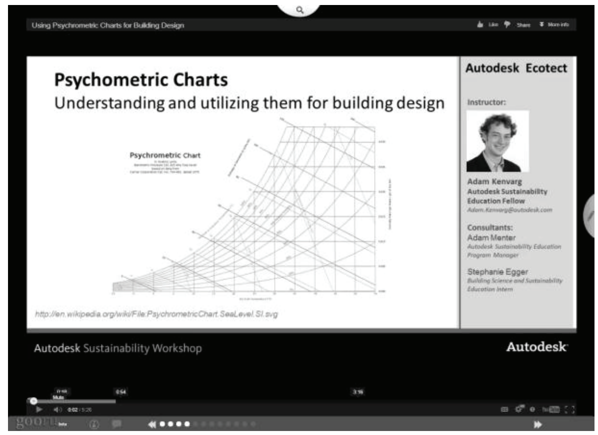


*Fig. 2: Playlist viewer that presents articles and videos in a logical order.*

At the same time, new website navigation was introduced with a stronger content taxonomy, so students could understand the concepts as part of a consistent framework. The new navigation allows users to parse through topics as they are related to fundamentals and software use.

**Make the takeaways actionable**

Another takeaway from the pilot programs was the need for more practical applications, and real project examples that put the concepts into practice. Fifty-eight percent of students from the Fall pilot responded positively that they would use the knowledge they gained from the BPAC program in future projects. However, during a final call with the educators who participated in the same pilot, their closing remarks were that they wished the program included more practical project examples, design practice, and detailed software guidance.

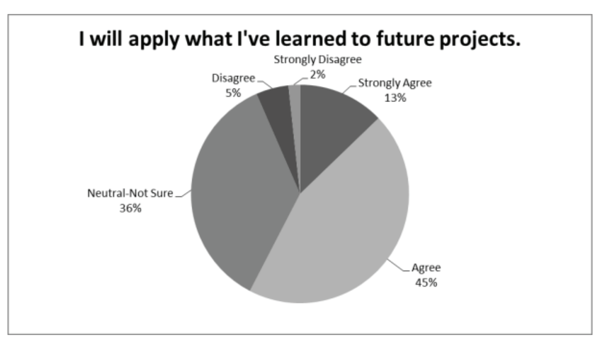


*Fig. 3: Application to future projects from the Fall feedback.*

Educators admitted that even after reviewing the content and passing the quizzes, their students were not always clear on how to apply their knowledge to their design projects. Additionally, they requested that the workflows be more detailed and specific.

This feedback brings up the issue of how much material the BPAC program can and should cover. For example, the program could feature a capstone style case study that requires students to perform a thorough analysis of all the topics covered, however when the program is used as supplemental material in an existing course, this may be too time consuming for the students and also raises difficulties in the ability for the quizzes and exercises to be machine graded.

Currently though, a compromise has been developed, in which an effort will be made to feature more pertinent case studies in the Sustainability Workshop Project Gallery to give students a sense of how all the fundamental and software knowledge can come to play in real life applications. Additionally, partnerships with professional architecture firms have been made in order to increase accessibility to case studies and relevant examples of sustainable building design applications.

**Give instructors confidence and help fill knowledge gaps**

Educators proved enthusiastic about using this material to introduce concepts in a classroom setting. They acknowledge that sustainable building design is an important subject - however their knowledge of all aspects of the subject may not be at an expert level. For example, instructors teaching BIM may not know many of the design concepts and instructors teaching design may not know the software tools. Furthermore, keeping up with the latest tools and practices is difficult. It is important that educators “continually evolve their knowledge base” so that they may properly prepare their students for the needs of the industry (EDUCATE Project Partners, 2012).

From the Fall 2012 pilot survey, students admitted that they had some experience with the topics covered in the BPAC, but were not very familiar with the concepts. These topics were new to 26% of the students, and only 5% considering themselves “Very Familiar” with the topics. Additionally, forty percent of the students were learning this material through their current coursework.

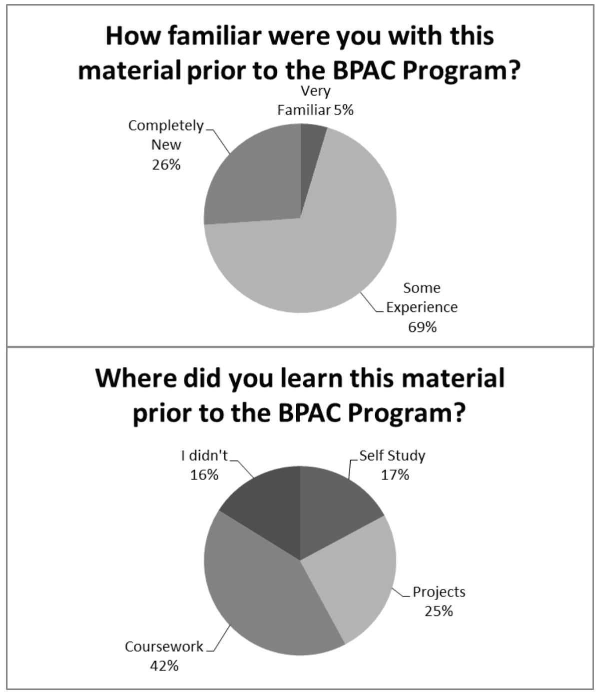


*Fig. 4: Student experience with the material and where they were learning about it prior to participation with the BPAC.*

These figures conclude that while the BPAC program can be completed independently without the guidance of an instructor, it is quite often the case that students are only being exposed to this material in the classroom. This course material can give instructors confidence to engage more with their students on the topic of sustainable design. A live student-teacher interaction is very effective for learning and instructor-led coaching sessions were often paired with a design studio project.

**Response**

All feedback received through the pilot programs has been valuable. It has helped to clarify the educational needs and methods necessary for improving the BPAC. More so, the feedback has underlined the need for the BPAC. Fig. 5 includes several quotes from students who have participated in the pilot rounds. These quotes reassure that the BPAC program is filling a hole in the current education system, and that the students see the experience as a valuable use of their time. Additionally, they acknowledge that information they learned can be applied to their future designs.

What we're hearing from students so far…

*"I had already used the Ecotect Weather Tool but with this section I´ve understood how use it properly and the meaning of most of the graphics of this tool."*

*-Ana Martinez, Universidad Politecnica de Valencia 2015*

*"I now know how to analyze the shadows in Vasari. It's a really effective tool and I will use this in future studio projects. It will be very helpful when figuring out window placement."*

*-Allison Gloude, University of Illinois Urbana-Champaign 2014*

*"I have heard the concept of "Net Zero Energy Buildings" before, but never with so many suggestions of how to achieve it. For the first time I'm learning how to actually design these buildings instead of it seeming like a dream/utopia type thing."*

*-Brian Moserwitz, University of Maryland 2015*

*Fig. 5: Student quotes about the BPAC program.*

## 6. FUTURE WORK

Still in the pilot phase, the Autodesk BPAC program is continuously adding new aspects in preparation for the global launch in Fall 2013. Plans include student design simulation awards, featuring more project examples, external content review, continuing work with industry thought-leaders, and packaging content as AIA and GBCI Continuing Education Units for professionals.

On a broader scale, there is an intention to create a community of practice around Autodesk's building performance analysis tools, with the BPAC program as a strong channel for gaining expertise. In an effort to bring together the building science community, students, educators, and professionals will have a space where they can interact and share thoughts, questions, and projects. This environment can provide new case studies, workflows, and practices.

The value in the Autodesk BPAC program lies in its ability to be adaptable. As best practices in the industry change and as new software is released, it is essential that the learning material that the BPAC is built from also evolves. As the global launch nears, efforts are being made by Autodesk to close knowledge gaps in their products and increase software transparency to build trust and confidence among new and current users.

## 7. ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank the ongoing support and insight from the Autodesk Sustainability Team. Additional gratitude is extended to the educators and students who have participated in the pilot launches of the BPAC and provided valuable feedback on the program.

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# Integrated Design Education:
## Shifting the design paradigm

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*ABSTRACT: Professional and student architects, engineers and contractors are learning the integrated design process through a course called DesignShift™ Charrette. The DesignShift format has been created to explore methods and technologies to bridge the independent silos in today's design and construction industry. Funded through Energy Design Resources, the curriculum has been taught to a wide range of California university students and design team professionals. The program was introduced to undergraduate and masters of architecture students as a four-hour class and has evolved to one- and two-day workshops for students and professionals. Participants are tasked with developing strategies in a team setting for new buildings that focus on high performance solutions. The curriculum includes training in: (a) process change in integrated design intent, solutions and strategies; (b) process-oriented tools that create the infrastructure for integrated design; and (c) quantitative analysis tools that provide a network of information to guide integrated design decisions. The instructors address how to implement integrated design, present a process to achieve integrated design, and provide tools that can be used in charretting and early design processes. This paper provides an overview of the DesignShift process and outlines its history, curriculum, team dynamics and implementation components.*

*Keywords: integrated design charrette, zero net energy buildings*

### 1. INTRODUCTION

The Design*Shift*™ Integrated Design Process and Charrette Delivery System is an educational program developed to train both students and professionals in methods that support collaboration, systems thinking and integrated design and construction efforts. The course breaks away from traditional fragmented design and construction models to teach a holistic process that encourages interdisciplinary participation in the early design stages for streamlined project delivery of a high-performance building. Attendees learn a replicable process that emphasizes team dynamics, tools and case studies to directly influence the built environment toward Zero Net Energy (ZNE) design.

The concept was launched in 2008 by key members of the Energy Design Resources (EDR) statewide team in California, who identified integrated design as an industry strategy with high potential to impact building efficiency. Southern California Edison (SCE) spearheaded the concept development. The integrated design initiative was developed in response to the goals of the California Long Term Energy Efficiency Strategic Plan, specifically strategies for new construction goals toward ZNE and heating, ventilation and air conditioning (HVAC) optimization for California's climate. Since its inception, the course has evolved into a flexible curriculum that has been tailored to accommodate students or professionals with varying levels of experience, typically delivered in one- or two-day workshops. More than 200 participants have completed the Design*Shift* program, which so far has been offered through 16 California universities and two public utility training centers. Workshop participants have included students from California State Polytechnic University, Pomona; California Polytechnic State University, San Luis Obispo; University of California, Santa Barbara; University of California, Berkeley; University of California, Davis; and Stanford University, among others. Feedback is collected following each workshop, resulting in a continuously refined workshop model.

The program continues to be supported by the EDR statewide team, which includes representatives from SCE, Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), Southern California Gas Company, and Sacramento Municipal Utility District (SMUD). EDR offers tools, educational opportunities and other resources to the building community to support the design, construction and operation of more energy efficient buildings. Energydesignresources.com is a key resource to design teams in California and has provided the opportunity for workshop participants to attend the workshop free of charge.

## 2. CURRICULUM

The Design*Shift* curriculum encourages participants to practice skills in systems thinking, integrated design and collaborative communication with the goal of bridging independent silos that inhibit integrated design. Participants learn about the fundamentals of climate change, energy consumption data, various integrated design and zero net energy definitions, appropriate design and technology principles and industry case studies of successful integrated design projects, so they are better equipped to communicate realistically about the importance of setting, communicating and reaching high performance goals.

Additionally, the charrette – a collaborative session where a group of individuals craft solutions to a design problem – introduces participants to working together with industry tools in the early design phase of an example building project to create integrated design solutions. Participants spend a significant portion of the workshop in small teams exploring an integrated systems approach on this mock project.

Each person is assigned to play a different role on the design team. The experience highlights the interplay between disciplines and offers opportunities early in the design process (Fig. 1) to create quantifiable, integrated high-performance building solutions and to exercise communication skills. Individuals are matched as much as possible to their real-life roles or area of expertise (e.g. owner, architect, engineer, civil engineer/landscape architect or contractor).

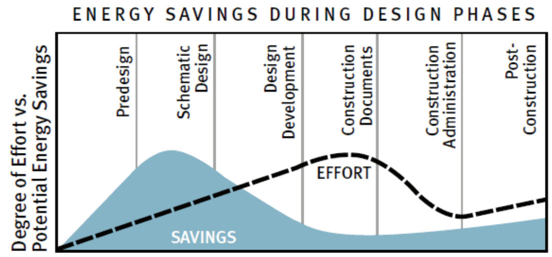


*Fig. 1: The best opportunities for optimizing integrated design are early in the process when changes minimally impact cost. Inversely, the effort and cost increase as the design process progresses.*

The four primary learning objectives and curriculum goals are to:

A. Explore the importance and benefits of an integrated design approach that emphasizes cross-discipline participation to achieving ZNE building goals
B. Create an understanding of project management delivery structures associated with integrated design
C. Explore a suite of software tools for use during the early design stage to quickly guide a project in setting attainable goals
D. Experience a repeatable project methodology that promotes passive design approaches, encourages new technology and addresses larger infrastructure issues.

### 2.1 Curriculum Development and Approach

The Design*Shift* Charrette is presented in an interactive format over one or two days for professionals or students respectively. Since the first workshop event in 2009, post-workshop surveys have informed course designers of ways to refine the curriculum to fully engage participants and use class time more efficiently. For example, the student workshop was lengthened from one day to two in order to cover each topic more fully; and the online design competition timeline was revised to better suit the students' needs. The professional charrette presenter lineup was modified to accommodate the one-day format based on feedback from participants.

Additionally, a set of adult learning principles used by the SCE Energy Education Center guided the presentation and hands-on learning format. These principles emphasize the inclusion of a lesson plan with clear alignment of learning objectives with specific outcomes; learner-centered content decisions; participatory activities; stand-up presentation; and effective group facilitation. These principles ensure that a variety of learning styles are supported and keep a strong focus on the organizing principle. Hands-on activities are used to check comprehension before leaving a key topic area; an emphasis is placed on maintaining a positive and supportive learning environment.

The workshop is led by expert instructors with professional experience implementing integrated design strategies and whose work focuses on energy efficient, low environmental impact design. The presentation mimics a Thought Map, a concept taught in the course, to convey the interrelation of human, environmental and building infrastructure systems. An accompanying workbook provides the participant with definitions, graphics, case studies and in-class exercises. The workbook facilitates group discussion during the presentation and becomes a reference resource for participants later.

For the professional charrettes, interactive communication is emphasized by rewarding group discussion and knowledge sharing with “play money,” which is used to purchase or sell project ideas and expertise. For both the professional and student workshops, multiple exercises enable participants to practice team dynamics and cooperation. Individuals are assigned roles (e.g. owner, architect, engineer, contractor) to play on their mock project. Hands-on activities using tracing paper, colorful drawing implements and netbooks teach habitual documentation and recording of the design process, a vital concept to evaluate the success and repeatability of design approaches on projects. Without a record of processes explored on a project, achievements would be difficult to replicate, and ineffective ideas may make it back onto the drawing board without modification.

The curriculum is grouped by concepts and definitions in order to be easily adapted to accommodate participants with varying degrees of design and professional experience. The intent is for the next generation of designers to use integrated design customarily rather than as an innovative practice, as well as to provide an opportunity for practiced professionals to refine their expertise by gaining integrated design skills. Reaching both students and professionals aims to expedite the shift in design approach, thereby increasing energy efficiency and working toward ZNE design.

### 2.2 Curriculum Components

The curriculum is organized into modules addressing:

- Components of integrated design including definitions and overview
- Team dynamics
- Project management and delivery
- The charrette process
- Simulation tools

#### 2.2.1 Components of Integrated Design

Participants learn that integrated design concepts and definitions include both an impetus for shifting the design approach and an inter-connection of systems as parts relating to the whole. Collaboration among disciplines and open communication are shown to positively affect project success. Project roles and educational backgrounds that may seem non-traditional to building design are discussed to shed light on the many sources of input that go into a project.

Core principles are introduced to evaluate and respond to project context. Considerations such as cultural setting, existing site conditions and interaction with current infrastructure, materials and microclimate are explored.

#### 2.2.2 Team Dynamics

To reinforce the interdisciplinary imperative, participants engage in exercises to practice and understand team dynamics. Games that encourage creative thinking and help identify right- or left-brain dominance promote understanding of how different types of thinkers contribute to group-based problem solving. An important element of integrated design is bringing together logic-, linear-based personalities with creative, innovative types so that visionary ideas can be brought to life through pragmatic solutions. For instance, in one workshop event, a student team conceptualized a seaside school design with an innovative roof system that visually imitates a wave pattern, which works synergistically with the wind and incorporates cutting edge technologies – all while enhancing the whimsical nature of design.

As mentioned, participants explore thought mapping, following a diagram style to outline information with branches of concepts and ideas. The processes for thought mapping are then applied in an exercise (Fig. 2) with the group.

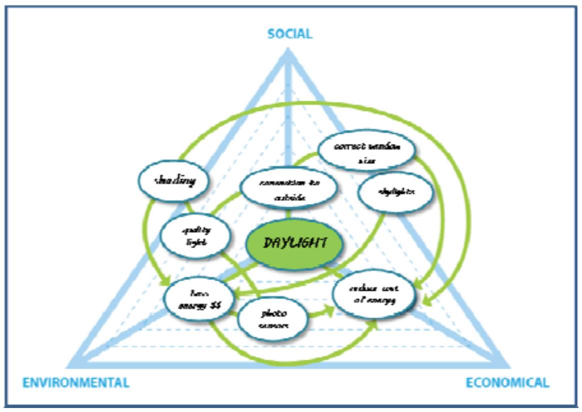


*Fig. 2: Example of Thought Map.*

2.2.3 Project Management and Delivery

The team dynamics module is followed by project management approaches pertinent to integrated design. Project roles and responsibilities are defined and then organized to illustrate connections between project team members. Lean construction principles are incorporated to raise awareness of materials sourcing and efficient installation to reduce waste.

The AIA Integrated Project Delivery (IPD) guidelines for contractual structures are presented to clarify how documentation, accountability and risk are distributed across the project team in various structures. Case studies of projects that successfully followed the IPD process are presented to both reinforce the concepts defined in the workshop and elicit ideas for application in participants' mock project work.

A key aspect of IPD is the ability to better manage risk for the owner, architect, engineers, and contractor. By aligning the goals of these parties to be focused on the best outcome for the project and making each party responsible for the behavior of the others, everyone gains more control of the overall process. Thus, increased certainty among the principal parties mitigates risk.

In some projects, performance-based incentives built into the principal parties' contracts also help align project design and construction goals and their achievement.

2.2.4 The Charrette Process

The practice of design charretting is essential to gathering group requirements, goals and ideas effectively. The method of conducting this group brainstorming exercise is defined both historically and in common contemporary usage. The Pyramid Approach (Fig. 3) was developed as part of Design*Shift* to guide project teams along a logical trajectory of design development that utilizes resources most effectively.

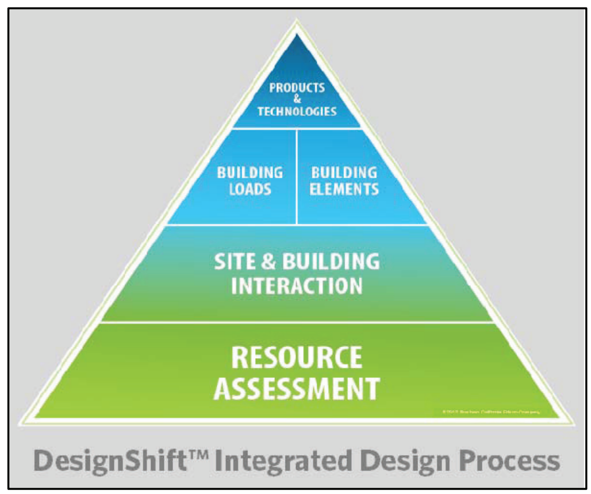


*Fig. 3: Integrated Design Process Pyramid.*

The approach begins at the base of the pyramid, with an assessment of climate conditions as well as considerations for available wind, sun and water resources. Cultural and community factors are also assessed. Enclosure or building envelope design plays a key role in the second stage of pyramid building, as do site interaction and site topography.

The discussion then flows into minimizing building loads and optimizing building elements. Participants move through successively narrower stages until specific products and technologies appropriate to the project are identified at the last stage of the charrette process.

2.2.5 Simulation Tools

The next section of the curriculum presents a suite of open source tools to help project teams create synergistic, efficient and sustainable designs from the outset. For optimized results, participants are encouraged to utilize these tools in preparation for the design charrette stage. Entering a design charrette with site and other key characteristics pre-identified will help guide the project team to ascertain which ideas will enhance synergies and optimize project results.

Instructors provide a tutorial on tools that provide participants with new skills immediately applicable to projects. Two tools focused on in the integrated design process were developed by the Design*Shift* creators to convey methods and concepts unique to the program. These tools, the Design*Shift* Project Delivery Creator and the Integrated Design Checklist, simplify integrated design tasks and reinforce a successful process. Other quantitative tools demonstrated include:

- NREL MapSearch to consolidate renewable energy source information based on location.
- Climate Consultant to display climate data, psychrometric chart and wind rose analysis by location.
- eQuest® for building energy simulation and analysis.
- Sensor Placement + Optimization Tool (SPOT™), for quick rendering of an interior space to evaluate lighting and daylighting options.
- NREL's In My Back Yard (IMBY) to calculate energy produced by wind turbines and photovoltaic panels.
- ATHENA® EcoCalculator to assess life cycle for common building assemblies.

