A RESEARCH ON EMBODIED ENERGY OF BUILDING MATERIALS: REFLECTIONS ON TURKEY

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Summary

As buildings play an important part in the energy consumption of a nation, the purpose of this paper is to attract attention to the importance of embodied energy of building materials for sustainable architecture. Therefore in the first part of the paper an overview of current researches on embodied energy is made and the necessity of life cycle analysis is emphasized. In the second part firstly an evaluation of the building stock in Turkey has been made. Afterwards the underlying motives of the formation of the urbanization and building stock are analyzed on Antalya, one of the biggest tourism centers of Turkey on the Mediterranean coastline. Later on preliminary results of an ongoing research on embodied energy of several building materials in Turkey are presented. According to the results of this survey combined with researches on building stock, as they are consumed in higher amounts, concrete structural system and brick envelope is concluded to be the most energy intensive design preferences in building sector in Turkey. Conclusively the advantages of appropriate material selection in design projects along with passive design solutions are put forward and the importance of an overall assessment process is underlined.

1. Introduction

Environmental issues are on the agenda since early 1970s, when the first energy crisis has occurred. From then on, societies are developing ways to prevent the risk of a global energy shortage. As building industry plays an important role in energy consumption of a nation, planners, architects and engineers are looking for better ways to minimize the energy usage in building processes and also prevent environmental pollution. Today we can easily see that these attempts are in a wide range. But they usually have a common starting point. They often consist of energy analysis of a building restricted only to the operational energy, and the impact of embodied energy to construct the building is ignored. Therefore in this paper it is intended to realize the importance of embodied energy of building materials for a sustainable living. Also some reflections on building materials mostly used in Turkey are exposed in order to guide future actions.

2. Embodied Energy and Life Cycle Assessment

2.1. Embodied Energy

Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, transport and administrative functions. Dr. Selwyn Tucker (2000) from CSIRO Building Construction & Engineering emphasizes the importance of embodied energy and records that, the energy embodied in existing building stock in Australia is equivalent to ten years of the total energy consumption for the entire nation. As we can also follow from the figure below (Figure 1) the embodied energy of a building is a significant multiple of the annual operating energy consumed, ranging from around 10 for typical dwellings to over 30 for office buildings. Making buildings such as dwellings more energy efficient usually requires more embodied energy thus increasing the ratio even further.

On the other hand as well as being energy intensive in their operation, most modern city buildings have been designed to have an average life of only 50-60 years. Even during this short time many of these buildings undergo major reconstruction, which can mean that some commercial buildings are effectively rebuilt twice or even three times during their brief existence (Storey and Baird, 1999).

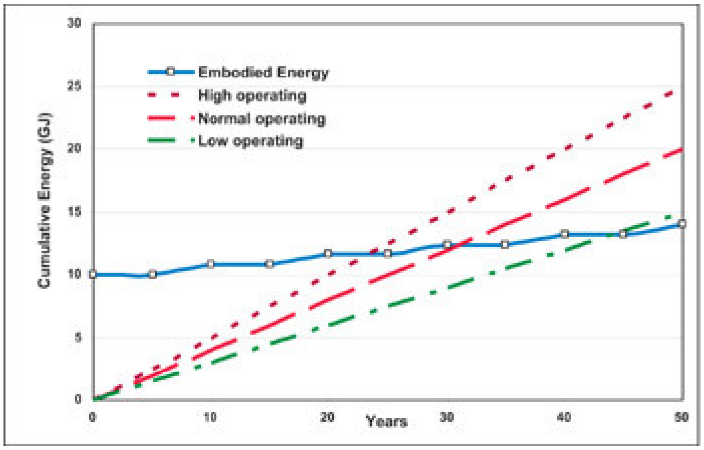

Figure 1 Cumulative life cycle energy of an office building (Tucker, 2000)

The total energy requirement of a building over its lifetime may be considered to have five main components (Farinola, 1999):

- The energy embodied in its initial construction
- The energy needed to operate the building in terms of heating, cooling, ventilation, lighting, power etc
- The energy embodied in the regular maintenance and periodic refurbishment of the building
- The energy required for demolition and disposal of the building
- The energy savings as a result of recycling

Choice of material and design principles has a significant, but previously unrecognized impact on energy required to construct a building. Embodied energy is one measure of the environmental impact of construction and the effectiveness of any recycling, particularly CO_2 emissions. CO_2 emissions are highly correlated with the energy consumed in manufacturing building materials. On average, 0.098 tones of CO_2 are produced per gigajoule of embodied energy (Tucker, 2000).

