ADAPTING ZERO CARBON HOUSES FOR TROPICAL CLIMATES - PASSIVE COOLING DESIGN IN THE PHILIPPINES

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Abstract:

Extensive research about passive house design in cold climates has been carried out in Europe in the last 2 decades and remarkable improvements have been achieved regarding the energy performance of buildings. For modern passive houses the heating load is no longer the main energy consumption aspect. Thermal comfort is being achieved by means of design and construction principles rather than by energy using appliances. As a consequence heating energy demand in passive houses has dropped by 90% compared to the existing building stock. This was a major step forward in the endeavor to transform the built environment from one of the main energy consuming sectors into being energy neutral or even net energy positive.

In comparison, for tropical climates far less documentation and examples are available. Only recently this climatic zone has gained attention of sustainable design initiatives. Cooling demand for residential, office and commercial buildings is still one of the main drivers for the constantly rising energy demand in the Philippines (and other tropical countries). Dealing with high humidity and an excessive heat load of buildings are the main challenges in order to provide thermal comfort for the users. In conventional modern constructions usually 200-400 kWh per m² and year are needed for the air conditioning systems. Limited access to electricity resulting in the need for back-up systems and high energy costs characterize the situation. Based on an analysis of traditional buildings a number of passive cooling principles can be derived that provide a sound basis for a modern Tropical passive house design.

Quantification and an indicator based benchmarking were the key strategies that made the passive house approach so successful, there is no reason why this would not work in hot climates as well.

The paper presents a systematic approach how to apply passive cooling principles in the tropics with a practical example of a Zero Carbon building realized in the Philippines.

Key words : Tropical zero carbon house; passive cooling; sustainable building; zero energy buildings, zero carbon design

1 INTRODUCTION

Over the last 20 years, the passive house has become synonymous with quality, comfort and ultra-low energy buildings that require little energy for space heating or cooling. These remarkable improvements have been achieved for cold climate with regards to the energy performance of buildings especially in Europe. For modern passive houses the heating load is no longer the main energy consumption aspect. Thermal comfort is being achieved by means of design and construction principles rather than by energy using appliances. As a consequence heating energy demand in passive houses has dropped by 90% compared to the existing building stock. This was a major step forward in the endeavor to transform the built environment from one of the main energy consuming sectors into being energy neutral or even net energy positive. Directive 2010/31/EU (EPBD recast) Article 9 requires that “Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings”. Member States shall furthermore “draw up national plans for increasing the number of nearly zero-energy buildings”. In other words the built environment is gradually transformed from being one of the main energy consuming sectors into being self-sufficient, or even into producing a surplus of energy. In tropical countries however research and demonstration is now picking up these topics and the prospects of zero carbon buildings are quite viable, especially with a view on the much higher solar irradiation compared to Europe. The Zero Carbon Resorts (ZCR) project is planning and building one of the first energy self-sufficient buildings in Palawan.

2 THE BUILT ENVIRONMENT

Applying the definition of sustainable development to building design, we could state that in sustainable building functions and construction components ideally correspond to the present needs of the occupants without causing problems for
future generations. However for most modern buildings this is still not the case. In fact the construction industry has become the most resource intensive industry worldwide and is responsible for about 50% of the global resource consumption as well as for half of the worldwide generation of waste streams.

During the use phase, buildings are responsible for about 30% of the total energy demand. Changing the way we plan, build and use constructions of tomorrow can remarkably contribute to solving global problems like resource scarcity, shortage of fossil fuels, global warming, etc. Additionally these buildings will be healthier to live in and cheaper to maintain, creating value in the region rather that global resource and waste streams. In order to understand the environmental effects of a building and its use we have to look at its entire life cycle, from raw material extraction, construction and use of the building until deconstruction and recycling.