2.3 Design Competition

Participants in the student version of Design*Shift* apply their learning through a team competition. At the end of the first workshop day, students divide into teams and receive specifications and requirements for a mock building project. On the second day, teams provide physical sketches of their designs and develop a PowerPoint presentation that shows analytical results from the suite of tools introduced above.

Student teams are given time on their own after the workshop to finalize their designs (Fig. 4) and submit them online. Judging is based on the best combination of integrated design, energy efficiency and sustainability. Winning teams are recognized on the EDR website and awarded a prize. The competition gives students the opportunity to apply the concepts, test drive the tools and seek feedback from instructors.

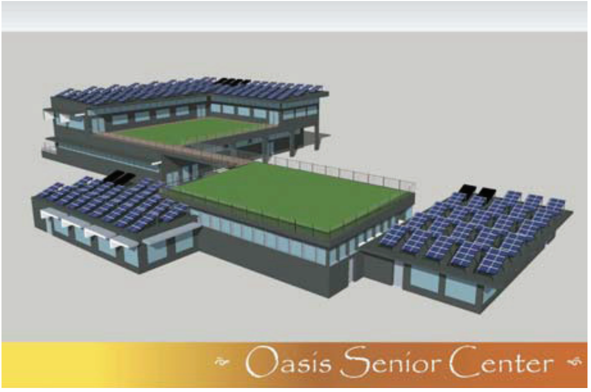


*Fig. 4: Team submittal for mock project for a senior center.*

For professionals, the workshops are one-day events with participants divided into teams that focus on a specific building system (e.g. cooling, heating, lighting/daylighting). The teams use play money to buy and sell their expertise. At the end of the session, teams present their work, and the winning team is recognized.

## 3. IMPLEMENTATION

The student program has reached participants from multiple universities in California, and the professional program has been presented at California investor-owned utilities' training centers. Response from participants has been positive overall with regular course refinements to enhance participants' experience based on real world feedback. Now that the program has a well-developed course agenda and class structure, the emphasis has shifted to creating a scalable and repeatable educational training process.

Efforts to affect greater market transformation and reach an expanded audience include outreach to design and construction industry groups, possible continuing education credits to professionals, and successive, smaller workshops that focus on portions of the curriculum. Topics may focus on building enclosures, contract mechanisms, cost evaluation, renewables, lighting and daylighting strategies or charrette facilitation.

Feedback from student and professional workshop classes (Fig. 5) has created tremendous opportunity for the program to evolve. Each time the course is taught, participants complete surveys online, including open-ended questions that generate meaningful commentary. When asked about beneficial aspects of the course, participants responded:

- "…the fact that we got to work with professionals and other majors not relating to us. It was a great lesson in communication and team work."
- "I believe that the program was organized and structured perfectly. We had enough time to do everything we needed and most importantly everything was fun. This was a great educational experience that will influence every participant's professional careers."
- "This was a fun workshop that integrated seamlessly across all stakeholder disciplines and should be experienced by others."

*Fig. 5: California undergraduate and graduate students engaged in team discussion and feedback with an instructor.*

## 4. CONCLUSION

The Design*Shift* Integrated Design Process and Charrette Delivery System transforms traditional design thought, breaks through independent silos and drives a new methodology into common practice. Using process-based and quantitative tools, case studies of successful projects and guidelines developed across disciplines, this effective, repeatable training approach has been successfully developed for both university students and professionals. Its versatile, scalable curriculum can be customized for different audiences and has evolved into a tool with realized project energy savings and sustainable benefits.

## 5. ACKNOWLEDGEMENTS

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# McKinley Sustainability Workshops

## Sustainability Seen Through the Eyes of Children

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*ABSTRACT: This paper will describe a series of children's workshops about environmental sustainability. In collaboration with educators from McKinley elementary school in Santa Monica, California, a team from HMC Architects developed a series of workshop about water, energy and waste for elementary school students. The workshops were taught by the HMC team on three days and repeated for McKinley Elementary's 3rd, 4th and 5th grade students, totalling 240 students per day and more than 13 hours of instruction. This project seeks to help train the next generation of environmental stewards in order to positively impact our planet and effect systemic change.*

*Keywords: education, sustainability, curriculum, stewards, kids, workshops, lab, children's' book*

### 1. INTRODUCTION

Education is important at all levels and for all ages. In order to positively impact our planet it is important to empower our younger generation with the knowledge and the tools necessary to actually make that very same impact. By bringing environmental issues to light in an interactive, fun and informative way, we will be able to inspire children to become the champions for the environment which they are all innately capable of being. Our sustainability workshop series strived to create a domino effect of knowledge sharing. Our goal is for each child, student and participant to share what they learned during the workshop with their friends and families, thereby cultivating a culture of environmental leaders who will be ready to take immediate action against the urgent issue of climate change.

### 2. INITIAL PLANNING

#### 2.1. Brainstorming session with McKinley Elementary

To ensure that the workshop fit the needs of the students and staff, we worked closely with the McKinley elementary school teachers in Santa Monica to develop the content. The group decided to address three topics: water, energy and waste. We planned to hold these workshops in the winter quarter of 2012. Each workshop would be 1.5 hours, and would be repeated three times per day, for three days. Each of these sessions would include about 80 elementary students from the third, fourth and fifth grades. Each workshop would consist of an interactive presentation that employed a variety of teaching techniques including interactive group discussion, movement, art, music and multi-media videos. Furthermore, the presentation would include kid friendly and appealing characters for each subject, which would be developed by a graphic artist. After the auditorium presentation, students would break into smaller groups to engage in a hands-on activity. Student volunteers from Cal Poly Pomona, educators from McKinley and volunteers from HMC Architects would facilitate the workshops and hands on labs.

In addition to the students from California, students from Maracaibo, Venezuela would participate via Skype. The Venezuelan students would virtually attend the workshop and would interact with McKinley students during a Question and Answer period.

### 3. WATER WORKSHOP

#### 3.1. Water Workshop Presentation Content

California is in the midst of a water crisis. With a growing population, water demand has been rising at an astonishing rate for the last 20 years; however water supply has been dwindling. The significance of this dilemma is the impact that it will have on future generations if action is not taken. The water workshop became a means to convey the importance of this challenge.

The beginning of the workshop presentation focused on the ephemeral and practical uses and benefits of water. The presentation focused upon the notion that water provides us with fun, refreshment, and even electricity; however most importantly, water was defined as being precious and scarce.

The notion of scarcity can often be difficult to understand however. Real life experience can aid in materializing this concept. As such, we devoted this part of the presentation to the McKinley Elementary Assistant Principle, who shared her recent travel experiences to Africa. The Assistant Principle recalled her account of villagers who were required to walk for several miles in dangerous and harsh weather conditions simply to access water. This real life account provided students with a genuine sense of gravity.

Students were surprised to find that only 3% of the Earth's water is actually drinkable. However students were even more mystified by the fact that only 1% of that 3% was actually accessible water, while the remaining 99% was frozen in ice caps or glaciers. To further emphasize this point, students were asked to stand. Three students were asked to remain standing while the rest of the students were asked to take a seat. We explained that these three students represented all the water on Earth that is drinkable. Lastly, two students were asked to stand, with only one student left standing. We then explained that this one student represented all the drinkable water on Earth that we had access to. Students were at first amused, but then surprised by the reality of our scarce water supply.

*Fig. 1: McKinley students participate in the water workshop question and answer session*

3.2. Water Cycle Song

To help the students understand the science behind the water, the water cycle was introduced to the class in an interactive way. An animated diagram which illustrated the water cycle was provided. This was followed by an interactive "water cycle song." Students at both McKinley and in Venezuela were asked to stand and sing along to the following lyrics:
"Water travels in a cycle, yes it does.
Water travels in a cycle yes it does.
It forms clouds as condensation.
Comes down as precipitation.
And goes up as evaporation.
Yes it does."

Students were entertained with the notion that an otherwise science subject could become a song. However, the simplicity of the tune and the lyrics ingrained the steps of the water cycle into each student's memory.

3.3. Water Workshop Lab

The impact of water was detailed in terms of where it comes from and where it goes. This provided students with a better understanding of how their actions can impact the environment as a whole. The route of water was detailed from the sky, to the earth, to treatment facilities, and back to the ocean.
As the majority of our water in the U.S. is supplied by underground sources, the concept of groundwater conservation and pollution prevention became the major focus. To demonstrate the concept of groundwater, students assembled their own small scale

aquifers. Students we were asked to layer materials to form a cross section of a typical aquifer. Using plastic cups, the students created a sloped hillside of earth using the following materials layered from bottom to top: sand, gravel, and clay. They then poured in clear water to represent untainted groundwater. Finally they were asked to drop “toxins”, represented by pomegranate and blueberry juice, onto the clay. The student observed as the pollutants slicked off of the clay, and trickled into the gravel and sand, and eventually made its way to the water. They also observed how the stain remained trapped deep within the sand. They then recorded their observations down on paper, drew diagrams of their aquifers, and listed ideas for how they could prevent water pollution. This exercise allowed the students to visually understand the immediate and long terms effects of pollutants on land and in our water. Students became aware that in order to have access to clean drinking water, they are charged with keeping their above ground environment clean and free of chemicals.

*Fig. 2: McKinley students build their own aquifers during the water workshop lab.*

*Fig.3: Sample aquifers showing ‘contaminated’ water from the water workshop lab.*

**4. ENERGY WORKSHOP**

4.1. Energy Workshop Presentation Content

Energy consumption is one of the largest contributors to greenhouse gas emissions. In order to curb the effects of global warming, an emphasis on energy consumption is required. The energy workshop aimed to teach the McKinley students alternative ways to conserve, use and produce energy.

The energy workshop presentation focused on both the conceptual nature as well as the very tangible aspects of energy. Energy was described as being all around us, as something that every living thing needs in order to function. The more tangible aspects of energy were then presented, which included how energy is used to power our multiple electronic devices and cars. Students were then asked to draw what they thought energy “looked like” on a piece of paper and then discuss their ideas with a partner. The student drawings ranged from sketches of the sun shining down on plants, to diagrams of the sun providing solar power.

4.2. Carbon Emissions and Energy

The effect of energy use on climate change was also discussed at length. To demystify the notion of what CO2 is, a short animation was shown which personified pounds of CO2 as elephants falling from the sky and landing on the cities below. The students found the animation humorous and informational. They understood the notion that carbon emissions can be detrimental to our livelihood in the end.

This analogy of elephants as pounds of CO2 was then extended to a set of graphs used to illustrate the amount of emissions released into the atmosphere from various countries. The students were astonished to learn that the U.S. had the most pounds per capita of emissions, or “elephants”, when compared to all the other nations of the world.

*Fig. 4: McKinley students communicate with students from Venezuela during the energy workshop.*

4.2. Energy Workshop Lab

To demonstrate the concepts of energy introduced during the presentation half of the energy workshop, a solar cooker lab was conducted. Solar cookers were an ideal method of showcasing how the sun could be used in an efficient way to provide a 'free' source of energy to conduct activities for everyday life. Students from CalPoly Pomona volunteered their time to show the McKinley students different models of solar cookers which they had built. The McKinley students broke into small groups and worked with the CalPoly students to create snacks such as s'mores, chocolate covered strawberries, quesadillas, and cheese and crackers. Students recorded their observations down on paper. The CalPoly students then showed the McKinley students how to make their own solar cookers at home. The lab was highly interactive, fun and a good role modelling experience for the CalPoly students.

*Fig. 5: McKinley students and CalPoly students work together to build and use solar cookers.*

**5. WASTE WORKSHOP**

5.1. Waste Workshop Presentation Content

The McKinley workshop series culminated in the third and final workshop which focused on waste. Waste was defined to the students as something that is used carelessly. To tie the three workshops together, waste was also defined as not simply being limited to 'trash', but which also applied to wastefulness of water and energy.

The students were introduced to a series of statistics about waste which proved to be illuminating. They were surprised to learn that The U.S. makes up only 5% of the population on the planet, yet consumes 30% of all the resources and produces 30% of all the waste, which equates to approximately 7 pounds of waste per person, per day. Furthermore, they learned that garbage production in the U.S. has doubled over the last 30 years.

Students also learned about current waste management practices such as landfills and incinerators. Diagrams were also provided which detailed how a landfill is used. Students discovered how waste housed within landfills can often seep into the surrounding environment, thereby polluting our soil, water, and even our air.

To combat the issue of waste, the presentation also focused on tactics that the students could employ at home or at school. These included the familiar mantra of: reduce, reuse, and recycle, but also included 'new' tactics such as sharing material possessions rather than buying new ones and composting food waste.

5.2. Waste Workshop Lab

To demonstrate waste management tactics introduced during the presentation, a "waste busters" lab was conducted. The students worked in small teams. Each team received a bag of 'trash'. Students were asked to sort the trash and eliminate or salvage as much as possible using the methods they learned about. Points were allotted for each method of waste management. These included:

- Reuse: 10 Points
- Recycle: 3 Points
- Compost: 8 Points
- Share: 10 Points

- Dispose in trash if required: 0 points
- Dispose in trash even though it is not required: -2 points

The team with the most number of points would win the game. Students were then challenged to create new things out of the salvaged trash. Creations ranged from art work to a full ensemble of musical instruments. Students had fun and learned from these hands-on activities while learning about how to rethink the notion of waste.

*Fig. 6: Materials used for the waste busters lab.*

## 6. Continuing Education

### 6.1. A Children's Book

To broaden the reach and purpose of the McKinley workshops, our team decided to develop the series into an educational book, titled "Sustainability Seen through the Eyes of Children." Working with the graphic artist who helped to create the characters for the workshop, the three subjects will be woven together through an illustrated storyline. The book is intended to be provided in both hardcopy and electronic copy for teachers, students and parents to use at home or at school. The appendix will include images of the McKinley students' work, as well as directions for each of the three subject labs.

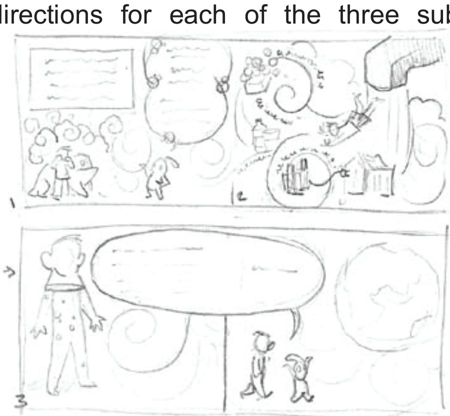

*Fig. 7: Cartoon sketches of the forthcoming book, titled "Sustainability as Seen through the Eyes of Children".*

### 6.2. Working with the USGBC

In 2012, the McKinley Sustainability Workshop received the first USGBC (U.S. Green Building Council) Impact Award. The USGBC is currently working with our team to develop the workshop presentations into a template which would become available on the USGBC outreach website. In this way, the McKinley workshops will become an educational resource with an unlimited scope, reaching numerous environmental stewards and educators around the globe.

*Fig. 8: McKinley student sketch of what energy "looks like".*

### 6.3. Measurable Outcomes

In order to assess the effectiveness of the program, a post-workshop interview was held with teachers, parents and McKinley workshop facilitators. Teachers were asked if they had noticed a marked difference in student perception or interests regarding environmentalism. The school's science teacher noted that weeks after the workshop, students were repeatedly recalling multiple facts they had learned during the workshop. A forum was held with 5$^{th}$ graders who had participated in the workshops while they were in 4$^{th}$ grade. The students shared that they continue to incorporate subject matter which they learned during the workshop into their everyday lives. For example students noted that they pick up litter from the ground to prevent pollution of the ocean, that they think twice about using a microwave rather than a solar cooker or that they are more conscious about not leaving the water running at home. This debriefing proved to our team that even a year later, the workshop was able to positively impact the social and environmental consciousness of 80 students. In this way, the McKinley Sustainability Workshop was effective in disseminating pertinent information regarding environmental stewardship across the school-home front, and over the course of several months.

6.4. Next Steps

The McKinley Sustainability Workshop has the potential to serve as a tool in California's Education and Environment Initiative (EEI), which requires environmental subject matter to be a part of core curriculum in all state schools. Final EEI curriculum was approved by the California Board of Education as part of a 2005 state law. The curriculum will be implemented in 100 percent of school districts by 2014, reaching more than 6 million students in 1,000 school districts. Incorporation of the McKinley Sustainability Workshops into the EEI would be an effective way of reaching a broad age group of students in an interactive, learning conducive and memorable way. Since its first facilitation at Santa Monica- Malibu Unified School District, the McKinley Sustainability workshop has been implemented at Diamond Bar Kindergarten and at the HMC Kids Go Green Earth Day event, and is slated to be held at the Getty kids' workshop in June 2013.

## 7. CONCLUSION

The McKinley Sustainability workshops provided students with a worldview perspective of the environmental issues, thereby increasing their awareness and giving them practical suggestions on how they, as elementary school children, can build a better planet for all. The workshops also reminded our team of the hard but rewarding work that our elementary school teachers do every day. We felt accomplished to have transmitted some love for the environment and knowledge about environmental stewardship to 300 kids who were separated by more than 3000 miles; however who were all sharing the same planet.

## 8. ACKNOWLEDGEMENTS.

This paper was a collaborative effort of the following individuals: Dr. Pablo La Roche, Sandra Kate, Sarah Banning, Adrienne Luce, McKinley Elementary School, and HMC Architect volunteers.

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# ZERO ENERGY FOR HIGH-RISE BUILDING:
## Challenges and Strategies

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ABSTRACT: The new generation of high-rise and super high-rise buildings is incorporating new developments of technology and design/delivery processes to produce intelligent, high performance buildings. This paper intends to identify the challenges to achieve net zero high-rise building, and analysis the potential technologies and design approaches to make high-rise building net zero.

*Keywords: Net Zero, High-Rise Building*

## 1. INTRODUCTION

Net zero energy architecture is not an idea for the distant future; it is an idea whose time is now. We have the technology and the knowledge to delivery net zero energy commercial building today. What we lack, more than anything, is the collective imagination to make it happen. As a major energy consumer, the tall building does not ordinarily conjure images of sustainable design, not to mention net zero. But a new generation of high-rise, super high-rise buildings is incorporating new developments of technology and design/delivery process to produce intelligent, high performance buildings. This paper is to identify the challenges to achieve net zero in high-rise building, and propose the potential technologies and design strategies to make high-rise building net zero.

## 2. DEFINITION OF NET ZERO

At its core, net zero energy is a measure of a building's energy performance, whereby it produces as much or more renewable energy as it uses over the course of a year in operation. Two key concepts make up this definition of net zero energy: First, net means that non-renewable energy sources may be used; but over the course of a year, enough renewable energy must be generated so that the project can offset or exceed the use of non-renewable energy. A net zero building does not mean that building uses no energy; rather, it refers to reaching a net zero energy position for buildings that have full program demands. Second key is operation. Net zero energy is an operational goal. It is possible to demonstrate a net zero energy in design. In fact, this is part of the process to achieve net zero energy. But a true net zero energy building must be achieved through actual measured operation.

In this paper, net zero is referring to "Net Zero Site Energy Building". A net zero site energy building produces at least as much renewable energy as it uses over the course of a year, when accounted for at the site. The measurement at the site is quite literal; that is, if a boundary is drawn around a building site, and all of the energy within the site boundary is measured and added up, the result is a site energy measurement.

## 3. THE CHALLENGE TO ACHIEVING NET ZERO IN HIGH-RISE BUILDING

Companied with the growth of the building technology and urbanization, high-rise, super-high rise building design have emerged rapidly in the past two decades, especially in Asia. The high-rise buildings required increased structural integrity and additional risers for the chilled water and sprinkler systems. The Mechanical, Electrical and Plumbing (MEP) system systems for the super high-rise buildings must be closely coordinated with the structural design and adapt to vertical configuration to optimize system working pressures. Making high-rise building net zero contains several challenges:

### 3.1. Microclimate

Compared to mid-low rise building, development of the high-rise buildings in urban environments would impose larger extent of the influence to the surrounding built environment as well as the microclimate, and vice versa. Therefore, more accurate and detailed investigation of site microclimate needed to be performed before the formation of design concept. The factors need to be considered include: dynamic fluid analysis, solar radiation, thermal comfort, etc. The presence of buildings that are taller than their surroundings creates the potential for additional windiness in surrounding streets and public areas. On one hand, windiness becomes annoying to pedestrians and can downgrade the value of the development if it interferes with activities that are an essential feature of the proposals; on the other hand, high-rises could utilize the on-site windiness to generate renewable energy.

### 3.2. Mixed-use function

High-rise and super high-rise buildings typically have mixed-use occupancy, including residential, hospitality, corporate headquarters and public offices. Multiple function carry different energy usage demands that carries building operation management complexities, challenges and difficulties.

### 3.3. Behaviour of Occupants

Studies have shown that occupant awareness, involvement, and commitment to energy use reduction can make a big difference even in conventional buildings. The behavior of building occupants is involved in the aspect of reducing consumption of energy. Occupants have to ask themselves whether they really need what they are using. In high-rise building, due to the mixed-use function it is hard to manage the occupant behavior. Residential portion of building reaches its peak energy demand during the nighttime, because of individual units activities, unlike commercial office portion, the central control system could monitor the energy consumption relatively accurately.

### 3.4. Building code and advanced façade design technology

Increasingly stringent regulations imposed in recent years mandate the adoption of high performance façades in new construction and encourage the substitution of existing-low performance envelopes in older tall buildings. The results are now evident both in terms of environmental performance and architectural impacts. For instance, in 2011, China published its energy conservation “ white book” as part of the 12$^{th}$ five-year plan, in which the central government sets goals for different regions. For Beijing and Shanghai, the energy consumption is planned to be reduced by 17% and 18% respectively. China also published the document-GB50189:2005 Design Standard for Energy Efficiency of Public Buildings. Compared to the current European energy conservation regulations, such as the UK Building regulation, Approved Document Part L 2010-L2A, GB 1089 sets much more stringent requirements. For Beijing climate, GB 51089 requires that, for an individual elevation, when the window-wall ratio is between 50 to 70 percent, the U-value of the curtain wall vision area shall be no higher than 2.0W/m$^2$K and U-value of the opaque area shall be no higher than 0.6W/m$^2$K. The stringent requirements impose both an opportunity and challenge for designer and entire industry. Innovative and creative design cannot be achieved by using the conventional design approach or simply relying on the building materials currently on the market.

The first impression created by high-rise buildings, either from afar or at street level, is the façade that encompasses the building, defining both its geometry and volume. Facades play a crucial role, not only in the function of a tall building, but also in its overall quality often termed the “skin” of a building, facades provide a controlled internal environment filtering the external elements. Building façade is a major passive design component of the building which governs the heating and cooling loads in tall buildings. Compare to other industry, building industry seems lacking behind. Car manufacture has been designing to optimize the car performance by reshaping the car form, using new materials, operating system. The building design by and large is still a function driven and aesthetic driven process. As a major energy consumer and environmental key player, building design should swiftly shift to performance-based design.

## 4. THE OPTIMIZED STEPS TO ACHIEVE NET ZERO IN HIGH-RISE BUILDING

### 4.1. First Step: Reduction

The first step to a high performance design is to identify as many opportunities as possible to reduce the amount of energy consumed. These reduction strategies need to focus on the largest consumers within the building, namely the HVAC and lighting systems. Improving energy efficiency and reducing energy consumption requires an aggressive analysis of energy efficiency measures. Understanding the science behind the energy reduction, conservation, efficiency improvement, and recycling or reusing of wasted energy, is important in achieving the net-zero. In order to make a significant reduction in the energy used by a building and its mechanical and electrical systems, a holistic approach is required. Most energy-efficient technologies that make a significant savings in energy have an impact on more than one discipline.

Case Study – Pear River Tower, Guangzhou, China

- The use of an internally ventilated high-performance active double wall façade with mechanised blinds.
- The use of a high performance triple-glazed (E/W) façades.
- A building-wide "chilled" radiant ceiling with perimeter chilled beam system for human comfort control.
- A "de-coupled" ventilation system delivered via a raised access floor.
- Dehumidification system which uses heat collected from the double wall façade as an energy source.
- Low energy, high efficient lighting system using radiant panel geometry to assist in the distribution of light.
- Double Skin façade would be a trendy system for the super high-rise building design. It is a fenestration system consisting of two skins placed such that the air flows in the intermediate cavity (see Figure 5). The system utilizes the strategy of the natural ventilation which enhance the thermal performance and the noise prevention of the fenestration system**.**

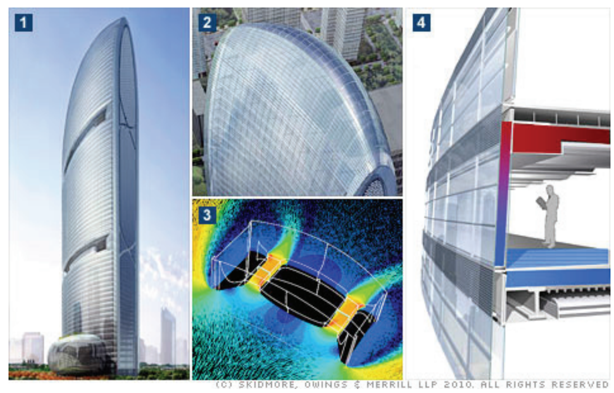


*Fig. 1: Double Skin and Ventilation in Pear River Tower*

### 4.2. Second Step: Absorption

The second step to this high performance design was to include several "absorption" strategies. These strategies are defines as those that take advantage of the natural and passive energy sources that pass around, over and under the building's envelope. In another words, is to neutralize the thermal loads of envelope. The design of the building envelope needs to address and neutralize thermal energy conduction, convection, and radiation loads related to thermal transmission, solar radiation, and infiltration. There is a dizzying array of technical issue to resolve in neutralizing the envelope in a net zero energy building, and an even greater number of technologies and emerging technologies that can provide solutions.

Case Study - Pear River Tower, Guangzhou, China

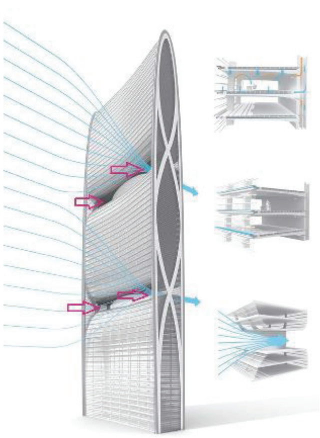

*Fig. 2: Vertical-axis wind turbines in Pearl River Tower.*

• A wide-scale photovoltaic system integrated into the building's external solar shading system and glass outer skin, which is located on the southern facade;

• The use of fixed external shades and integrated photovoltaic devices on the eastern and western facades, as well as integrated photovoltaic devices within the western facade shades;

• Maximizing the use of natural lighting via controls that respond to light and are integrated into a system of automated blinds;

• Vertical-axis wind turbines designed to take full advantage of the building's geometry.

Case Study – Norddeutsche Landesbank, Hannover

• Air is vented from the offices and similar rooms through a suspended ceiling system to the corridor, and from there to the large passive vents or chimneys that exhaust air to the roof. Room occupants are able to control the air flow with transom casement windows.

• The concrete foundation piles (120 of them) are sunk approximately 30 meters below ground and have water pipes embedded in them. Water is pumped through the piles to the building's exposed concrete ceilings that have polyethylene pipes cast into them.

• Lighting combined with ambient and computer equipment heat sources heat the ceiling slabs during the summer days.

• A system of operable thermal glazed windows and external louvers is used. The upper slats function like a series of light shelves that reflect light up and on to the ceiling to provide ambient lighting ( and passive heating in the winter).

### 4.3. Third Step: Reuse/Reclamation

Energy reclamation/reuse can be considered a subset of energy reduction. With reclamation, energy reduction is achieved by using “ waste” energy in one system to serve a productive function in another system. Techniques include heat exchanges, heat pumps, and transfer air (using waste heat for space heating or ventilation preheat).

In considering energy reclamation, the ideal is to create an energy ecosystem within a building. In biological ecosystems, energy enters as sunlight and is converted to chemical energy in plants. Plants are eaten by herbivores, which live out their lives and provide energy for their predators. Eventually, all creatures become an energy source for scavengers and decomposers, which serve their own vital functions in the ecosystems.

For example, Pearl River Tower design includes the use of re-circulated air for pre heat/cooling of outside fresh air prior to delivery of the occupied areas depending upon the time of year and outside air conditions, and the use of absorption chillers.

### 4.4 Fourth Step: Regeneration

There are many options for renewable energy integration for a net zero energy building. Which applications or combination of application is correct for any building is a complex question, one that involves variable such as available renewable energy resources, energy economics, and energy requirements, as well as building and site constraints.

Compared to regular height building, the disadvantage of high-rise buildings is that building horizontal surface is limited in comparison with the entire building envelope. Therefore the solar energy could be captured by solar collector is relative small in proportion to the regenerated energy needed to balance the consumed energy. Because of nature of the high-rise, wind energy has become more popular.

Urban wind speeds vary by altitude and as an example it can be common for wind speeds to increase over a height of 150 meters (492 feet) by up to 5 meters per second (16.5 feet per second). Thus, a calm pedestrian-friendly environment at grade can be very different from that encountered 150 meters (492 feet) up in the sky – providing a natural resource that can be converted into energy.

Case Study – Strata SE1

The design solution for Strata SE1 is in fact a further iteration of that adopted for the Bahrain World Trade Centre (the first building to explore building-mounted wind-turbine technology), also using the principles of a “venturi” to guide wind flow, but in that case between the two towers. There are other important differences too – notably the scale of the project, the fact that the three turbines are externally mounted on link bridges and its desert location, which necessitated full air conditioning which helped combat any adverse acoustic effects.

The three wind turbines are each mounted with a Venturi-like enclosure. This was to achieve three things: to channel the wind, to control noise and to integrate them within the form of the building. This leads to the adoption of a static solution for the orientation of the wind turbines. In the instance of the design load requirement for Strata SE1, the overall wind energy output requirement is 50 megawatt-hours of electricity per year. This equates to around 8 percent of the building’s total energy consumption.

*Fig.3: Wind Turbines on Strata SE1 Tower*

## 5. CONCLUSION

Net zero energy building offers a competing vision for the future, a vision that can be seen as new direction in architecture. The pursuit of this vision can be technically rigorous. High-rise, super high-rise building as new building typologies not only require advanced technology support, also require tremendous creativity and innovation in design. Two challenge and future vision together offer unlimited opportunities for new expressions of form to elegantly resolve energy solution responding to program, site and climate solutions. This opportunity will embraces the best of state-of-THE-art technology and renewable energy systems to provide solutions that set new standards for building and occupant performance.

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# SECTION 5

## VALIDATION

# Carbon and Energy in Efficient Building Envelopes:
## A Comparative Case Study in Life Cycle Phases

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*ABSTRACT: When buildings use very high-performing envelopes in order to reduce energy loads over the life of the building, it can be important to compare the environmental impacts in the manufacturing of the building envelope material with the lifetime environmental impact savings in building operations to avoid shifting the lifecycle environmental burden from the use phase to the construction phase. In this paper, we use a pair of case study buildings to offer a model for using life cycle assessment to compare the additional embodied carbon and energy in a high-performance building to the life cycle carbon and energy savings in its improved performance.*

*In this case study, the two subject buildings are identical multifamily housing blocks except that one is designed to the Passive House (PH) standard and one is designed to the Earth Advantage energy standard. In comparing the additional materials required to achieve the very ambitious Passive House energy standard with the resulting net use-phase savings, we found that there are significant environmental impacts associated with the additional construction materials for a PH upgrade but also that these impacts would be offset by the increased building efficiency. The study also shows the degree to which the energy grid mix and material choice impact the carbon and energy "payback time" for the improved envelope.*

*Keywords: life cycle, embodied carbon, life cycle assessment, passive house, multifamily housing*

## 1. INTRODUCTION

### 1.1 Life Cycle Phases in High Efficiency Buildings

In the context of very low operations energy buildings such as those built to Net Zero or Passive House standards, it is important to ensure that the impacts embodied in the improved building construction do not exceed the impact savings of the operations phase. The strength of life cycle assessment (LCA) as a method for quantifying the environmental impacts of buildings is its capacity to include and compare the embodied impacts in the construction of a building with the impact of its operations over the building's lifetime. An LCA approach to evaluation can ensure that the environmental cost of improved building construction (such as increased insulation) can be "paid back" through increased building efficiency instead of inadvertently shifting the environmental burden from the use phase to the construction phase with no overall environmental savings over the lifetime of the building.

Over its lifespan, a conventional building constructed to basic energy standards in the U.S. consumes about 84% of its lifecycle energy during the building's use phase (heating, cooling, and lighting). Only 16% of a typical building's lifecycle energy is embodied in construction, mostly from the manufacture of building materials (Committee on Technology, 2008).

In energy efficient buildings in which better design and construction is meant to reduce operations energy, the proportion of energy (and so greenhouse gas emissions and generally other environmental impacts) embodied in building materials can be significantly higher. In some cases, the environmental burden of the use phase could be inadvertently shifted to the materials themselves at no overall environmental benefit. In this context, LCA offers an appropriate model for analyzing the long-term environmental impacts of design decisions.

This study uses a life cycle assessment model to compare the difference between the full lifespan environmental impacts of a multi-family housing project built to the Earth Advantage energy standard with the same project built to the Passive House standard. While the use-phase energy of a project built to the Passive House standard is by definition extremely low, in this study we ask: What additional materials in the building's envelope are needed to achieve that energy efficiency and what are the environmental impacts associated with those materials? Is there a net improvement in full lifecycle environmental impacts with the Passive House upgrade?

This study is meant to primarily estimate greenhouse gas (GHG) emissions and non-renewable energy use, as energy use and climate change are the two most publicly recognizable impact categories. We also look at a handful of other impact categories, including acidification, carcinogenic and non-carcinogenic toxins to humans, respiratory effects, eutrophication, ozone depletion, ecotoxicity, and smog.

### 1.2 Project Goal

This study is intended to contribute to ongoing research on the environmental context of Passive House building design in the US and to the field of whole-building lifecycle assessment. The study results will also be made available to Stellar Apartment project team members and developers for use in their building planning.

## 2. METHODOLOGY

In this study we estimate the net change in total environmental impacts in upgrading an Earth Advantage energy standard apartment building to the Passive House energy standard, including additional impacts from the increased building materials and reduced impacts from the improved building efficiency over the course of the building's lifespan. The 'upgrade' here, it should be clear, refers to changes during the design phase in order to make the new design meet the PH standard. It does not to refer to physical alterations to an existing building.

To estimate the change in environmental impacts associated with the building materials, we subtracted the impacts associated with the materials removed in the upgrade from the impacts associated with the materials added in the upgrade. To estimate the difference in the environmental impacts associated with the building's operations, we subtracted the impacts of the estimated Passive House operations energy over the projected 60 year lifespan of the building from the impacts of the estimated baseline Earth Advantage operations energy. The net change in total environmental impacts in the upgrade from Earth Advantage to Passive House energy standards is the difference between the change in impacts from the materials and the change in impacts from the building's operations (figure 1).

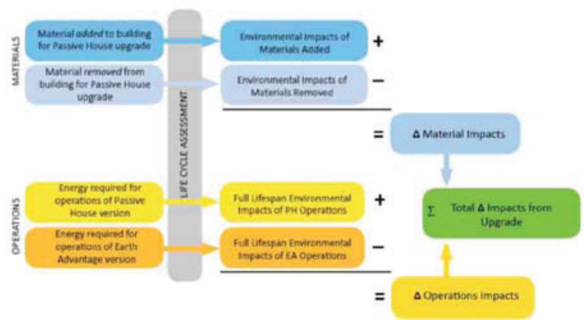


*Fig. 1: Net Change in Total Environmental Impacts*

### 2.1 Case Study Comparison

We are comparing two different versions of otherwise identical 5,000 $ft^2$, 3 story apartment buildings with 6 living units in terms of the materials in their building envelopes and mechanical systems and their estimated operations energy. The case study's baseline apartment building meets Earth Advantage energy standard. The Earth Advantage Homes Multifamily certification process includes prescriptive and performance-based components. Projects must be modeled to show a 10% increase in operational energy performance beyond code. For the Passive House standard, buildings must have an air-tight building shell measured by a blower-door test and an annual heating requirement of less than 4.75 kBtu/sf-yr and an annual Primary Energy Demand (total energy consumed including inefficiencies in production and transmission) of 38.1 kBtu/sf-yr. Figure 2 shows the materials removed and the materials added in the upgrade of the case study building to the Passive House standard.

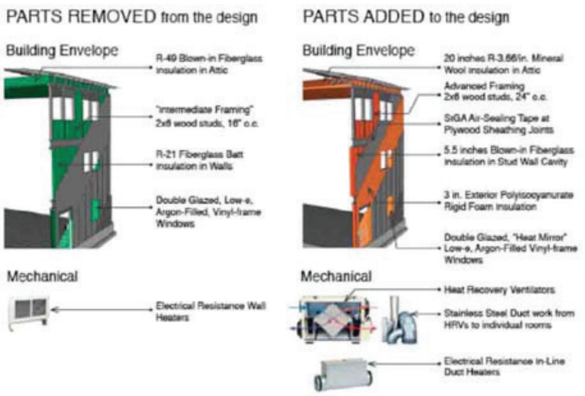


*Fig. 2: Materials Removed and Materials Added in the Upgrade of the Case Study Building*

2.2 PROJECT SCOPE AND ASSUMPTIONS

Because this project is meant to study the differences in environmental impacts between the two case study versions but not the total impacts of either project, the study boundaries are very narrow. We include impacts of the materials added to (and removed from) the case study to meet the Passive House standard but do not include the rest of the building that does not change. We account for the manufacturing of the building materials but not for their transportation to the site or their installation. We do include a factor for the replacement of these building materials over the projects' life spans and a factor for material waste during construction.

For both versions of the case study we assume a 60-year service life, in line with what little research exists on residential building service lives. We also understand that this assumption is relatively arbitrary since the actual lifespan of a building is subject to many unpredictable factors including land redevelopment, natural disaster, and wear.

For the materials impacts, we modeled the impacts inventory on the 2010 study completed by the Oregon Department of Environmental Quality, "A Life Cycle Approach to Prioritizing Methods of Preventing Waste from the Residential Construction Sector in the State of Oregon."

For this study, we focus on two key environmental impact categories to estimate the impacts of the building upgrade: non-renewable energy, measured in megajoules (MJ) and gigajoules (GJ), and GHG emissions, measured in kilograms (kg) and metric tons (MT) of $CO_2$ equivalents ($CO_2$e.)

To calculate operations impacts, we assign an energy use intensity (EUI) to each version (baseline EA and upgraded PH) of the case study's on-site energy used per square foot of floor area per year. For the Passive House version of the case study, we assume an EUI of 14.1 kBtu/sf-yr. This is based on the certification requirement for the Passive House standard, which dictates a maximum Primary Energy Demand (energy consumed at the power source) for a building and an efficiency factor that translates primary energy to energy used at the building.

While the Passive House standard prescribes maximum operations energy, an EUI study value for the baseline Earth Advantage version of the case study is more difficult to establish since that standard simply requires a 10% improvement over code. For the purposes of this study we assume an EUI for the Earth Advantage version of 40 kBtu/sf-yr, a "best guess" that we established by comparing this project to several comparable projects modeled by SOLARC Architecture & Engineering. Because this assumption is impossible to validate during the design phase and because this assumption is very significant to our study, we include alternate values for a baseline Earth Advantage EUI in our findings.

The way that we model the electricity grid mix is also significant. For our primary results, we chose to model a grid mix that represents that of the northwest region of the United States, the Northwest Power Pool (NWPP). If we were to assume a national average grid mix that includes a higher proportion of coal-generated electricity, then there would be higher impacts associated with the operations of the case study buildings. If we assume our local grid mix from the Eugene Water and Electric Board (EWEB) of primarily renewable energy sources like hydro and wind power, there would be smaller associated impacts. Because of the significance of this factor in our study, we also include results for local and national grid mixes in our findings.

## 3. FINDINGS

Given our study assumptions, we estimate that the total difference in life cycle environmental impacts in the upgrade from Earth Advantage to Passive House energy standards can be measured in a savings of about 13,000 GJ of nonrenewable energy and 987 MT CO2e in GHG emissions. Based on this estimate, we can infer that the environmental costs of the additional construction for the upgrade would be "paid back" in 1.6 years for nonrenewable energy and 1.4 years for GHG emissions.

There is some variation in results among the other impact categories studied. Acidification (measured in H+ moles eq), ozone depletion (measured in kg CFC-11 eq), and smog (measured in g NOx eq) all are similar to the results described above, in that the operational savings far outweigh the initial material impacts, by a factor of at least 9, and as much as 21. Carcinogenic toxins (measured in kg benzen eq), respiratory effects (measured in kg PM2.5 eq), and ecotoxicity (measured in kg 2,4-D eq), show a clear net benefit as a result of the upgrade, though not as dramatic as the impacts already listed. For these the operational savings outweigh initial material impacts by factors between 2 and 5. Impacts from the upgrade of eutrophication (measured in kg N eq), and non-carcinogenic human toxins (measured in kg toluen eq) are close to net-neutral.

The two most significant variables in determining upgrade payback time in our study model are the EUI we assign to the Earth Advantage version of the case study building and the way we define the electricity grid mix. If, as an alternative, we assumed a very inefficient case study building as in the 75 kBtu/sf-yr that the EPA Target Finder assigns to multifamily housing and if we assume a national energy grid mix that includes more coal power, we can estimate a payback time for the upgrade of only 0.3 years for nonrenewable energy and 0.4 years for GHG emissions. At the same time, if we assume a somewhat more efficient Earth Advantage building with an EUI of 33 kBtu/sf-yr with electricity just from EWEB, the payback time in non-renewable energy would be 5.7 years and the payback time for GHG emissions would be 14.9 years (figure 3).