![Figure 1 Life cycle](image)

Improving the energy performance during the use phase has been the main concern of the early “green building” approaches. This was for a good reason, knowing that up to 80% of the entire energy consumption in a building is being used for either heating (in cold climates) or cooling (in hot climates). The total consumption can reach up to 200kWh/m²/year for a residential building and up to twice as much for offices or shopping malls. Looking at this consumption from the “energy service” point of view we can conclude that by far most of the energy consumption is directly related to providing “thermal comfort” to the occupants and users of the built structure. (WIMMER 2012)

You feel cold? Turn on the heating! and vice versa turn on the AC if you feel hot. Availability of electricity and appliances for cooling have stimulated these seemingly simple solutions, however we recognize the “side effects” of this problem solving approach later. We can recognize it when receiving our monthly energy bill, when experiencing brown outs due to grid overload and even when changing weather conditions, global warming and rising sea levels are dominating the news.

The good news is that providing thermal comfort allows for a lot more diverse solutions (FANGER 1970) than the switching on of technical appliances. An old church in southern Europe is an excellent place to escape to during a sizzling hot city tour, cool and comfortable by design not by technology. The same is true for the cool breeze in a lightweight structure such as an Ifugao house. Design principles and materials for both examples are totally different, the result is the same: thermal comfort for the occupant or visitor. It is obvious that thermal comfort cannot be defined by the temperature alone, as it is suggested by the digital control display of the AC unit. In fact it is influenced by a number of factors and of course it is also a subjective sensation.

3 THE CHALLENGE

For tropical climates far less documentation and examples are available on zero energy houses. Nevertheless there are plenty of good examples available for passive cooling designs, especially when examining traditional buildings, such as the “Ifugao” house.
Thermal imaging reveals that the surface temperature on the inside of the roof remains in a tolerable level between 26°C and 30°C while a steel roof during the same weather conditions can peak up to 75°C. This shows how massive consequences from material choice are for the cooling load of a building. (WIMMER 2009)

Nevertheless foreign architectural models began to be widely adopted with little regard for tropical climate. The results are predictable, an enclosed buildings with glass windows that become unbearable ovens in summer. As it happens, air conditioning units are required in order to make this enclosed area comfortable which highly increases the energy consumption.

Cooling demand in buildings is still one of the main drivers for the constantly rising energy demand in the Philippines (and other tropical countries). Dealing with high humidity and an excessive heat load of buildings are the main challenges in order to provide thermal comfort for the users. Due to high temperature and the surrounding bodies of water, the Philippines has a high relative humidity. The average monthly relative humidity varies between 71 percent in March and 85 percent in September. The combination of warm temperature and high relative and absolute humidity give rise to high sensible temperature throughout the archipelago. It is especially uncomfortable during March to May, when temperature and humidity attain their maximum levels.

In conventional modern constructions usually 200-400 kWh per m² and year are needed for the air conditioning systems. Limited access to electricity resulting in the need for back-up systems and high energy costs characterize the situation.

Based on an analysis of traditional buildings on the other hand a number of passive cooling principles can be derived that provide a sound basis for a modern tropical zero energy house design. The challenge is to make use of the traditional design principles and elements that work for the buildings and translate them into a modern context.

It is obvious that thermal comfort cannot be defined by the temperature alone, as it is suggested by the digital control display of the AC unit. In fact it is influenced by a number of factors and of course it is also a subjective sensation.

The well-known thermal comfort equations derived by P.O. Fanger (FANGER 1970) combine the effect of 6 parameters:

- Metabolism
- Clothing level
- Air Temperature
- Mean Radiant Temperature
- Air Velocity
- Humidity

While metabolism and clothing are up the users’ behaviour the remaining parameters can be dealt with by the creative designer.

For the designer most relevant is the correlation of air temperature and humidity as well as the influence of surface temperatures (such as walls, ceilings etc.) and air movements on the comfort level of the occupants. The cooler the wall temperatures the bigger is the tolerance to higher air temperatures and the other way round. The typical situation in many buildings in the Philippines is that due to insufficiently insulated ceilings surface temperatures reach high levels...
measurements of >45°C on the ceiling are not an exemption) and in return ask for a lower air temperature that can only be achieved by excessive air conditioning. Another rule of thumb indicates that for every 1 m/s of air movement 1°C air temperature increase is tolerated.