It is also important to note that our case study upgrade assumes rigid polyisocyanurate foam for exterior wall insulation. Polyisocyanurate is relatively benign in terms of GHG emissions in its production, and if that were replaced with equivalent amounts of extruded polystyrene (XPS), a foam that is much more GHG-intensive in its production in the U.S., the modeled payback time for GHG emissions would increase to 48 years, approaching the estimated lifespan of the building.

## 4. IMPLICATIONS

### 4.1 Stellar apartments

This study confirms that in terms of total life cycle nonrenewable energy consumption, GHG emissions, and several other environmental impact categories, the upgrade of this apartment building from the Earth Advantage to the Passive House Energy standard would be well worth the environmental cost of the additional construction materials. Our study of alternative EUI values for the Earth Advantage case study and for alternative grid mixes shows just how environmentally significant such an upgrade could be for regions with high emissions electricity production and poor energy codes. The study also shows diminishing returns for regions that have fewer emissions associated with their electrical production or in cases when additional building materials have a high proportion of GHG emissions associated with their manufacture.

When we break down the environmental impacts of the materials added and removed in the upgrade, it is clear that while there are incremental differences in other materials, the largest additional impact in materials comes from the two types of additional insulation. In this case this is the mineral wool attic insulation and the polyisocyanurate wall insulation.

### 4.2 Broader implications

While the results of this research are tied to the particular circumstances of this case study, the study results can help to fill in a larger picture of the relationship between improved building efficiency and the environmental impacts of the additional materials to make a building more efficient. The study offers a model for using life cycle assessment to predict manufacturing and construction phase impacts.

While in most cases it is probably a very good decision to improve a building envelope, building designers and developers should consider the possibility of no net benefit in terms of total life cycle environmental impacts with an improved building envelope. To avoid this rare circumstance, particular attention should be paid to the global warming potential of insulation materials and the relative emissions of the operations energy sources.

4.3 Limitations of Study

It should be noted that this study does not aim to draw general conclusions about the relative lifecycle environmental impacts of Passive House buildings. As this study is region-specific, there is a particular utility grid mix, as described above. In addition, the types and quantities of materials used to attain the Passive House standard cannot be generalized. Other climatic regions will require different amounts of materials and different types of construction. The Passive House standard does not prescribe construction types or materials, only benchmark performance standards, so even within the region of the case study, there are many different configurations of materials and assemblies that could be used to achieve the standard on the case study building. Different material choices would lead to different outcomes in terms of embodied environmental impacts.

It should also be noted that while the methodology used here is sufficient to address the question of lifecycle environmental impacts associated with a building upgrade to the Passive House energy standard, it does not estimate the building's total lifecycle environmental impacts. As the trend continues towards buildings with lower operational energy needs, it will be important to determine what portion of their overall associated environmental impacts can be attributed to materials and what portion to operations. Especially in regions of relatively clean energy production, this will help to determine where design interventions will be most effective in terms of reducing overall lifecycle impacts.

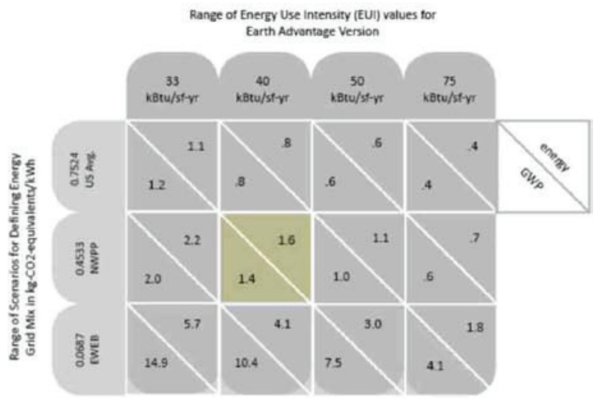


Fig. 3 *Variables in Environmental Payback Time in Years for Energy and Global Warming Potential*

ACKNOWLEDGMENTS

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# Environmental impact assessment of building materials on GBTool and SBTool rating systems:

## Evolution in the use of Lifecycle Thinking

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*ABSTRACT: Life cycle assessment (LCA) is an important tool for the evaluation of building systems and materials which should be explored by the building sustainability certification systems. The present paper analyzes the development in the application of Life Cycle thinking to the assessment of building materials from the environmental certification system GBTool to its improved version, the sustainability certification system of buildings SBTool. This certification system is the main academic initiative to assess the environmental performance of buildings, and several groups have been working in the development of regional assessment criteria worldwide. In our study GBTool 2002 was compared to the new principles approached in its latest version (SBTool) released in 2012. The purpose was to generate a comprehensive discussion on the methods used by these certification systems for the environmental assessment of building materials and systems based on the literature. The analysis has revealed that GBTool uses exclusively the assessment of building components by the recognition of product attributes, such as cost, durability, renewability and recycled content, whereas the SBTool has some application approaches based on life cycle management strategies.*

*Key-words: Environmental Assessment of Buildings; Life Cycle Assessment; Building Materials; Sustainable Building Initiative.*

### 1. INTRODUCTION

The preoccupation with sustainable development, especially in its environmental dimension, has lead to the creation of Assessment Methods of Building Environmental Performance in different countries, with several certification methods, whose efficiency of the application is directly related to the context to which they are applied (Patricio and Gouvinhas, 2004).

In order to better assess the overall environmental impact of a building during its lifetime, a life cycle assessment of the building and its materials and components has shown to be a valuable tool (Verbeeck and Hens, 2010).

The Life Cycle Assessment (LCA) methodology consists in analyzing the environmental impacts of a product or activity through an inventory of inputs and outputs of raw materials, energy, products, sub-products and waste of the system (Soares et al., 2006). This procedure enables a scientific assessment of the situation and facilitates the recognition of possible changes associated with different stages of the life cycle, which may result in improvements in the product's environmental profile.

From an environmental point of view, LCA provides as complete inventories as possible of the mass and energy flows for product systems and allows the comparison of these balances converted into potential environmental impacts (Soares et al., 2006). The life cycle of a building includes the production of building materials, construction, operation, maintenance, disassembly and waste management (Gustavsson and Joelsson, 2010), thus the LCA methodology may be an important part of the environmental assessment methods of buildings.

Studies of Erlandsson and Borg (2003) Haapio and Viitaniemi (2008) and Nibel et al. (2005)

have reviewed the LCA methodology for buildings, however there are still some lacks regarding environmental indicators, complexity of LCA disclosure for users, simplifications and adaptations for different purposes (Bribián et al., 2009).

Regarding the evaluation of building components - within the main building environmental certification systems - recognition of product attributes, such as cost, durability, renewability, and recycled content currently prevail. This approach deals with such attributes alone, when in fact they are often in conflict and interfere with each other (Silva, 2007). For this reason, the attributes approach lacks a sense of the overall impact of a product.

Given the current scenario of the assessment of the environmental performance of buildings and their materials, this paper reports on the evolution of the application of lifecycle thinking from the GBTool (Cole and Larsson, 2002) to SBTool (Larsson, 2012) building certification systems.

## 2. GOALS AND JUSTIFICATION

The purpose of this study is to build a summary table and a comprehensive discussion on evolution of the use of lifecycle thinking for the environmental assessment of building components from the GBTool 2002 (Cole and Larsson, 2002) to the SBTool 2012 (Larsson, 2012) certification systems. Such a discussion will be performed through data collected from the literature review.

Those certification systems stand out because they are the first certifications which seek flexibility and score balance in order to be adaptable to different regional characteristics. The evaluation of the methods used to apply the LCA to these certification systems may contribute to understand whether such strategy is possible and how to replicate it in other rating systems.

## 3. METHODS

The basis of the discussion proposed here is a literature review of the studies on the applications of the LCA methodology to civil construction, as well as parameters used by the environmental certification systems for the assessment of building components. According to that the methodology procedures are divided into three main stages:

- Survey of the state of the art of the building components assessment by the main environmental performance certification systems of buildings;

- Development of a summary table of the methodologies of environmental assessment of building components used by the GBTool 2002 and SBTool 2012 environmental certification systems of buildings;

- Discussion on the main methods of evaluation of building components and strategies of application of the LCA to GBTool and SBTool environmental certification systems of buildings.

## 4. RESULTS AND DISCUSSION

Tables 1 and 2 show the evaluation methodologies present in the credits related to the building components in the building sustainability certification systems GBTool 2002 and SBTool 2012, respectively.

GBTool evaluates most of the credits using the attributes approach. An advance is the evaluation method of its credit "Primary energy embodied in materials," which evaluates such an issue by an inventory of energy inputs throughout the life cycle of the materials used in a building (Table 1). However it is important to stress that this is still very incipient in lifecycle thinking, since the evaluation of that issue by a partial life cycle inventory (since it only computes the energy inputs and outputs) is still an attribute evaluation once such a methodology does not evaluate the product holistically.

Other credits in the Resource Consumption category of the same certification (namely “net life-cycle use of primary energy”, “use of salvaged materials from off-site sources”, “recycled content of materials from off-site sources”, “use of certified or equivalent wood products”), as also seen in Table 1, evaluate the environmental performance of the building components using attributes.

**TABLE 1: MATERIALS AND COMPONENTS ASSESSMENT METHODOLOGY IN THE GBTOOL CERTIFICATION SYSTEM**

| Evaluative credits regarding building components | Category | Assessment methodology |
|---|---|---|
| Net life-cycle use of primary energy | Resource Consumption | Partial LCI – Energy inputs over the life cycle of building materials. |
| Use of salvaged materials from off-site sources | Resource Consumption | Attributes – Percentage of materials recovered from external sources in relation to the total weight of materials used in the building. |
| Recycled content of materials (off-site sources) | Resource Consumption | Attributes – Percentage of Recycled content in the total mass of materials used. |
| Use of certified or equiv. wood products | Resource Consumption | Attributes – Percentage of wood systems which comprise certificate or equivalent materials. |
| Embodied emissions of materials annualized over the life-cycle | Loadings | Attributes – Annualized greenhouse gas emissions normalized for building areas. Only for the production process of materials |
| Emission of ozone-depleting substances | Loadings | Attributes – Annual kg CFC-11 equivalent normalized for building area. |
| Emission of acidifying gases from building use. | Loadings | Attributes – Annual kg of $SO_2$ equiv. normalized for building area. |
| Avoidance of solid waste resulting from construction processes | Loadings | Attributes – Percentage of weight of solid waste from the construction of new or renovated facilities that will not be sent to landfills. |

The item "Using recovered materials from external sources" measures the percentage of materials recovered from external sources in relation to the total weight of the materials used in the building.

**TABLE 2: MATERIALS AND COMPONENTS ASSESSMENT METHODOLOGY IN THE SBTOOL CERTIFICATION SYSTEM**

| Evaluative credits regarding building components | Category | Assessment methodology |
|---|---|---|
| Embodied non-renewable energy in construction materials | Energy and Resource Consumption | LCA – Use and embodied energy estimating system, based on LCA. Alternatively use the crude estimating method provided in the system. |
| Reuse of suitable existing structure where existing | Energy and Resource Consumption | Attributes – Report of the structural, functional and economical assessment of an existing structure. |
| Material efficiency of structural and building envelope components | Energy and Resource Consumption | Attributes – Analysis of efficient use of physical resources by building components. |
| Use of virgin non-renewable materials | Energy and Resource Consumption | Attributes – Estimate of the use of virgin non-renewable materials in the project, in order to minimize their depletion. |
| Use of finishing materials | Energy and Resource Consumption | Attributes – Estimate of the use of finishing materials in the interior of the building, in order to minimize direct or indirect resources consumption. |
| Ease disassembly, reuse or recycling | Energy and Resource Consumption | Attributes – Ascertainment of the building disassembly possibilities so that its components can be further reused or recycled. |
| GHG emissions from energy embodied in construction materials | Environmental Loadings | LCA – Use and embodied energy estimating system, based on LCA. Alternatively use the crude estimating method provided in the system. |

The credit "Recycled content from external materials used" considers the recycled content percentage of the total mass of used materials.

The item "Using certified or equivalent wood products" assesses the percentage of the used wooden systems composed of certified materials.

Still regarding the GBTool certification system, the credits comprised by the Loadings category also use the attributes approach as an evaluation methodology. It is the case of the credits regarding emissions of ozone-depleting substances, gases leading to acidification from building operations and avoidance of solid waste resulting from construction processes.

Those items evaluate the environmental performance of building components through the accounting of emissions by the area of the building. The percentage os solid waste generated in relation to the mass of materials used in the construction os the building is also calculated.

This certification system comprises one more credit named “embodied emissions of materials, annualized over the life-cycle”. Such credit only considers the emissions from the production process of the analyzed material.

Regarding the newest version of the SBTool certification system (2012) several changes can be identified in the rating system in comparison to the GBTool 2002 version. As some of these changes comprise important advances concerning the incorporation of the lifecycle thinking in the assessment methodology, they are considered significant improvements in the rating system in this research.

Several changes have also occurred in the attributes approach credits, where GBTool credits as “Use of salvaged materials from off-site sources”, “Recycled content of materials from off-site sources” and “Use of certified or equivalent wood products” - all concerning the limitation in the use of resources - were replaced by more general and actual credits as “Reuse of suitable existing structure”, “Material efficiency of structural and building envelope components”, “Use of virgin non-renewable materials” and “Use of finishing materials”.

Such changes, even when implying generalizations and simplifications have pointed out to the updating and improvement of this evaluative tool in the current design practices as they facilitate its application to various building typologies, implantations and construction techniques.

The credit “Avoidance of solid waste resulting from construction processes” has also been replaced by the credit “Ease disassembly, reuse or recycling”, pointing out to new strategies and building systems suitable to be disassembled for reusing and recycling in the end of life, automatically decreasing the waste generation during the construction process.

Some credits such as those regarding emissions of ozone-depleting substances (mostly CFC) and gases leading to acidification (mostly $SO_2$) have been removed from the certification system. Such a removal is probably related to the rise of a more restrictive standardization regarding the emission of those substances. However the consideration of those potential impacts must be assessed in order to assure the constant emissions decrease.

Finally two credits (one in the Energy and Resources Consumption Category and another in the Environmental Loading category) have shown an evolution in the application of the life cycle methodology to the building rating systems: “Embodied non-renewable energy in construction materials” and “GHG emissions from energy embodied in construction materials”.

Both credits existed in the GBTool 2002 version, however the evaluation method applied was based on the counting of the annualized energy consumption or emissions normalized for building areas, covering only the inventory phase of a LCA. In the SBTool 2012 version, the applied method is based on a complete LCA study, providing more reliable results.

The last two credits mentioned above must be highlighted as the main evolution from GBTool 2002 to SBTool 2012. Furthermore, the use of LCA to analyse embodied non-renewable energy may lead to conclusions not only on the consumption of fossil fuels and energy, but also to results on the potential impacts during the production process of such materials and its embodied energy.

## 5. CONCLUSIONS

Many changes have been introduced into the SBTool 2012 rating system in comparison to GBTool 2002. Most of them regard the inclusion of economical and social issues into the evaluation criteria.

Changes have also been identified in the environmental assessment of construction materials, but these are still incipient regarding the application of LCA methodology.

The lifecycle thinking can already be identified in the criteria related to the assessment of energy consumption and CO2 emission. However these two are the only issues considered and the environmental impacts from different emissions and resources consumption are not covered by the proposed evaluation system.

Such a partial LCA application may be useful though, in order to observe the behaviour of the user to a rating system based on a more complex environmental assessment. The complexity of a complete LCA study might be a barrier to the SBTool spreading, and its partial implementation must minimize such effect.

Thus it is possible to conclude that the SBTool 2012 rating system has a significant better assessment methodology regarding the initial implementation of life cycle thinking in some evaluative credits.

It is also important to highlight that such an implementation is still incipient and may be considered a first step towards a more complete and holistic building environmental assessment rating system.

## 6. ACKNOWLEDGEMENTS

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# INHABITING THE ENEAL

## Teaching approach of a passive cooling and zero carbon buildings in an extreme hot humid climate. Studio cases: Sinamaica Lagoon, Venezuela

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***ABSTRACT:*** *The Caribbean zone presents a hot and humid climate with high and constant temperatures during the whole year. In summer the maximum temperature is 34ºC and the minimum is 30ºC; the annual humidity is around 90%. There are two periods of rain, April to May and September to October.*

*This paper describes the teaching methodology used and some of the proposals made by second and fourth architecture students. The course focuses on developing a draft for a home and public buildings palafítica architecture, which clearly expresses its relationship with the surrounding environment, taking into account socio-cultural values of the site and extrapolating current architectural features.This paper describes some of the proposals made by second and fourth year architecture students, attending the possibilities for flood. The buildings had to be self-sufficient about energy and gas, thinking about recycling, appropriate construction materials and the water, use passive cooling and lighting and solar and energy efficiency technologies; developing a good architectural design that incorporates a structural integrity, function and comfort with aesthetic appeal.*

*To evaluate the proposals we used a small wind tunnel to study cross ventilation. A heliodon and simulations programs (SketchUp, Autocad, 3Dmax) were used to study solar geometry.*

*Keywords: teaching methodology, energy, comfort*

### 1. THE SITE

The *Sinamaica* Lagoon is located in Nor-Occidental area of Zulia state, in Venezuela, and constitutes part of a National Park since 1974. This zone is inhabited by the population of *Paraujanos*, of the *Añu* tribe, which has been established above water, living in *palafitos* since the pre-colonial time. The *palafitos* are mangrove wood structures which are weaved with bulrush, above the water or flooding grounds.

Besides being one of the icons of Zulia State, the *Sinamaica* Lagoon is of great relevance to the country of Venezuela, as it is there that its name was given, which means "Little Venice".

This lagoon has an extension of 50 square meters and is formed by the fluvial current of the Limon River and its continuous collisions with the tide; it's full of beautiful wide cannals with nice mangroves and coconut palms, and it's inhabited by 4.000 people, most of them from the *Añu* tribe, who are known to be hunters, gatherers and artisans.

This area is facing diverse social, environmental and cultural problems, nowadays. Such as the contamination and frailty of its mangrove-lagoon ecosystem, the progressive extinction of their language, the contrary cultural elements presented against their socio-cultural dynamics and the precarious life conditions.

*Fig. 1: The Sinamaica Lagoon, Venezuela.*

This work shows the academic experience developed through some of the projects executed by architecture students of the 2nd and 4th year in their major.

*Fig. 2: Palafito house.*

## 2. THE TEACHING METHODOLOGIES

Architecture and environment are tightly connected. The quality and survival of the planet depends greatly on the sustainability of an architectural project. Therefore, it's important to get acquainted with the place where the project will be developed, be sensitive to it, be aware of the own architectural characteristics of the place so as to take the appropriate design measures and select the materials that will best suit the spot and won't affect the environment around it.

The objective of performing such exercises is to sensitize architecture students of different academic levels of the major, in order to make them conscious of the great impact that architecture can have in a place with such particular ecologic terms as it is the *Sinamaica* Lagoon.

## 3. THE EXAMPLES: residential buildings

The housing being developed is immerse in a sensitive but adverse ecosystem, therefore this must be able to counteract the adversities of its surroundings, be self-sufficient in terms of gas and electricity, think about recycling: of liquid and solid waste that may be produced, as well as used construction materials, plan for passive cooling systems and natural lighting, re-use of gray waters and rain water.

It is designed for a family group of 4 people, two children and their parents, and it must be developed in an area not bigger than $70m^2$.

3.1. *Palafito*: habitat and inhabitant.

The goal is to understand the *palafito* as a creature that inhabits the lagoon and develops indispensable processes for its survival in the medium. This is why the processes of birth, evolution, breathing, change, adaptation and identification are executed through the formalization of the *palafito*, the dynamics of the space and the materials used.

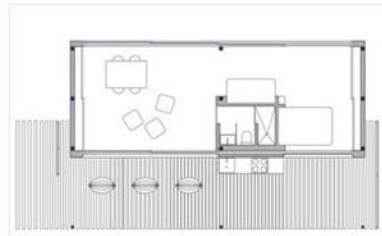

*Fig. 3: Floor plan: Palafito: habitat and inhabitant.*

The *palafito* is constituted by three elements: "the organ", which holds all the services, (bed, bathroom, stove) and has a solid compact materiality, of little communication with the exteriors. Then, "the skeleton", as a great mass that has disintegrated partially in its attempt to open up to the landscape and frame it. Lastly, "the membrane" of threads of mangrove which finalizes the disintegration and generates the full contact with the landscape. The mangrove membrane comes from the water, grows and surrounds the rest of the mass to protect it and form a refuge.

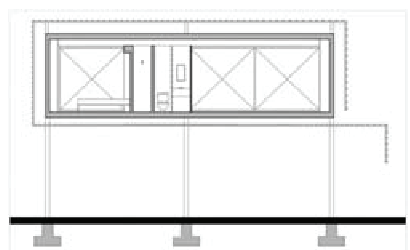

*Fig. 4: Section: Palafito: habitat and inhabitant.*

Also, the dynamics of the lagoon and the ephemeral character of those spaces such as the primitive *palafitos*, translates into the space's dynamics, as it is a free plant where multiple activities may take place it refers to the functioning of the thicket.

It can be stated that this *palafito* is an ensemble of the original and mixed versions (with a platform and piles of concrete and closings of mangrove and bulrush). Since it tries to mutate the ephemeral characteristic of the *palafito* in regards to the quality of its spaces.

Lastly, the materials used for the closings allow the utmost profit from the wind and sun light. The longest front walls oppose the direction of the winds with framed mosquito mesh, which allows crossed ventilation; the short walls (east and west) are completely solid as to control sun light.

The mix of natural artisanal materials from the lagoon, like the mangrove, and those more industrialized but still commonly used in Venezuela for construction, such as concrete, generate architecture as the sum of the nature and the historic and cultural community. Authentic, local, sensitive and conscious architecture.

3.2. House of intertwined bands.

This *palafito*, as a model house built on this very particular environment is the perfect reflection of the mangrove, as it is built from it and with very similar anatomy; it constitutes an ideal refuge for the development of the life of the inhabitants of the lagoon, by providing them of the protection from external elements.

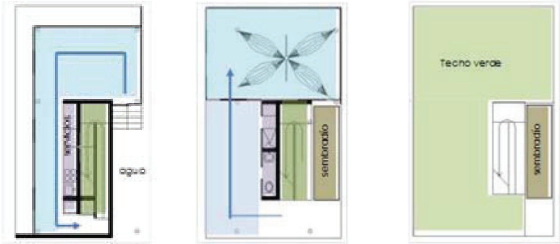


*Fig. 4: Floors plan: House of intertwined bands.*

"The house of intertwined bands" is founded on an elongated plant which directs the journey in a longitudinal format, as to witness the horizontality that dominates the landscape.

Beginning with the first stage of the house, a retracted volume, full of shadow, with sliding translucent closings, but not permeable; moving into an ascent through a ramp with closings that disintegrate as we go from the first to the second stage, reaching this point of the journey, a volume of which the limits have begun to disintegrate and become more permeable, exploring always the longitudinal format.

Projecting views towards the landscape, with great open spaces, the fusion between man and the nature surrounding him becomes clearer. Placing closings with shutters and elongated panels on both levels, the horizontal language is maintained at the same time that light and wind are regulated and allowed, making the house comfortable in different climatic conditions.

Just as well, by placing the nucleus of bathrooms and kitchen on the same longitudinal axis through the house, the flow around the house is more clearly defined.

Finishing the ascent through the ramp to a green passable roof we obtain the complete fusion between the lagoon and the man, by exploring these transitions in the bands and concluding it with a total domain of the landscape, the person who inhabits it also becomes it.

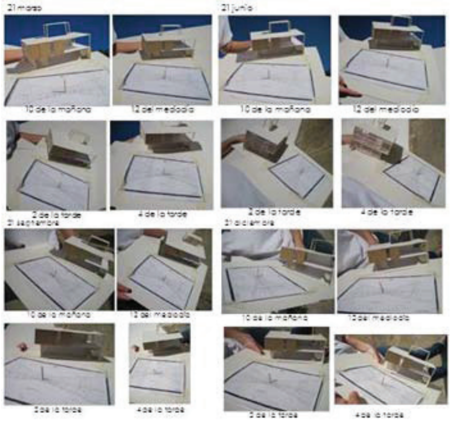

*Fig. 5: Solar study: Intertwined bands house.*

3.3. Filter house

In the exterior, the mangrove is showed compact and confined in itself, but always keeping the permeability that makes it have such a role on the environment. Then, inside it, the internal space of the mangrove can be experienced; its own and immediate landscape, unstable and irregular, bathed on a sieve of shadows formed by the weave of the mangrove roots which form the surroundings.

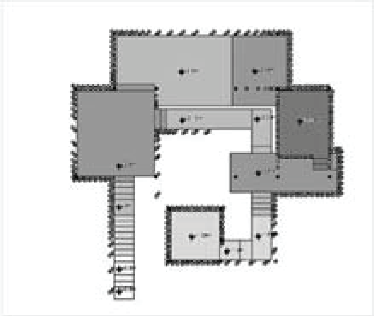

*Fig. 7: Floors plan: Filter house.*

From these ideas, emerges the proposal of a filter house, generated as a surrounding that reproduces the internal landscape, by creating different perspectives and experiences from the journey of the location.

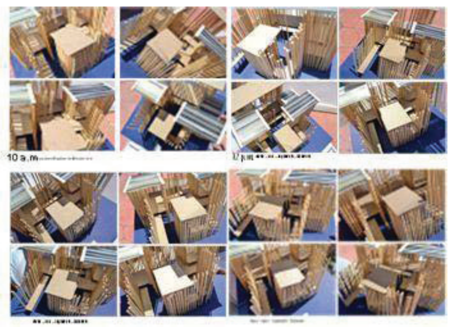

*Fig. 8: Solar study: Filter house.*

This surrounding is constituted by the disposition of tubular elements, which built a thermal barrier as they allow the wind through. The densities of these elements vary in the spaces, proposing irregularities that offer different perspectives within the same house.

The platforms and covers also contribute to the instability of the internal proposed landscape, varying in heights and densities. These covers composed by translucent panels play with the influence of sun light; the different opacities of these elements propose a variation of the quality of the inner spaces.

The combination of these aspects intends to suggest the experience of an irregular journey, a back and forth discovery of a changing space, an immediate landscape which co-exists with the elements of the surrounding landscape.

**4. THE EXAMPLES: public buildings**

The main objective was to develop the subject in the student's ability to handle problems at the urban scale, through a proposed development, management, consolidation or rehabilitation of an urban, with sustainability criteria based on world problems on energy expenditure from the phenomenological interpretation of the place.

4.1. Place like a weaved strata. Specialized education center**:** for the young adults of the *Sinamaica* lagoon

When the location was analyzed in a sensitive way, there were found three different strata that determine the landscape: water, vegetation and sky. The idea is recreate those strata and then having three different sensitive experiences in the site, dwelling in each one, using cane from the site (*caña brava*) and mangrove as a principal constructive material that becomes less dense depending of the strata that needs to recreate.

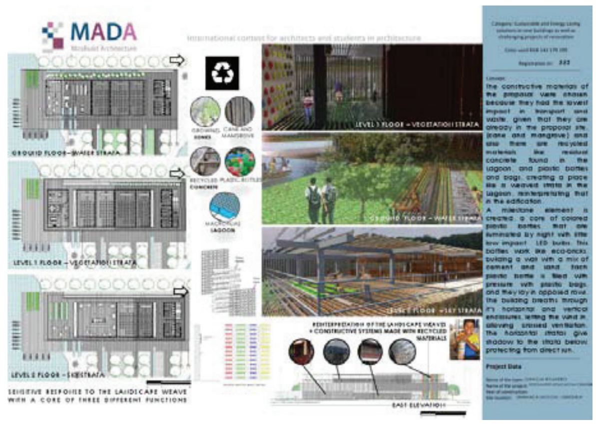


*Fig. 9: Place like a weaved strata. Specialized education center**:** for the young adults of the Sinamaica lagoon.*

When developing the specialized education center, around 600 students will have the opportunity of a professional career in this area: agricultural production, fishery technology, and environmental management, all of the above approved by the Venezuelan state. The program of the building consists in classrooms, cafeterias, an administrative office and a library for the use of all the community.

*Fig. 10: Place like a weaved strata. Specialized education center**:** for the young adults of the Sinamaica lagoon.*

The constructive materials of the proposal were chosen because they had the lowest impact in transport and waste, given that they are already in the proposal site, (cane and mangrove) and also there are recycled materials like residual concrete found in the Lagoon, and plastic bottles and bags, creating a place like a weaved strata in the Lagoon, reinterpretating that in the edification.

A milestone element is created, a core of colored plastic bottles, which are illuminated by night with little low impact LED bulbs. This bottles work like eco-bricks, building a wall with a mix of cement and sand. Each plastic bottle is filled with pressure with plastic bags, and they lay in opposed rows. The building breaths through its horizontal and vertical enclosures, letting the wind in, allowing crossed ventilation. The horizontal strata's give shadow to the strata below, protecting from direct sun.

4.2. Green Network Connection. Unlimited Connectivity System + Recycling Center

Based mainly on the problem of mobility, the project proposes to create a green network connection, which has an unlimited connectivity system and a recycling center. The first presents a new model of environmentally friendly mobility: water bikes as an environmental sensible system, built out of native mangrove for the loading platform and seats, and recycled barrels of fuel for the floating system. The water bikes also have a battery that saves energy to be used for the recycling center. this system has seven stations, each has an estimated of 30 rental water bikes and public areas, located throughout the lagoon, eliminating the need to own a boat and the dependence on third parties, giving the community a new mobility system accessible to all.

*Fig. 11: Green Network Connection. Unlimited Connectivity System + Recycling Center*

The site is understood as a horizon closed by planes. based on this, the building is materialized by a plane that is projected and permeate horizontally to accommodate nature as well as the program, thus forming the permeable envelope, then arise the permeated volumes called the sequential and the dilated permeable layers to build a permeable horizon inhabited by nature and the community.

*Fig. 12: Section. Green Network Connection. Unlimited Connectivity System + Recycling Center*

The recycling center comes with a recycling program in process that starts with the construction of the water bikes, having storage of selected materials, workshop materials recovery, storage of recovered materials, construction area of water bikes, store of recycled products and a repair shop. The device also has an extensive program for the community as the administration offices, a cafe and public areas.
The permeable envelope is a concrete structure with wowed ropes that create a permeable filter that gives reflected lines of lights and shadow to the floor. The floor is built out of slabs of low cost and recycled concrete. Some slabs slide up to create the public furniture, alternating with vegetation trays made of recycled barrels of fuel cut in half. In the sequential permeable layer (where the sequence is given by the programming process) and the dilated permeable layer, the spaces are delimited by adjustable and sliding venetian doors made with recycled wood.

For the more private spaces we have developed a concrete block combined with recycled plastic lids; all items and materials used in both components of the green connections work together to create a permeable horizon inhabited, which is completely adapted to the place with the use of typical materials from site, recycled and low impact, providing solutions to the mobility problem with a new model for accessible transportation for all and environmentally sensible, while generating new jobs and new opportunities for the community.

## 5. CONCLUSION

The achievements accomplished, by the different strategies executed, after having this experience declare to have been, as follows:

The realization of the design experience outside their city of residence, in a new area to them, and without any type of previous influence about it, made the students connect more profoundly with the location, recognizing the social, cultural and natural values. This experience helped them to recognize, in the future, in other places of study, the weaknesses and strengths of a location, with a wider knowledge and confidence.

To choose a place so delicate in ecological terms, due to the biodiversity and the fragile balance present, all this under the influence of foreign technologies, materials and construction systems developed in neighboring areas that threaten the balance; allowed the students to become aware of the value and importance of the choice of materials, systems and technology that won't affect the work place, thus reducing the impact of architecture, developing projects with a very small or null ecological footprint.

## 6. ACKNOWLEDGEMENTS.

We must thank all the students that took the subjects, without them, their work and their commitment, the experience wouldn't have been the same. Very especially to those chosen to present this paper: Andrea Rangel, María Betina Rincon, Silvia Atencio, Gracia Romero y Cecilia Alvarado.

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# Net Zero Energy Through Passive Downdraft Ventilation:
## The Design & Operation of the Conrad N. Hilton Foundation

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*ABSTRACT: The new campus for the Conrad N. Hilton foundation is designed to establish a regional precedent for environmental stewardship, with the goal of being a net-zero energy institute through the use of an extremely innovative ventilation system, excellent daylighting, and on-site renewable energy. The first completed phase of the campus is a 22,000 SF office building with an indoor environment that balances the needs for excellent indoor air quality, daylight and energy usage through an innovative new passive downdraft ventilation system that is inspired by ancient designs.*

*Passive downdraft has the potential to significantly reduce building energy and enhance air quality (through significantly increased outside air rates (P. Wargocki et al, 2000)) in many building types and, especially, in relatively mild climates like coastal California. The concept works extremely well when combined with natural lighting systems. This paper reviews the techniques of enhanced natural ventilation through the design of the passive downdraft, also known as a buoyancy HVAC system and the performance of the facility as a net zero building after occupancy through the measurement and verification process.*

*Keywords: passive downdraft, net zero energy, measurement & verification, natural ventilation*

*Fig. 1: Overall view of Conrad N. Hilton Foundation at night.*

## 1. INTRODUCTION

This paper provides a case study for the Conrad N Hilton Foundation project, located in Agoura Hills, CA. The 22,000ft² office building project, completed in 2012, had a goal of achieving net-zero energy use in operation. As part of the strategy for achieving that goal, the project sought to achieve substantial energy savings of at least 50% each in HVAC and lighting systems to limit the amount of renewable energy that would be needed to power the building.

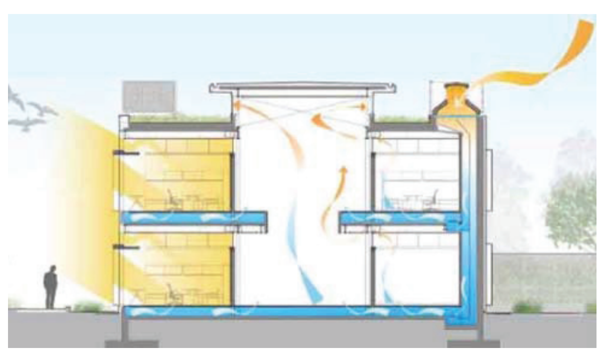

*Fig. 2: Building section showing the passive downdraft and daylighting components of the facility.*

This paper explores the history of passive downdraft systems, how the concept inspired the HVAC system and how it was implemented to achieve significant energy savings. It also describes how the architectural response to the passive downdraft system brought additional natural light into the building by using that space as an architectural ventilation exhaust pathway. In addition, there is a review of the process for showing net-zero performance through post occupancy measurement and verification.

## 2. HISTORY OF PASSIVE DOWNDRAFT

A wind-catcher is an ancient architectural feature used to promote passive ventilation primarily to cool buildings. Its use dates back centuries, and its effectiveness has led to its continual use as a cooling device in middle-eastern architecture.

The ancient Persians' understanding of wind behavior was an important survival tool. They predicted the rare seasons of rain that were dictated by wind movement. They learned to protect themselves from the warm winds that dried their bodies of valuable and scarce water. Through a conscientious trial-and-error process, they understood the physical behavior of wind—buoyancy, convection, evaporative cooling—and were able to harness it to adapt to the harsh climate of the desert.

The design of wind-catchers can vary greatly based on the climatic conditions of their regions. The two main types are unidirectional—Malqaf, used widely in Egypt—and multi directional—Bâdgir, used widely in ancient Persia.

The Malqaf consists mainly of a scoop, which rises above the roof of a building to catch the prevailing cooler, stronger winds. The force of the prevailing wind drives the cooler air down the chimney and into the occupied spaces below. This pressure forces the air out through openings at the top of a central hall. Comfort is achieved by promoting air flow over the body and by removing excess heat that is generated by occupants.

The Bâdgir is a shaft that rises three meters above the building, with openings on all four sides to catch breezes from any direction. It was developed in Iran around 900 AD. Designed to work both as an intake and as an exhaust, a Bâdgir's apertures can be opened or closed depending on the air circulation desired. Wind can be driven into the indoor environment by opening the windward faces of the tower, or exhausted by negative pressure through openings on the leeward side of the tower.

Today, with the increasing awareness of the application of natural ventilation as a passive means for cooling buildings and their occupants, the wind-tower vernacular is increasingly being used. Notable examples are the Visitor Center at Zion National Park, the campus at the University of Qatar, and the Saint Etienne Zenith Metropole.

## 3. PASSIVE DOWNDRAFT - A STRATEGY TO ACHIEVE NET-ZERO ENERGY

With HVAC energy expected to be at least 40% of the building energy use, the net zero energy target relied on a low energy HVAC solution for the project. The goal of the design was to achieve savings of at least 50% when compared to an equivalent ASHRAE 90.1 compliant HVAC design for the building type. Passive Downdraft was identified early on as a innovate means to achieving deep savings in HVAC energy while also providing excellent air quality.

Many case studies of other projects that have tried passive downdraft have described water ingress, humidity and cooling capacity challenges with direct evaporative cooling. The passive downdraft concept adopted for the Conrad N. Hilton Foundation sought to avoid these well-documented issues by using cooling coils in the airstream at the top of the shaft instead or direct evaporative cooling. This would enable the natural ventilation airstream to always be conditioned in warmer months down to a supply air temperature of 65°F so that the system could maintain internal temperatures at 75°F at all times.

This concept drew from precedents from existing buildings which had used cooling coils as part of a passive downdraft design, including the National Institute of Dramatic Art foyer in Sydney, the NELHA visitor center in Kona, Hawaii and the School of Slavonic and Eastern European Studies in London.

*Fig 3: Passive downdraft chimneys at rooftop.*

## 4. CONTEMPORARY SOLUTION DESIGN OVERVIEW

The architecture of the Phase-1 office building sets a precedent for the future phases of the campus. As the product of a sustainability-driven design process, the building is a minimalist architectural ensemble. All elements of the built form serve at least one, and in most cases two or more, performance-driven requirements that create a resulting environment that expresses the integrated systems that work passively to make the building an uplifting place to work. Through the careful use of natural materials—stone, wood, glass—the architecture attains a sense of warmth and textural richness.

### 4.1 Building Massing to Achieve Net-Zero

The building's simple, rectangular form is sited East/West to optimize solar exposure and to respect the natural slope, enhancing the users' experience of the native hillside setting. The lucid, box-like form is eroded to allow views to nature and to admit daylight in diverse but controlled ways, creating a remarkably pleasant indoor environment. Further articulation of the form facilitates a dialog between building and site, with inhabitable outdoor spaces as extensions of the indoor environment, giving voice to the interface between the architectural form and the local landscape.

The narrow East-West bar parti is layered with offices and conference rooms along the North and South edges, optimizing daylight while minimizing unwanted solar gains. The office zones flank a double-height space that serves as a circulation spine as well as the social heart of the building. This inner atrium's ceiling is pushed up, admitting natural light via clerestory windows. The inner atrium sees additional controlled daylight and direct views out through glazing that opens to screened terraces at the East and West ends. The inner atrium also receives borrowed light from the perimeter offices through the use of internal clerestories, light shelves and tall, reflective ceilings.

The windows on the building's south façade are protected using exterior roll-down dynamic solar shades. The shades are deployed by a computer clock, with a manual override located in each individual office. Protection from solar gains is an integral part of the building's performance, tying the design of the envelope intrinsically with the design of the building's passive conditioning systems. The shading system's high wind rating allows it to operate on hot windy days, which are known to occur yearly during the Santa Ana wind events.

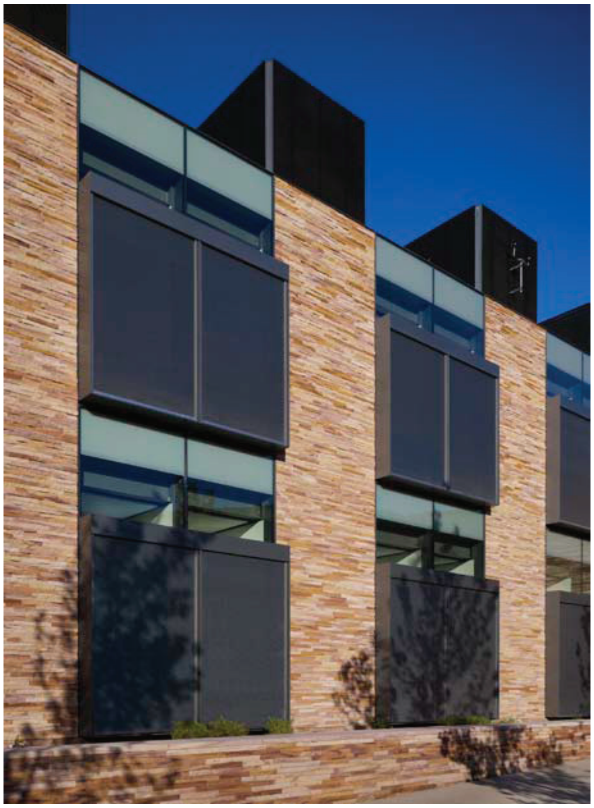

*Fig 4: Automated screens at south façade in lowered position.*

### 4.2 Improving Interior Performance Through Passive Lighting Design

Daylight is the primary light source used for all work and circulation areas within the building. The natural daylight in each space gives building's occupants the ability to control the electric lighting by turning artificial lights off during daylit hours. Also, daylight sensors turn off electric lighting when adequate daylight is available. Visual comfort is optimized by exterior shading and also by redirecting and redistributing sunlight. Interior finishes with high reflectance were carefully selected along with accent colors and finishes, to achieve maximum reflected daylight along with visual character and warmth. Occupancy and daylight controls run in series in the larger open areas to maximize energy savings.