![Diagram of Passive Cooling methods](image)

**Figure 3** Passive Cooling methods

Knowing this correlations, almost automatically leads to a number of design principles which are commonly known as the “passive cooling” principles:

- Shading
- Reflection
- Insulation
- Radiation
- Ventilation
- Evaporation
- Heat sinks by thermal mass

These measures do not have to be expensive to construct, most likely they are even cheaper than the cooling equipment they are replacing and certainly they will continue to save on running costs every month. A combination of the above effects (shading, reflection, and evaporation) can for instance be realised with a simple and aesthetic shade house grown from vines on trellis, preferably with vines of a reddish or whitish leaf color (MOLLISON 2012) since those species reflect most of the sunlight. Together with the evaporation effect of the plants this can serve as a valuable source of cool air in combination with natural ventilation.

In recent years tremendous achievements have been made in making buildings more energy efficient. Looking at the Passivhaus trend in Europe heating demand has been reduced by more than 90% at minimal additional investment costs, the benchmark of energy consumption has been lowered to 10 kWh/m²year.

There is no reason why designers of tropical architecture should not be able to reach the same results by minimizing cooling demand.

And what can be done for the “thermal comfort” as the main energy consuming energy service we can consequently also do with all the other functions and energy services in a building. It is important to know that this energy services are a function of time and occupant behaviour as well as requiring different forms of energy. This concept is called “Supply-demand matching” in the Zero Carbon Resorts Project.

### 4 THE ZERO CARBON RESORTS FLAGSHIP COTTAGE

The Zero Carbon Resorts project in the Philippines is funded by the European Union under Switch-Asia program. The ultimate goal of the project is to reduce the carbon emission of the tourism sector through energy and resource efficiency practices following a progressive 3R approach. The ZCR’s 3R (Reduce-Replace-Redesign) intervention ranges from simple measures with low or zero investment to efficient high-end technologies depending on the innovation stage the establishments have already reached. Innovations are needed at all levels, from an efficient operation of energy-using products, to technical
innovations in lighting, ventilation and cooling, up to sustainable architecture strategies.

During the “Redesign” phase, a zero carbon cottage has been designed and will be constructed, to showcase sustainable building and energy systems using appropriate technology solutions. The project’s added value comes in its acknowledgement of the local context and the fact that solutions are tailored accordingly.

The Overall objective of this showcase is to demonstrate the feasibility of an innovative building concept that significantly reduces CO₂ emissions and demonstrates resource-efficient solutions in the building sector. To this end, a highly resource and energy-efficient building will be built in Puerto Princesa Palawan. The showcase building will supply its complete energy services from a highly innovative energy-supply system using renewable resources. The building is therefore literally carbon neutral over its entire lifecycle and a milestone in sustainable building with an immense potential of replication and up-scaling.

It shows a minimum of grey energy over their entire life cycle, from production of materials to the use phase and the recycling possibilities due to a maximum utilization of regional renewable resources (bamboo), and a 100% energy-autonomous, demand-oriented system based on solar energy.

The planning was guided by the following principles:
- High functionality and quality
- Minimized consumption of energy and resources
- Use of regional building materials and renewable resources
- Sustainable planning considering the location and context
- Environmentally sound solutions for a healthy room climate
- Life cycle perspective including an easy separation of building materials during deconstruction and plans for recycling and reuse
- Economic efficiency of sustainable construction: during planning already the whole life cycle of the building (construction, use, removal deconstruction) is taken into account and the negative impact on the environment is minimized
- Dissemination of sustainable building technologies to a wider audience

![Figure 4 ZCR Zero Carbon Cottage design by Arch. Edgardo Mallari](image)

The whole building process as well as the results are monitored and prepared for knowledge transfer and dissemination. Monitoring devices will be installed to determine a quantified performance of the building and its operational consumption. These data will be available to the public for knowledge sharing and enables policy makers to have a basis for the revision of standards and guidelines for building and energy system in the whole of Philippines. The showcase will also feature the efficient devices and technologies installed that contribute to its low energy demand.
The design process has been unique as well, since it originated from the Zero Carbon Resorts capacity building program, where 35 innovative Filipino architects have been trained. A number of design suggestions have been elaborated and the final design has been assigned to Arch. Edgardo Mallari, team lead of the participating architects group from the Green Architects of the Philippines (GreenAP).