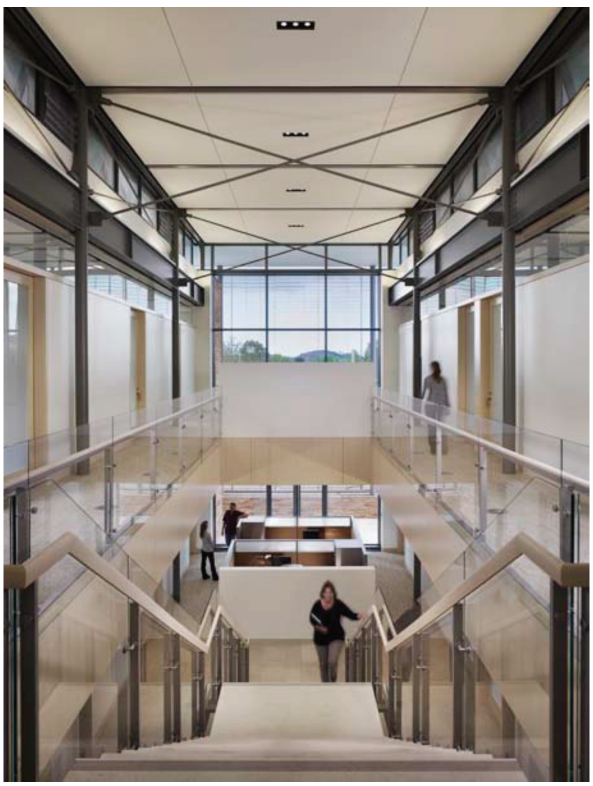

*Fig 5: Air is expelled through digitally controlled clerestory windows at top of atrium.*

## 5. DESIGN CHALLENGES RELATING TO BUILDING ENVELOPE

There were three key architectural challenges in integrating a passive downdraft system into the building enclosure: Space, Air Distribution and Solar Gain.

The airflow in a passive downdraft system is considerably slower than for a fan-driven conditioning system – about 200 fpm as compared with 1,000 fpm or more with a fan forced design. This placed added space requirements for vertical distribution of air on the project totaling approximately 2% of the floor area for air supply.

To address the space issue, the perimeter C-shaped structural piers were integrated into the ventilation system. By also using the piers as the primary lateral support, the overall impact of shaft space and structure to the floor area was greatly minimized. This enabled spans that will provide long term flexibility in the floor plate.

The second challenge regarding passive downdraft is air distribution. Many other examples of passive downdraft had used vertical faced openings to distribute the air for cooling and ventilation. Given the way that the building was being broken up into enclosed office space, this was not particularly practical for the foundation. As a result, a raised floor system was used for not only the ventilation distribution but also for the distribution of data and power. This enabled a high degree of control over the distribution of air into different spaces within the building.

The final key challenge of the enclosure was solar loads. As the passive downdraft system provides 100% conditioned outside air, direct solar loads at times of high external air temperatures can dramatically increase the energy of the building cooling. On the south façade, automated external shades provide extensive solar control whenever there is direct sun and high external air temperatures. This control strategy enabled the building to address solar gain at times that it would cause a spike in energy use but also gave control to the users during cooler months where some direct sun may be desirable.

The passive cooling intakes represented a customized solution that had not been used before in California. In response, the design team developed a pre-fabricated prototypical design that would be built up in a factory in Mexico and shipped to the site for assembly. This helped ensure that during construction there was a minimal risk of damaging any components of the system.

## 6. PREDICTED PERFORMANCE – REDUCTIONS AND RENEWABLE ENERGY TO ACHIEVE NET-ZERO ENERGY

The following table shows the expected performance of the facility as submitted for LEED. This shows that the expected energy usage of the facility is beyond net-zero annually as the PV system can generate more energy than the building uses. One of the most significant energy saving gestures was to use passive downdraft, which on its own is expected to save the project over 100,000kWh in fan energy.

| | LEED Baseline (kWh) | CNHF Design (kWh) |
|---|---|---|
| Lighting | 62,128 | 39,918 |
| Space Heating | 9,754 | 6,347 |
| Space Cooling | 54,746 | 7,328 |
| Pumps | 0 | 14,125 |
| Heat Rejection | 0 | 23,620 |
| Fans | 113,290 | 11,493 |
| Service Water Heating | 13,143 | 4,202 |
| Receptacle Equipment | 35,857 | 35,857 |
| Elevators & Escalators | 5,710 | 5,710 |
| Total | 294,628 | 148,600 |
| Savings over baseline | | 50% |
| 115kW PV Array Generation | | 167,449 |
| Percent of Energy Generated On-Site | | 113% |
| Total Energy Use Intensity (kBtu/sf/year) | | 22.6 |

**TABLE 1: Modelled Energy Performance**

The heating load in the design is also much lower than the baseline as the building has a 1,000ft² solar thermal array consisting of evacuated tubes and a 3,000 gallon storage tank. This is expected to provide almost 70% of the hot water heating and all of the domestic hot water for the project. Another significant portion of the energy savings is due to the ability of the passive downdraft system to eliminate fan energy.

## 7. NET ZERO THROUGH MEASUREMENT AND VERIFICATION

The next step towards a sustainable future for the building industry is verifying the actual performance of occupied buildings. Though buildings are designed to meet high performance targets many often fall short of their goals as buildings are occupied and operated. This is due to the fact that energy models have to make many assumptions about how a building will be operated and occupied. It is very common for buildings to have actual energy performance off by over 50% of what was modeled (Turner, 2008). This can be due to systems that are left on when not needed, others running at a very low level of performance and some not working at all. M&V in combination with advanced commissioning allow a design team to work with an owner to ensure a facility reaches its original design goals.

This building is currently undergoing its one year post occupancy M&V period which has already proven to be extremely valuable at finding issues in the building within the finest details that have a great impact on occupant comfort and energy performance.

### 7.1 M&V Process and Team:

In order to have a proper M&V process an owner needs to have a team working together after occupancy to ensure the performance of a facility. The team needs to include the contractor, commissioning agent, architect, design engineer and the M&V analysts.

The M&V team has been working closely to monitor the building operation since occupancy. As part of this process the team has had regular post construction coordination meetings to resolve conflicts in the building. In addition to this the commissioning agents are providing the data to the M&V analysts to use within calibrated energy models. This is required to be able to test the actual performance of the building compared to what was predicted through simulations during the design process.

### 7.2 M&V Overview and System Design:

A typical M&V process is setup with data dumps from a BMS that are in a spreadsheet format, such as CSV. This data can be analyzed to look for performance trends of systems. The challenge with this approach is that it takes a significant amount of time to post process the data and find the links between the components that you need to compare. This is especially true for finding problems that are unknown to anyone as they can be hidden in the numbers.

The following is a schematic diagram showing the transfer of information from the facility to the calibrated energy model. A unique component in the schematic is the use of analysis software that allows the team to interact with the data in an interactive and visual process. Many of the issues that have been found so far were found not through algorithms looking for relationships but through the visualization of graphs and charts which help to show issues with specific components.

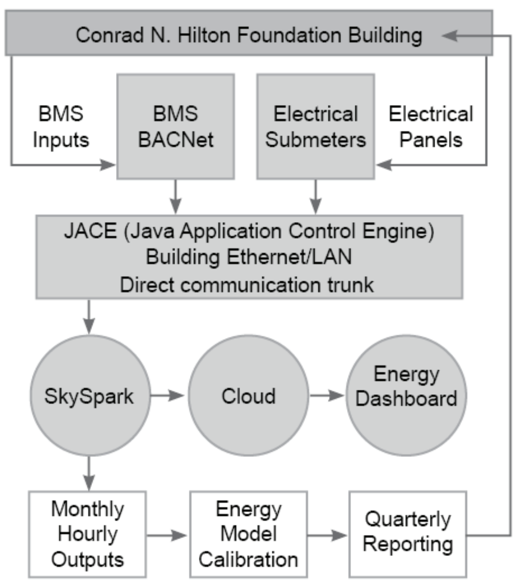


*Fig. 6: M&V communication schematic.*

The facility contains both an Alerton BMS system and electrical submeters that all directly communicate into a JACE system. The JACE is a data logger that takes all the information from all the different equipment and makes it usable with SkySpark, the analysis software used. SkySpark is setup on remote servers for the project collecting all of the information from the JACE and creating a large database that is used for analysis.

### 7.3 Trending Performance:

As part of the M&V plan seven rooms were given test shaft status with additional sensors to monitor the trending of performance in the shafts, raised floor and adjacent zones. The zones included typical conditions for the building including the boardroom, private offices and shared offices.

These detailed zones provide additional information to assist in understanding how energy use in the passive downdraft system relates to occupancy trends. The measurement sensors and energy meters have been designed and detailed in coordination with the commissioning agent to be able to fully optimize the performance of these systems. This detailed system monitoring will both help optimize the ventilation and energy performance of the passive downdraft ventilation system.

### 7.4 Outcomes of Post Occupancy Analysis:

At the time of writing this paper, three months of operational data had been collected for the project. The first quarter energy performance is currently being compiled as compared to a calibrated baseline energy model.

The energy results published in table 1 were established using Energy-Pro as part of the Title 24 and LEED reviews. Though Energy-Pro is a state-certified and LEED approved software, significant limitations exist in its ability to accurately model energy usage. This is partially due to its simplified controls. Currently the team is calibrating a new M&V IES-VE energy model. The building has been undergoing controls tweaks throughout the first period which has made calibrating the model very challenging. At this time, the calibration has not been fully completed and synchronized with the building controls.

Some key trends were clearly identified in the operational building data:

- The spaces are generally being maintained within the desired comfort range of 70-75F;
- PV and solar thermal outputs are in expected ranges;
- Heating energy was higher than initially expected due to unseasonably cold weather.

Through the analysis of operational data many items have been observed to require adjustments since occupancy. These have already made significant changes in the energy use of the facility. Aspects of system operation that have been changed as a result of the information provided by verification include:

- Morning warm-up controls
- Temperature set points in offices and corridors
- Under floor heating coil controls
- Lobby heating coil controls
- Exhaust damper and window controls
- Solar hot water controls

The common trend in all these adjustments is that they are all related to building controls.

There are many challenges with designing, implementing and maintaining proper controls of building systems as the interrelationships of one decision can have big impacts on another and might not be so obvious. The controls of the passive downdraft system are critical due to the passive nature of air movement and its need for the right conditions to perform.

The calibrated M&V energy model combined with SkySpark allow for improved commissioning (Visier & Buswell, 2010) based on energy performance rather than just equipment operation. These tools are allowing the team to make better informed control changes to improve the system's performance. During the M&V process the controls sequence has been updated a number times to accommodate different occupancy schedules than were expected and to optimize performance for occupant comfort during unusually cold weather in December and January.

As a result of controls changes, heating energy for equivalent days has already been reduced by over 50% and much closer to anticipated energy usage levels. The project is tracking to achieve its net zero operating goal and it shows the clear value in conducting post-occupancy verification of performance on all projects.

## 8. CONCLUSION

The Conrad N. Hilton Foundation building is a great step forward in net zero design showing that enhanced natural ventilation through the design of the passive downdraft is possible in modern buildings. The net zero building will continue to be monitored for the next year to verify performance and share its lessons with the larger design community.

## 9. ACKNOWLEDGEMENTS

We want to thank the Conrad N. Hilton Foundation for their commitment to sustainability and using this building as a reference case for net-zero buildings.

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# The Acoustic Performance of Double-Skin Glass Facades:

## A Design Support Tool For Architects

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*ABSTRACT: This study assesses and validates the influence of sound in the urban environment and glass façade components in responsively reducing sound transmission to the indoor environment. Among the most reported issues affecting workspaces, increased awareness to minimize noise led designers to reconsider the design of building envelopes and its site environment. Outdoor sound conditions, such as traffic noise, challenge designers to accurately estimate the capability of glass façades in acquiring an appropriate indoor sound quality. Field-measurements for sound transmission loss can establish a baseline performance in a context for sound levels common in urban areas. INSUL is a sound insulation software utilized as an informative tool correlating glass façade parameters with the outdoor sound level based on ISO 717 to predict indoor sound levels. This study validates the acoustic performance of glass facades early in a project's design through prediction methods and acoustic field-testing. Results from the study support that acoustic comfort is not limited to a singular solution, but multiple design options responsive to its environment.*

*Keywords: acoustic, urban noise, sound transmission loss, indoor environmental quality, double-skin facade, design support*

## 1. INTRODUCTION

One of the most frequently reported issues of indoor environmental quality (IEQ) affecting workspaces is noise breaking through the building façade. This concern has led building designers to reconsider the building envelope with regard to its performance resisting outdoor sound (Acoustics Continuing Education Unit 2009). The visual aspects of glass facades allow natural daylighting and transparency between the exterior and interior with the objective of improving IEQ, occupant comfort and productivity. In contrast to the available design guidance for other environmental aspects of the building façade, the influence of acoustics contributing on workspace comfort is not fully realized until after project completion. Determining and understanding the acoustic performance for glass facades during design remains a challenge for most projects, and is an area where designers are limited with acoustic guidance. Improved acoustic design guidance for building enclosures is needed to increase awareness of acoustic quality and its influence on occupant comfort. The intent of this study is to aid designers in making informed decisions for envelope design and material selection appropriate to the acoustic environment of the project site.

## 2. PROBLEM STATEMENT

While advances in design tools and facade performance criteria primarily focus on daylighting, thermal performance, and ventilation, acoustic design is often not the highest priority. Among these factors, the impact of acoustic performance in affecting workspace comfort is underestimated and confronted in every design project (Paradis 2012). Due to urban density, urban noise, and increasing levels of urbanization, designing towards acoustic comfort is an increasing design challenge. As urban environments vary, façade design solutions for one setting may not be applicable to, or effective in another. Each design project and each façade elevation requires sensitive consideration and response to site-specific acoustic conditions and material choices.

## 3. METHOD

The objective of this research is to provide acoustic design guidance to assist architects in designing glazed facades in areas where significant control of outdoor sound is needed. The approach is aimed at acoustic design support during early stages of design decision-making.

Methods included field-measurements using a hand-held sound meter device, and sound transmission simulations using INSUL, a sound insulation prediction software (INSUL 2011). Sound levels measured from field-measurements and INSUL simulation results were graphed on Microsoft Excel. Field-measurements were directly exported from the Decibel 10$^{th}$ application into Microsoft Excel. As an iPhone application, Decibel 10$^{th}$ is utilized as a sound meter that measures sound pressure levels. Composed by SkyPaw Ltd., Decibel 10$^{th}$ detects sound levels ranging from 0dB to 110 dB. Within the given timeframe, it identifies peak sound levels and maximum sound levels. Although Decibel 10th is not classified as Class I equipment, the iPhone application is used as relative measurement tool. It serves as a diagnostic tool to compare the relative difference between measurements.

Documenting its peak values in decibels, sound data was organized to compile indoor conditions and outdoor conditions for an overall comparison. Comparing the indoor condition to its actual outdoor condition was also documented to determine the acoustic performance of each condition's building enclosure. Implementing field-measurements, INSUL simulations in compliance with ISO standards, analytical simulations were obtained to provide realistic levels of traffic noise.

Focusing on sound transmission loss solely from façade assemblies, this study identifies indoor sound levels to derive from sound transmission loss from the building façade, dismissing room parameters influencing indoor sound levels. Although this research study focuses on sound transmission loss from façade components and parameters, INSUL simulations also determined room and façade parameters, such as room volume, reverberation time, and façade area, to influence sound transmission loss. Graphs for each simulation display outdoor sound levels, amount of transmission loss, and resulting indoor sound levels below 5000 Hertz. Graphs were initially classified by glass type and glass thickness for single-glazed facades and single-skin facades since building envelopes from field-tests were constructed of single-glazed facades.

Single-glazed facades contain one glass panel. Since the medium for six field-test sound conditions were single-glazed facades, single-glazed facades were simulated to determine the acoustic performance a façade with a single glazing. In this study, single-skin facades are composed of an insulated glazing unit, IGU. Standard dimensions for IGU is of two quarter-inch (1/4") glass panels separated by half-in (1/2") air space (Fig.1). For double-skin facades, graphs were also classified by glass type and glass thickness, along with air-cavity depth. Double-skin facades consist of an inner skin and outer skin-the secondary glazing separated by a specified air-cavity depth. The inner skin of double-skin facades are commonly composed of IGUs while the outer skin is a single glass panel; however, both skins can be composed of IGUs.

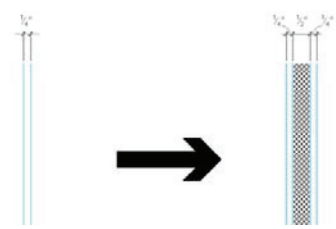

*Fig. 1: Diagram (left to right) Single-glazed and single-skin*

Simulated single-glazed facades and single-skin facades of three glass types were classified into three charts.

1. Monolithic glass
2. PVB laminated glass
3. TSC laminated glass

With each graph focusing on a glass type, it displays the indoor sound levels for industry-standard glass thickness. Glass thickness is indicated by its shade of color, the darkest shade corresponds to the largest dimension and lightens as the dimension decreases. Double-skin facades followed the same format as sealed single-glazed facades and sealed single-skin facades.

1. Monolithic glass
2. PVB laminated glass
3. TSC laminated glass

### *3.1. Field Testing*

Field-testing is performed to measure and establish baseline outdoor acoustic information, and to examine the efficacy of conventional curtain wall assemblies in reducing sound transmission. Measurements were taken at six existing sites in Los Angeles of office and study workspace occupancies (Table 1). Sites were selected from mapping high employment density and midday vehicular traffic, indicating a concentration of activities that are common noise conditions in an urban environment (Fig. 2). Noise conditions at sites included vehicular traffic and aircraft noise. Indicating traffic congestion as red line segments, mapped street traffic was attained from Google Maps' interactive traffic feature. Each site was recorded and documented within closely related conditions. In measuring and recording indoor sound levels, an iPhone, utilized as a sound meter using the Decibel 10th application, was situated no more than 3 meters from glazed facades. In efforts to respond to sound levels affecting the workspace environment, all field tests were conducted on weekdays between 12:00–15:00, during active business hours. To compile a range of sound levels and reduce isolated test conditions, outdoor and indoor sound conditions were measured and recorded within a 4-minute timeframe (Fig. 3-6).

It is fundamental to identify and understand the influence a façade design has on a workspace environment and its site conditions. Among the most challenging sound conditions is traffic noise, a common condition in the urban environment. Serving as initial measurements, the highest sound level obtained from field-testing- the most extreme condition, was implemented to weigh traffic sound spectrum simulated in INSUL, ISO 717. ISO 717, a rating of sound insulation in buildings and of building elements: airborne sound insulation, is defined as single-numbered values for airborne sound insulation in buildings and building elements, such as walls, flooring, doors, and windows (ISO 717).

Field-measurements were used as a correction factor to INSUL's ISO 717 traffic noise prediction method to resemble the outdoor sound environment results in increasing the accuracy of simulations. Field-measurements provided single-figured dB levels. Implementing field-measurements in INSUL's ISO 717 traffic noise prediction method, a 1/3-octave band sound spectrum was obtained. This strategy aims toward enabling designers to determine design goals to reduce sound transmission through the facade.

**TABLE 1: FIELD-TEST SITE CONDITIONS**

| Condition | Exterior | Interior | Area | Outdoor 4:00 | Indoor 4:00 |
|---|---|---|---|---|---|
| 1 | Downtown LA Bunker Hill | Central Library | Business | 60-100dB | 49-67dB |
| 2 | Downtown Culver City | Office | Business | 42-87dB | 45-76dB |
| 3 | LAX Arrival | Arrival | Transit | 65-90dB | 57-75dB |
| 4 | LAX Departure | Departure | Transit | 68-84dB | 57-82dB |
| 5 | USC | Tutor Hall | Education | 59-79dB | 41-71dB |
| 6 | USC | GER Library | Education | 50-75dB | 40-65dB |

*Fig. 2: Mapped sound levels in Los Angeles: Intensity of red indicating increased sound levels with reference to concentrated traffic (staggered streaks)*

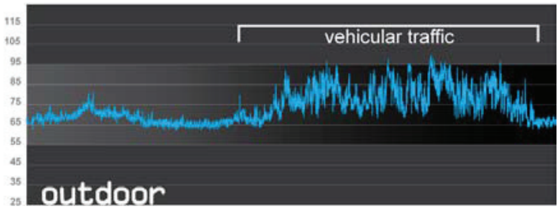


*Fig. 3: Field-tested outdoor sound level: Bunker Hill & LA Central Library*

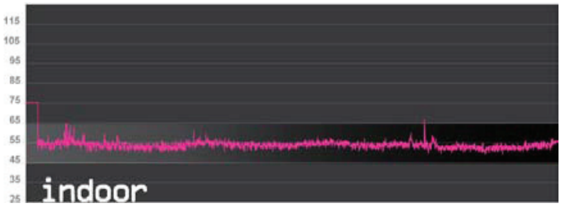


*Fig. 4: Field-tested indoor sound level: Bunker Hill & LA Central Library*

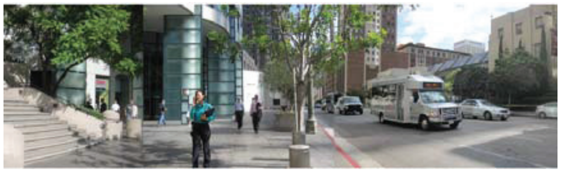

*Fig. 5: Field-tested outdoor condition: Bunker Hill*

*Fig. 6: Field-tested indoor condition: LA Central Library*

### *3.3 Sealed Single-Glazed Facades and Sealed Single-Skin Façades*

The intent of assessing sound transmission loss from glass facades through simulations was to further analyze the performance of double-skin glass facades in reducing sound transmission from immediate distanced outdoor levels within frequencies to 5000Hz. Frequencies indicate the number of cycles-per-second (cps) a sound pressure wave repeats in hertz (Hz) and is used to determine the audible range of human hearing, 20Hz to 20,000 Hz. Sound levels measured at 5,000 Hz are audible to humans. Sound levels (dB) indicate whether the audible sound source is identified by the human ear as sound or noise.

In accordance to EN ISO 717, varying conditions of sealed facades were simulated (British and International Standards 1997). Weighting ISO 717 sound levels with the maximum outdoor sound level from field-tests, 90dB, increased the accuracy of simulations to resemble a realistic setting as well as adjust sound levels to be audible Since field-test conditions consisted of single-glazed facades, 12 single-glazed facades were simulated in INSUL to determine the acoustic performance of a façade with single-glazing (Fig. 7).

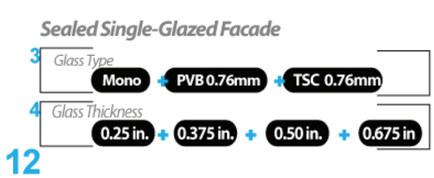


*Fig. 7: Classified conditions indicating number of simulations achieved for sealed single-glazed facades*

In analyzing the acoustic performance of single-skin facades, 12 iterations derived from variables such as glass type and glass thickness. Selected glass types, such as monolithic, PVB Laminated Glass (PVB), and Trosifol Laminated Glass (TSC), and glass thickness simulated for this study are typical models in the most glass manufacturing companies. five standard glass thickness were analysed (Fig. 8).

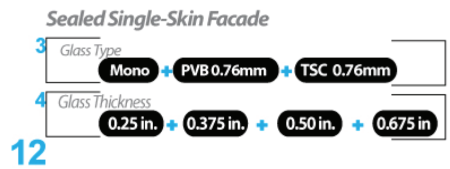


*Fig. 8: Classified conditions indicating number of simulations achieved for sealed single-skin facades*

Comparing transmission loss obtained from both forms of façade assemblies (single-glazed and single-skin) determined the amount of transmission loss improved by adding an additional glazing. In addition to comparing sound transmission loss in field-tested conditions and simulated conditions, data obtained from field-tests served to validate the accuracy range of INSUL's estimations. Demonstrated to provide sound transmission loss estimations within close range of single-glazed facades field-tested, double-skin glass facades were modelled and simulated within the same INSUL configurations used to simulate sealed single-glazed facades and sealed single-skin facades.

### *3.4. Sealed Double-Skin Glass Façade*

Using INSUL, sealed double-skin facades composed of three glass types were simulated under varied components. Considering standard parameters, three glass types, four thickness and four air-cavity depth, 48 were analyzed (Fig. 9).

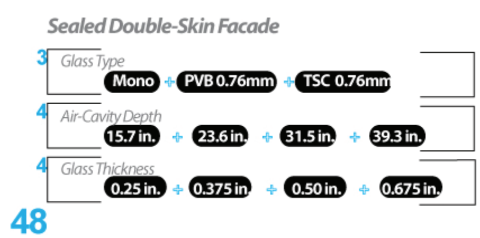


*Fig. 9: Classified conditions indicating number of simulations achieved for sealed double-skin facades.*

## 4. RESULTS

With field-measurements involving single-glazed facades as its enclosure, measured and recorded site conditions served as a baseline differentiating outdoor sound levels and indoor sound levels (Table 1). Identifying differentiations between outdoor and indoor conditions in decibels (dB), its highest noise levels for traffic was implemented into simulated sealed single-skin facades and sealed double-skin facades. Obtained from field-tests, inputting the highest outdoor sound level to weight INSUL's standard traffic noise (ISO 717) provided a more realistic setting for the analysis.

Sound transmission loss (dB) obtained using INSUL were ordered by four standard glass thickness and separated based on the three laminate types: monolithic, PVB, and TSC. All graphs display the same outdoor sound level used in simulations as a white horizontal segment. It serves as a reference line to determine the magnitude of sound transmission loss due to varying parameters.

Simulated sealed single-glazed facades and sealed single-skin facades were composed into 3 charts separated by glass type. Displaying the influence of glass type and glass thickness in reducing sound transmission, indoor sound levels resulting from the remaining outdoor sound level transmitted through IGUs of four standard *glass thickness correspond to a shade of a given color*. The darkest shade of a given color indicates the thickest glass simulated. Sharing the same given color, each shaded segment indicates the indoor sound levels of a glass thickness. As the darkest shade indicates the largest glass thickness, lighter shades represent the smaller glass (Fig. 10).

For sealed double-skin facades, results were formatted similarly to the results for sealed single-skin facades; however, considering an additional component, air-cavity depth, require graphs to be separated based on glass thickness and glass type. Instead, the color-shaded plots indicate the air-cavity dimension. Three charts of the same glass thickness consist of four horizontal plots, indicating four standard air-cavity dimensions. Displaying indoor sound levels within frequencies of 5,000Hz, graphs separated by thickness and glass type compare the acoustic performance of air-cavity dimensions (Fig. 11). Comparison from single-glazed facades to single-skin facades, and single-skin facades to double-skin facades validated improved transmission loss.

### *4.1. Sealed Single-Skin Facades*

Sealed Single-skin facades with laminated glass, either PVB or TSC, provided significant transmission loss in mid-frequencies. Using PVB laminated glass increased transmission loss by increasing glass thickness in mid-frequencies while smaller thickness provided greater transmission loss in higher frequencies. Although TSC laminated glass is claimed by product manufacturers to improve transmission loss by at least 3dB compared to PVB laminated glass, this study determined TSC to improve transmission loss by 1dB (Kuraray Trosifol).

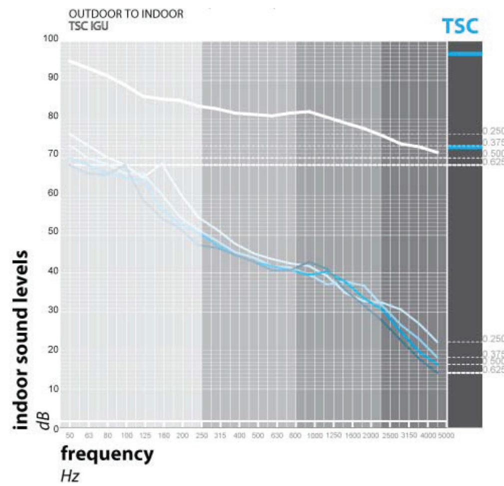


*Fig. 10: Sealed single-skin façade under ISO 717, TSC*

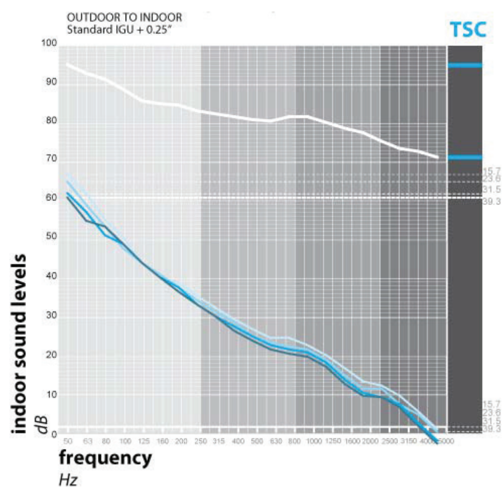


*Fig. 11: Sealed Double-Skin Façade under ISO 717, TSC*

### *4.2. Sealed Double-Skin Facades*

Increasing the air cavity depth for double-skin facades effectively reduced sound transmission within higher frequencies. Towards lower frequencies, air-cavity depth linked with maximum glass thickness improved sound transmission loss. Although double-skin facades dramatically reduce sound transmission in comparison to single-glazed facades and single-skin facades, increasing the air-cavity depth minimally improves sound transmission loss by 1 to 2 dB.

Simulating sealed single-glazed facades, sealed single-skin facades, and sealed double-skin facades, increasing the air-cavity dimension provides increased sound transmission loss in comparison to glass thickness.

## 5. DISCUSSION AND CONCLUSIONS

Using INSUL simulations configured to resemble realistic settings, sealed double-skin facades demonstrated to improve sound transmission loss. However, responding to higher frequencies, the amount of sound transmission loss was not dramatic as transmission loss achieved within frequencies below 500Hz.

Field-testing is a fundamental procedure that reflects noise conditions in the current environment. In determining the components of a building's glass facade, measuring existing conditions of its site enable building designers to specifically address to its sound environment. As field-tests were conducted in Los Angeles' most concentrated commercial areas and traffic intersections, the simulations and design support tool provides designers design solutions that would specifically respond to its current context.

Composed from INSUL simulations and field-testing, the design support tool enable building designers to compare transmission loss based on façade components within frequencies below 5000 Hz (Fig. 12).

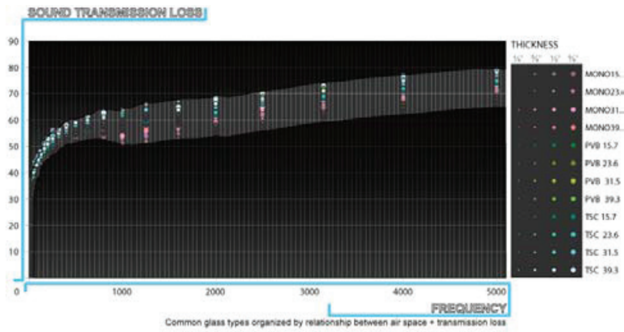


*Fig. 12: Design support plot for double-skin facades: Common glass types organized by relationship between air space and transmission loss.*

Utilizing this study's approach can increase building designers' awareness in designing glass building enclosures and its response to its acoustic environment. This study approach demonstrates the careful consideration necessary to provide acoustic comfort. As the methods conducted in this study redefines acoustic design for glass facades, it provides designers the opportunity to collaborate with the city in continuing efforts to improve indoor acoustics as well as environmental acoustics.

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# Thermal, Visual and Energy Performance in LEED buildings:
## Two Case Studies

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*ABSTRACT: The sustainability movement has influenced and changed the architecture practice and client's expectations. After focusing on building aesthetics and code compliance for many years, the architecture practice has been educated to put more responsibility in the building performance by the recent sustainability movement. This responsibility shift affects how architects approach a design and how design excellence is perceived.*

*This paper focuses on the use of post occupancy evaluation (POE) in thermal, visual and energy performance in HMC's Concours and Frontier projects, two LEED certified buildings. The evaluation of design intent versus real performance was analyzed by using measurement and statistical models. Both subjective and objective measurements were employed. To analyze energy performance, the actual energy usages were compared with initial energy simulation calculation.*

*Due to POE, problems were found with both buildings, but overall the buildings performed fairly well. Based on the findings, the corrective measures were taken to remedy the buildings and to enhance the building performance. In energy performance, the assessment showed that the energy model was capable of predicting the trending of the real usage although there were some number discrepancies.*

*Keywords: Thermal Comfort, Visual Performance, Daylight, POE, Energy*

## 1. INTRODUCTION

The green building movement has grown into a major architectural discourse to create ideal cities in the mid-21st century. Unfortunately, the movement has been focused on implementing sustainability metrics such as LEED and green building codes. The implementation of the metrics and codes that form sustainable buildings and cities assist designers in determining their sustainability target during the design process, but there is a discrepancy between the target and the real performance of the buildings - especially in thermal, visual and energy performance. Therefore, Santosa (2007) suggested that the post construction performance shall be included in the LEED rating system.

To determine the real performance, a post occupancy evaluation (POE) is the key. Preiser (2002) described the origin of POE which was started in the late 1960s. The latest step in the evaluation of POE is to emphasize a holistic and process oriented approach to evaluation. The following research was based on two LEED buildings, the Concours Office Building and the Frontier Project. In the two cases, thermal, visual and energy performance were studied along with the correlation between the sustainability target and the real performance of the buildings. The Concours Office Building is HMC Architects' Ontario, California office and it is LEED Silver certified under LEED version 2.1. The Frontier Project is LEED Platinum certified under LEED version 2.2. The buildings are only three miles apart.

POEs consisted of subjective and objective measurements. The subjective measurement was based on the occupant responses in thermal performance and visual performance; while the objective measurement was based on the data collection based on the measurements. In energy area, the real energy usage would be compared to the LEED energy simulation performance results.

Regarding the benefits of the POE, Preiser (2008) mentioned that the POE, a rigorous systematic assessment of past successes and failures, can build knowledge, improve future designs, and demonstrate the contributions of the design professions to the community. Additionally, the Higher Education Funding Council for England (2006) defined 3 type benefits such as short term, medium term and long term benefits. The short term benefits include:

- identification of and finding solutions to problems in buildings;
- response to user needs;
- improve space utilisation based on feedback from use;
- understanding of implications on buildings of change whether it is budget cuts or working context; and
- informed decision making.

For medium term benefits, they consist of:

- built-in capacity for building adaptation to organizational change and growth;
- finding new uses for buildings; and
- accountability for building performance by designers.

Moreover, the longer term benefits are

- long-term improvements in building performance;
- improvement in design quality;
- strategic review

For the research, the intents are to provide feedback to the building management for improving their building performance and to give invaluable information for the designers, especially at HMC Architects, for enhancing their design. Moreover, the study proposes solution for issues in those building, to enhance the performance and to increase occupant satisfaction.

## 2. Project Backgrounds and Methodology

The research studies two LEED certified buildings that are HMC Concours (See Figure 1: HMC Concours (photo: Ryan Beck)) and Frontier Project (See Figure 2: Frontier Project (Photo: Ryan Beck)). HMC Concours has received LEED Silver certification level under LEED version 2.1 and the project achieved 34 points. Frontier Project (See Figure 2: Frontier Project (Photo: Ryan Beck)) is a showcase building for energy efficiency and sustainable strategies. The second floor of the project is used for the office area for Cucamonga Valley Water District, the owner of the building. The Frontier Project received LEED Platinum certification level under LEED version 2.2 with 56 points.

Both projects achieved different level certifications, but for thermal performance and visual performance related credits, the projects have similar credits achievements. Additionally, during the certification process, the HMC Concours building substituted some its version 2.1 credits requirement with version 2.2 credits.

| | | HMC Concours | Frontier Project |
|---|---|---|---|
| I. | Minimum IAQ Performance | ✓ | ✓ |
| II. | Outdoor Air Delivery Monitoring | ✗ | ✓ |
| III. | Increased Ventilation | ✗ | ✗ |
| IV. | Controllability of Systems: Thermal Comfort | ✗ | ✓ |
| V. | Thermal Comfort: Design | ✓ | ✓ |
| VI. | Thermal Comfort: Verification | ✓ | ✓ |

**TABLE 1: THERMAL PERFORMANCE RELATED CREDITS**

| | | HMC Concours | Frontier Project |
|---|---|---|---|
| I. | Controllability of Systems: Lighting | ✓ | ✓ |
| II. | Daylighting and Views: Daylight 75% of Spaces | ✓ | ✓ |
| III. | Daylighting and Views: Views for 90% of Spaces | ✓ | ✓ |

**TABLE 2: VISUAL PERFORMANCE RELATED CREDITS**

The Frontier Project achieved more the thermal performance credits than the HMC Concours building, but both buildings achieved the same visual performance credits. (see Table 1 and Table 2).

*Figure 1: HMC Concours (photo: Ryan Beck)*

In the optimize energy performance credit, the frontier project performed 45.8% better than Title 24 2005 and earned 10 points while the Concours performed 17.9% better than Title 24 2005 and earned 3 points based on the energy simulation calculation.

*Figure 2: Frontier Project (Photo: Ryan Beck)*

For the data collection sampling method, each building used a different sample type due to its number of occupants and its occupancy type. The HMC Concours Building used cluster sampling method based on sitting locations that represent the relationship between the building orientation and the proximity to the windows. There were 5 sitting areas that were investigated in the study. The data collection focused on the open space office area where most of the occupants were located in the building. For the Frontier Project, since the number of the occupants is relatively small, the survey forms were provided to all full time employees that are seven persons.

As a result, 41 survey responses from the HMC Concours and 6 survey responses from the Frontier Project were collected. The collected data were utilized to analyze thermal performance and visual performance. Because the HMC Concours had bigger sampling data and different cluster sitting areas, the more robust and detailed statistical method by using ANOVA would be employed.

### 3. Thermal Performance Data and Analysis

3.1. Thermal Performance Data – HMC Concours

Based on the survey, the thermal performance result was summarized in two major areas such as: occupant temperature perception (see Figure 3: Occupant Temperature Perception during Winter and Summer at HMC Concours) and occupant thermal comfort perception (see Figure 4: Thermal Comfort Perception at HMC Concours).

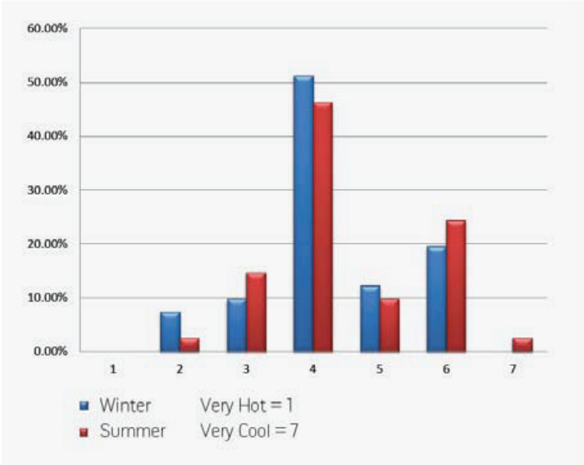


*Figure 3: Occupant Temperature Perception during Winter and Summer at HMC Concours*

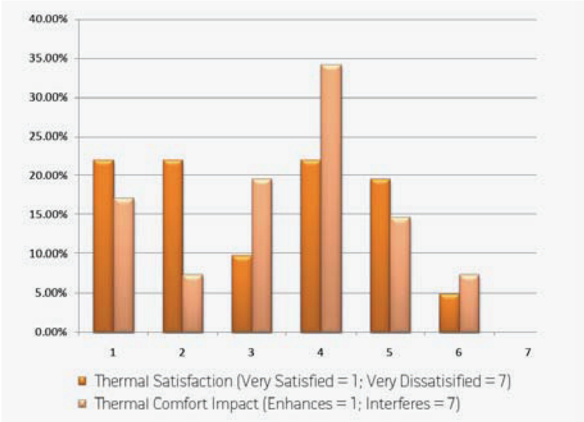


*Figure 4: Thermal Comfort Perception at HMC Concours*

Based on the feedback, there was 24% dissatisfaction in the thermal comfort perception. This number was slightly higher than LEED and thermal comfort condition standard that requires no more than 20% dissatisfaction. The result aligned with the occupant temperature perception that described the temperature tended cooler during summer and winter.

To analyze the thermal impact perception, Anova method was utilized to see the perception in each cluster. The result (see Figure 5: Anova Analysis for the impact of thermal comfort) showed that the thermal impact perception to the staff performance was same because the F was lower than F critical.

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Seating Group 1 | 2 | 5 | 2.5 | 0.5 |
| Seating Group 2 | 7 | 23 | 3.285714286 | 1.571428571 |
| Seating Group 3 | 13 | 50 | 3.846153846 | 1.807692308 |
| Seating Group 4 | 12 | 47 | 3.916666667 | 2.628787879 |
| Seating Group 5 | 7 | 16 | 2.285714286 | 1.904761905 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 16.1314438 | 4 | 4.03286094 | 2.017379837 | 0.1127238 | 2.633532094 |
| Within Groups | 71.9661172 | 36 | 1.999058812 | | | |
| | | | | | | |
| Total | 88.097561 | 40 | | | | |

*Figure 5: Anova Analysis for the impact of thermal comfort at HMC Concours*

Looked the average number of the each cluster only, the occupants expressing that the thermal performance interferes their ability to work are all located in the north part of the building. However, it was statically not significant to conclude the impact perception was different.

The temperature and humidity information were also collected. The result described the temperature and humidity was well-controlled across the cluster areas (See Figure 6: Temperature and Humidity data at HMC Concours)

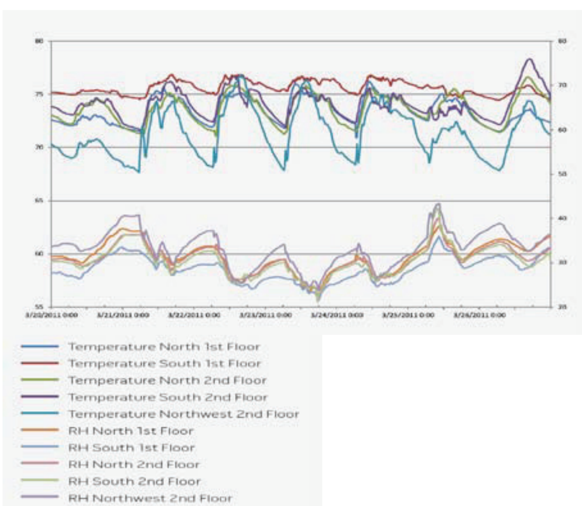


*Figure 6: Temperature and Humidity data at HMC Concours*

3.2 Thermal Performance Data – Frontier Project
In the two thermal major areas, the result of the survey at the Frontier Project demonstrated that the building performed slightly better than HMC Concours (Refer to Figure 7: Occupant Temperature Perception during winter and summer at Frontier Project and Figure 8: Thermal Comfort Perception at Frontier Project).