Figure 5 ZCR Zero Carbon Cottage design by Arch. Edgardo Mallari

5 SUSTAINABLE BUILDING MATERIALS

The environmental impact of a building is strongly influenced by the choice of building materials. Building materials made of renewable resources and regionally available materials are a substantial basis for sustainable construction. Especially biomaterials with a relatively short time of reproduction like grasses, bamboo etc. have a far better environmental profile compared to concrete, steel and aluminium but also compared to hardwood timber with a long growth period of 80 years and more, these species are often protected for a good reason since they play an important role in the forest ecology.

The example S-House in Austria (www.s-house.at) has shown that the consequent use of regionally grown renewable materials can reduce the environmental impact of the building materials by a factor of 10 compared to conventional constructions. While the construction of the straw-wood-clay wall caused an ecological footprint of only 2364 (m²a/m² wall), a comparable conventional wall construction (concrete, Styrofoam) consumes with 24915 (m²a/m² wall) an area 10 times larger.

For the use of renewable materials in the tropics special challenges have to be mastered. Bamboo e.g. is an excellent candidate for zero carbon constructions is exposed to a number of vermin like termites and borers (bokbok in Tagalog). Those insects are well known to damage constructions within a relatively short period of time, if the bamboo is not treated.

Figure 6 ZCR Redesign Capacity Building in Puerto Princesa
Resistance to vermin is one of the reasons why “modern” construction materials like metal and concrete became so popular despite their high costs and unfavourable environmental profile.

The only alternative seems to be to treat the bamboo poles with chemicals in order to make them more durable. Conventional treatment methods use synthetic and/or toxic substances, which brings along another set of environmental problems. Promising newer treatment methods like “sap replacement” with less or non toxic salts have the disadvantage of relatively high costs and require special machinery to apply high pressure to the bamboo poles.

Looking back in history shows that for traditional buildings soaking in water of bamboo poles and mats (like sawali) has been used ever since with good results. The procedure was relatively simple and not harmful: the building material was placed in water ponds or in running water for several weeks to wash out starch from the bamboo which make it not attractive to insects.

In an effort to combine traditional treatment methods with modern know how, namely the fact that pressure treatment is far more effective in terms of penetration depth, I am suggesting a modified and inexpensive treatment method:

Pressure seawater treatment is being used for bamboo poles for the ZCR demonstration building. The pressure is being applied not by using compressors but by utilizing the natural pressure in deeper waters. In practical terms this means that the bamboo poles will be brought off shore and dropped in seawater, 30meters below the surface. Down there a controlled seawater treatment with 4bar pressure is being applied naturally and without additional energy use. After the required retention time (currently evaluated from experiments) the poles are dried and used for the construction. No adverse environmental effect is expected from the pressure seawater treatment.

6 CONCLUSION

Only recently the tropical climatic zone has gained attention of sustainable design initiatives. While in Europe heating is the main energy requirement, the tropical climates have to focus on cooling and dehumidification. By using passive design concepts and principles, thermal comfort for tropical buildings can be achieved. The ZCR flagship cottage of the ZCR project will be a living proof for applying passive design in a modern context. The project’s added value comes in its acknowledgement of the local context and the fact that solutions are tailored accordingly.

A combination of traditional knowledge and modern design is applied in the ZCR cottage in order to achieve the best possible solution. Already in the planning stage the criteria for easy deconstruction and an optimal reuse are drawn into account in order to prevent waste and disposal problems in the future.

REFERENCES