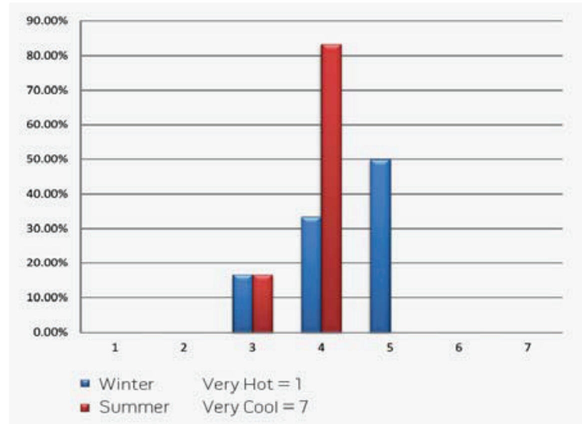


*Figure 7: Occupant Temperature Perception during winter and summer at Frontier Project*

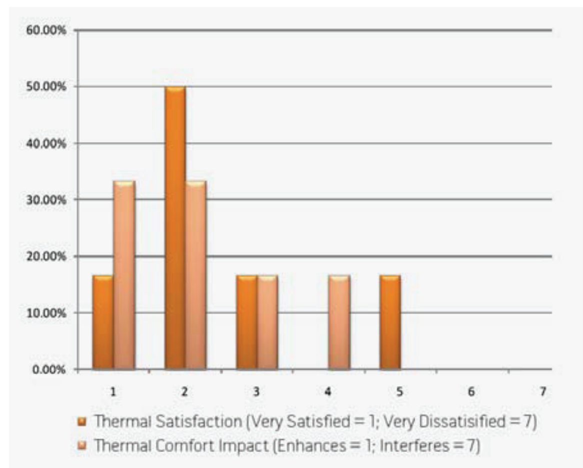


*Figure 8: Thermal Comfort Perception at Frontier Project*

The better performance was illustrated in both above figures showing the thermal comfort for the staffs were good and conformed to the design intent. The dissatisfaction was less than 20% in this building. The occupant temperature perception also showed a comfortable range (all occupants responded in from 3 to 5 range value in the Figure 7: Occupant Temperature Perception during winter and summer at Frontier Project). Based on the interview with the facility manager, he said that he was very satisfied with the HVAC system for the office area located on the second floor of the building. The Frontier Project uses VRV system for that area.

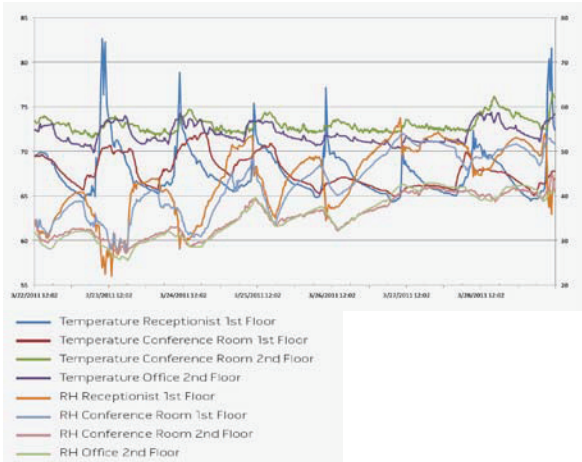


*Figure 9: Temperature and Humidity data at Frontier Project*

Data loggers were also located at Frontier Project for a week to verify the performance of the systems. Interesting findings were found. The second floor where the staffs work on showed comfortable temperature and humidity range. However, the first floor supplied by the under floor system with evaporative cooling unit had slightly high temperature during noon time. The high temperature was expected during the design since the system relies on 100% OSA (outside air). However, the thermal condition would be sufficient to provide comfort to the visitors in the exhibition area.

3.3. Visual Performance Data – HMC Concours

To identify the visual performance and its relationship with the LEED points, the survey was conducted with focusing on electrical lighting performance and daylight performance. The result described that the building performed well in term of the visual performance. The less preferable and negative responses were less than 10% for this survey (see Figure 10: Visual Performance Survey at HMC Concours)

There were a few comments from occupants regarding the lighting performance. Some of them concerned about the direct sunlight during certain time. To address the issue, the automatic blinds were adjusted accordingly to eliminate the direct sunlight coming to the office area.

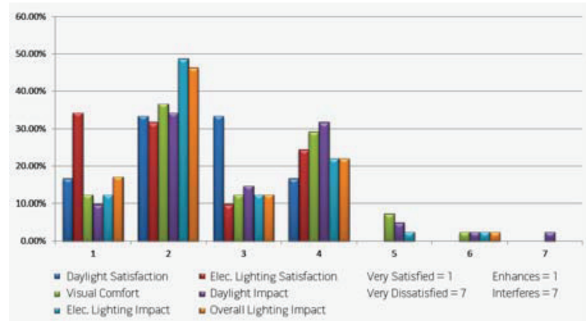


Figure 10: Visual Performance Survey at HMC Concours

The measurements were also taken in the sampling cluster areas by using a light meter on March 20th at 12 noon. The results (see Figure 12: Illuminance level samplings on the first floor at HMC Concours and Figure 13: Illuminance level samplings on the second floor at HMC Concours) showed that the lighting levels were at least above 20 fc.

The design intent in the building was to keep the illuminance level in the lower side of the standard requirement because the occupants work primarily with computers and they could request task lightings on their desk. There was no complaint or comment regarding the electrical lighting from the occupants in this survey.

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Seating Group 1 | 2 | 8 | 4 | 8 |
| Seating Group 2 | 7 | 16 | 2.285714286 | 0.571428571 |
| Seating Group 3 | 13 | 30 | 2.307692308 | 1.730769231 |
| Seating Group 4 | 12 | 31 | 2.583333333 | 1.174242424 |
| Seating Group 5 | 7 | 17 | 2.428571429 | 0.619047619 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 5.41514786 | 4 | 1.353786965 | 0.998107184 | 0.4212375 | 2.633532094 |
| Within Groups | 48.8287546 | 36 | 1.356354294 | | | |
| | | | | | | |
| Total | 54.2439024 | 40 | | | | |

*Figure 11: Anova Analysis for the impact of lighting performance at HMC Concours*

ANOVA analysis was also conducted in here. Similar to the thermal performance, there is no significant different among the clusters in the lighting performance impact perception.

*Figure 12: Illuminance level samplings on the first floor at HMC Concours*

*Figure 13: Illuminance level samplings on the second floor at HMC Concours*

### 3.4. Visual Performance Data – Frontier Project

Similar to the HMC Concours, the survey collected the visual performance information at the Frontier Project. The result showed interesting information (see Figure 14: Visual Performance at Frontier Project). Most occupants felt satisfied with the daylight performance but they were dissatisfied with the electrical lighting. 50% of the respondents concerned about the electrical lighting performance in this building.

The follow-up interview revealed that the problem was in the photo sensor. Apparently, the furniture cubicle system that has high partitions did not reflect the original design intent that allowed the daylight to penetrate inside the room (See Figure 15: The Interior of the office area at Frontier Project). The measurement taken in the office area on March 21st at 12 noon also showed the similar issue. The daylight wasn't distributed evenly. To resolve the issue, the corrective measure by adjusting the photo sensors were planned and conducted.

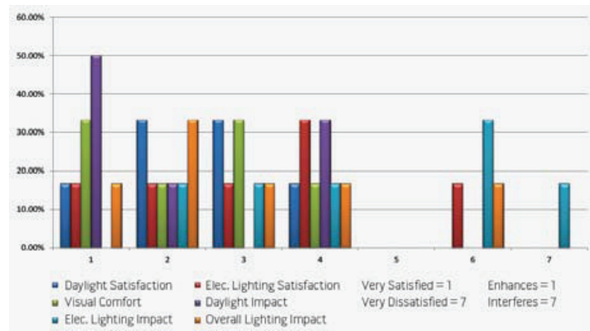


*Figure 14: Visual Performance at Frontier Project*

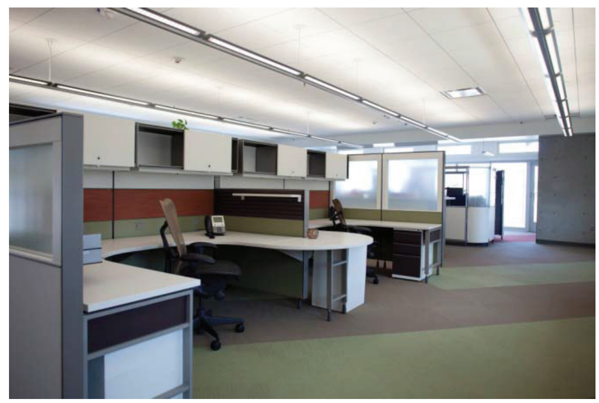

*Figure 15: The Interior of the office area at Frontier Project*

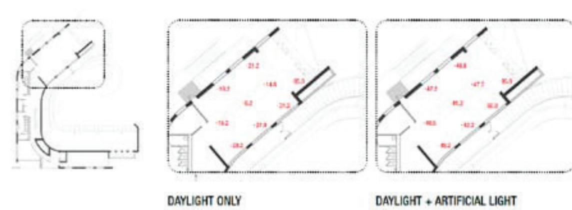


*Figure 16: Illuminance measurements at Frontier Project*

### 3.5. Energy Performance Data – HMC Concours

To study the energy performance data, the real usage was collected based on the energy bill. The data from the energy bill was compared to the energy simulation result that was submitted for the LEED certification.

The result showed that the electricity actual usage was 28% higher than the predicted number (see Figure 17: HMC's predicted energy usage vs. actual usage). Based on the analysis, the discrepancy was occurred because of the longer office hours and the plug loads in the building. The problem in temperature consistency shall be conducted later to determine the direct correlation between the occupant thermal comfort issue and the energy usage.

Additionally, the natural gas actual usage showed higher usage than the predicted number due to the longer office hours, and the load of the equipments.

More detail assessment in this issue may be required to get more detailed explanations. However, the current information showed similar trending between the predicted usage and actual usage.

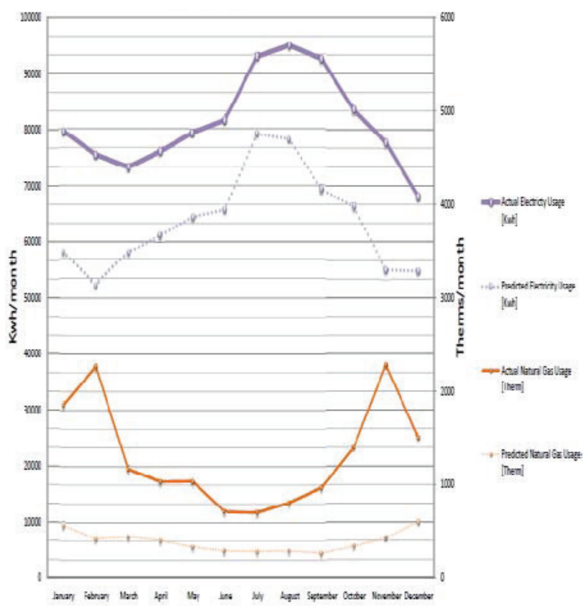


*Figure 17: HMC's predicted energy usage vs. actual usage*

3.6. Energy Performance Data – Frontier Project
For the Frontier Project, the real data was collected based on the touch screen kiosk that is available in the exhibition area.

Comparing to the HMC Concurs, the real usage at Frontier Project was very close to the predicted energy usage. The discrepancy between both data was only 0.1% in the electricity usage and 6% in PV production, while the natural gas real usage was 41% from the predicted one. (see: Figure 18: Frontier Project's predicted energy usage vs. actual usage)

Per initial analysis, the heating portion in the first floor might be less than what we initially predicted in the energy model. The higher occupancy during the event and instantaneous heat gain may be the primary source. However, the further study shall be conducted to test the initial analysis/hypothesis.

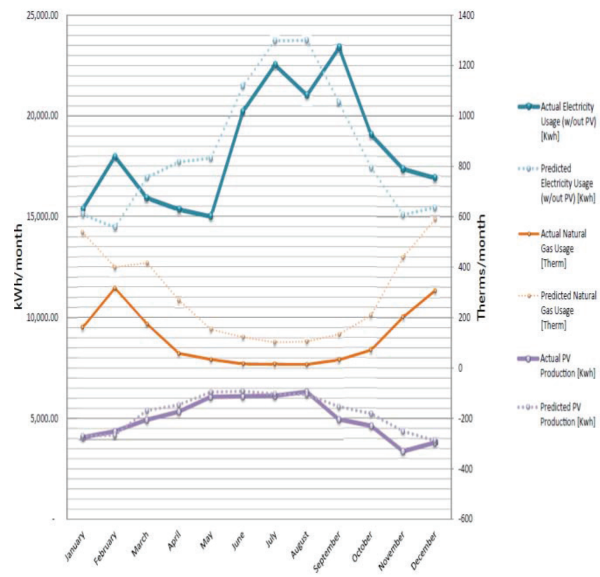


*Figure 18: Frontier Project's predicted energy usage vs. actual usage*

## 5. CONCLUSION

Both projects were designed to achieve the thermal comfort. However, there were few problems found during the POE which showed that the thermal comfort had not been accomplished. The problems were related to more to the installation than to the design process.

In lighting performance, both projects achieved same points. Although most of the occupants in both projects were satisfied with the lighting performance, each project had different issues the lighting system. The HMC Concours had an issue with the daylight while the Frontier Project had an issue with the electrical lighting.

The study in the energy area revealed that the predicted energy simulation could provide good trending information for the real energy usage, although there were discrepancy numbers. By comparing the energy usage, thermal performance and visual performance, there were a few initial relationship that can be analyzed further to reveal the issues.

The research was able to reveal and identify a few problems in the buildings. As a result, the corrective measures had been exercised to enhance the performance the building. The implementation of the POE definitely has assisted the buildings performing better. Therefore, the POE shall be conducted in each building to enhance its performance and to give feedbacks to the designer on how his/her design works and impact the occupant satisfaction.

## 6. ACKNOWLEDGEMENTS.

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# BIOGRAPHY'S

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Alya Al-Hashim is a graduate student at the University of Arizona, majoring in Masters of Science in Architecture. Her thesis topic is about creating an energy performance baseline for residential buildings for her country Oman. She earned her Bachelor's degree in Architectural Engineering from Sultan Qaboos University, Oman. She worked in an architectural firm called (Simon Engineering), where she worked on various projects and developed interest in Energy Conservation and BIM system.

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## MONA AZARBAYJANI

Mona Azarbayjani is an Assistant Professor School of Architecture at the University of North Carolina at Charlotte (UNCC) where she is currently teaching Design Studio, core building technology courses, Energy Simulation and the use of renewable energies in architecture. Dr Azarbayjani holds a PhD from the University of Illinois Urbana Champaign. She is the Project manager and faculty team leader for the UNC-Charlotte Solar Decathlon team 2013. Her research in energy performance, natural-ventilation, High performance skins, and carbon neutral building will serve current building technology expertise in the Integrated Design Labs, Energy Performance Lab (EPL).

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## DALIA HAFIZ

Dalia Hafiz is a PhD student in the school of Architecture and Design in Virginia Poly-technique Institute. Dalia received her master's of Architecture in May 2011 from the same school. She received her engineering architecture bachelor degree in July 2007. Passion in Architecture is her motivation in life. She loves designing using virtual models, that's the way she feels the building with all senses. She is Interested in Environmental design and Daylighting use in buildings.

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Tasha Halevi's leadership in the education of green building concepts has been instrumental in the creation and execution of Energy Design Resources (EDR)'s DesignShift Charrette . She has lead teams of instructors in teaching the EDR DesignShift Charrette to California university students, as workshops for professionals, and at conferences including Rocky Mountain Green (USGBC Colorado). In practice, Halevi has worked with teams to achieve LEED certification on over 25 buildings, created hybrid integrated design processes for projects, and has worked on energy use research. Halevi also hosts Footprint Radio for the Colorado Green Building Guild on KGNU Boulder/Denver.

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Simi Hoque teaches courses in sustainable building systems. Her focus is on the design and optimization of environmental controls. Current research is on occupant comfort and parameters that improve indoor environmental quality. She is also working with colleagues in Urban Planning on urban metabolism modeling for sustainability, combining energy modeling with policy evaluation tools. She is trained as an engineer, architect, and mechanical systems designer.

## MING HU, AIA, LEED-BD+C, AP

Ming Hu, AIA, LEED-BD+C, AP, is Project Designer and Project Architect at HOK. HOK is international leading design firm in sustainable design. Her creative work, teaching and researching interests and specialties have been Sustainable Design, High Performance Design and new Digital Design Technology. Sustainable design is shifting from LEED certification to the true performance-based design. Her specialty in array of BIM technologies and environmental simulation tools allow her to lead the integrated sustainable process in big-scale and complicate project.

She is adjunct faculty in the School of Architecture, Planning at the Catholic University of America where she taught in the comprehensive design studio program, "Environmental Design I" and 'Environmental Design II". She now is focusing on integrating the energy simulation process into the lecture course and design studio.

Hu served as a member of City of Rockville, Environmental Committee. The commission consists of Rockville residents appointed by the Mayor & Council. The purpose of this commission is to recommend policies and programs to the Mayor & Council relating to the environment.

Her presentation include "Form Follow Performance: Case Studies of Daylight Design and Computer Simulation" ( 2nd International Conference for Sustainable Design, Engineering and Construction); "Performance-Based Design": (18th International Conference of Associate of Computer-Aided Architectural Design Research in Asia). Her publication include " Zero Energy for High-Rise Building: Challenge and Strategies" (Building Enclosure Sustainability Symposium/Sustainable Building 2013).

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Karen Kensek is an Assistant Professor at the USC School of Architecture. Her current research work includes building information modeling, BIM analytics, virtual reconstruction of ancient places, and digital design. Kensek has hosted six BIM symposia at USC from 2007 to 2012: education, sustainable design, construction and fabrication, analytical BIM, extreme BIM, and practical BIM. Under her leadership, the School was honored with the Autodesk Revit BIM Experience Award in 2008 and an AIA TAP BIM Award (honorable mention) in 2010.

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Tomas Mikeska is in second year of his Phd studies at Technical University of Denmark, Department of Civil Engineering. The project, Tomas is working on, focuses on Radiant Heating and Cooling Systems and Diffusive Ceiling Ventilation integrated into the highly insulated sandwich panels made of High Performance Concrete. His main interest lies in the development of sustainable buildings by applying different kind of innovative technologies and "common sense" resulting in extraordinary solutions.

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Erin Moore is Assistant Professor in the Department of Architecture at the University of Oregon where she works in teaching, research and practice on lifecycle thinking in ecology, design and construction. She uses her research practice FLOAT as a testing ground for designing with explicit intentions for the life spans of materials. She teaches design studios, Introduction to Building Construction, and is currently teaching Molecular Innovation in Material Lifecycles, focusing on concrete and polymers.

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Peter Simmonds is Chair of TC 9.12, Tall Buildings,
Member of TC 2.1, Thermal Comfort,
Member of TC 6.5, Radiant Heating and Cooling,
He has been a member of SSPC 55, Thermal Comfort since 1996,
Member of the Handbook Committee for the chapter Fundamentals
A member of ISO 205, workgroup 8, radiant heating and cooling,
He is one of the prime authors of the new ASHRAE/REHVA Beam design guide.

He has authored or co-authored more than 60 technical papers, articles and books. Publications of his work led to the development of radiant systems in the USA and are included in the ASHRAE Handbooks. He has received the Carter Bronze Medal from the Chartered Institution of Building Services Engineers in 1993.

Peter also teaches Graduate and Post Graduate Architectural students at the University of Southern California and Woodbury University.

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Lena Spiric is a graduate student at the University of Arizona's (UA) MS in Architecture program. Originally from Nis, Serbia, Lena is an alumnus of University of Nis School of Architecture. Lena's research focuses on use of renewable energy in architectural design. She is a recipient of 2013 UA "Green" grant intended for improving energy performance of campus infrastructure. In addition to BESS conference, her paper was published at 2013 ECOSUD Conference in Bucharest, Romania.

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Nabih Tahan, AIA is an architect based in Berkeley, and Austria. In 1992, he moved to Austria where he was introduced to European energy efficiency and sustainable construction methods. In 2005 he introduced the Passive House Standard to California by retrofitting his own home. Currently, he is assisting Cree Buildings, an Austrian general contracting firm, to adapt its timber based "system approach" method to designing and building commercial and residential projects in North America.

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Cristina von Essen completed her BA in Architecture in the Polytechnic University of Puerto Rico in 2007 where her thesis received international recognition. She later went on to receive her MSc in Renewable Energy and Architecture in the University of Nottingham, England in 2009 where she studied models of natural ventilation design in Puerto Rico. Since then participated in courses and discussed the results of her research with prominent architects on the island.

# INDEX

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