2.1.1 Demolition/Disposal-Reuse/Recycle

Currently less than one percent of the materials in city buildings is recycled (Storey and Baird, 1999). However the reuse of building materials commonly saves about 95% of embodied energy which would otherwise be wasted. Some materials such as bricks and tiles suffer damage losses up to 30% in reuse. As it can be followed from the figure below (Figure 2) the savings by recycling of materials for reprocessing varies considerably with savings up to 95% for aluminum but only 20% for glass. Some reprocessing may use more energy, particularly if long transport distances are involved (Tucker, 2000). For instance imported stone for cladding has double the embodied energy of the same stone, quarried locally (Robinson, 1999).

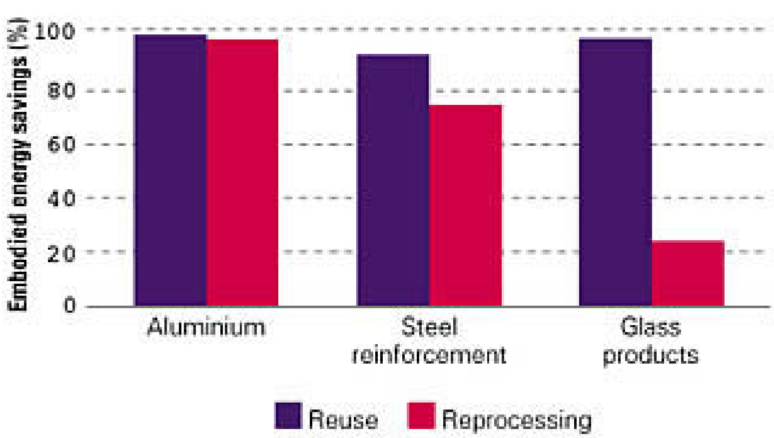

Figure 2 Potential energy savings (Tucker, 2000)

2.1.2. Assessment of Embodied Energy

According to Baird, Alcorn and Haslam (1997), while not covering all considerations, energy analysis is one method which can be used, albeit crudely, to estimate the environmental impact of different activities. All being one of the methods for analyzing energy, Statistical analysis utilizes published statistics to determine energy use by particular industries; Input-output analysis captures every dollar transaction, and hence every energy transaction, across the entire national economy and Process analysis involves the systematic examination of the direct and indirect energy inputs to a process. But most effective one seems to be Hybrid energy analysis which attempts to incorporate the most useful features of the three analysis methods outlined above, especially input-output analysis and process analysis.

Gross Energy Requirement (GER) is a measure of the true embodied energy of a material. In practice this is usually impractical to measure. Process Energy Requirement (PER) is a measure of the energy directly related to the manufacture of the material. This is simpler to quantify. Consequently, most figures quoted for embodied energy are based on the PER. This would include the energy used in transporting the raw materials to the factory but not energy used to transport the final product to the building site. In general, PER accounts for 50 to 80% of GER. Even within this narrower definition, arriving at a single figure for a material is impractical as it depends on:

- Efficiency of the individual manufacturing process.
- The fuels used in manufacture of the materials.
- The distances materials are transported.
- The amount of recycled product used, etc.

Each of these factors varies according to product, process, manufacturer and application. They also vary depending on how the embodied energy has been assessed (Milne and Reardon, 2005). Factors that have considerable bearing on the final energy coefficient are firstly whether heat, and how much, is needed in the manufacturing process, followed by the amount of physical force needed in the manufacturing process. Transport, especially if it is by an efficient means such as sea transport tends to have only a small influence on the final result. Fuel type, internal wastage and efficiency of the manufacturing plant all have a noticeable, but usually rather less significant bearing on the final result.

As embodied energy differs among assessment methods, regions, countries, cities, and building types, here it is not intended to present different materials' embodied energies. Most extensive research in this field is made by Alcorn and Wood (1998) building on George Baird and Chan Seong Aun's report on *Energy Cost of Houses and Light Construction Building*s dating back to 1983 and published by NZERDC and which was completely redone in 1995 by Andrew Alcorn and George Baird, funded by the Building Research Association of New Zealand (BRANZ) and Victoria University under the title *Embodied Energy Coefficients of Building Material*s.

2.2 Life Cycle Assessment

Assessment of embodied energy of a building material alone can not determine the buildings environmental properties. For instance, the embodied energy figure for a material will be different for residential construction, because it is usually less complicated than the larger, multi-floor commercial construction (Robinson, 1999). Materials such as concrete and timber have the lowest embodied energy intensities but are consumed in very large quantities; whereas the materials with high energy content such as stainless steel are used in much lesser amounts. Besides steel can be re-used and/or recycled in the building industry. Nevertheless the greatest amount of embodied energy in a building is often in concrete and steel. However using these values alone to determine preferred materials is inappropriate because of the differing lifetimes of materials, differing quantities required to perform the same task, different design requirements (Tucker, 2000) and also different reuse, recycle properties.

Further more embodied energy must always be considered in the context of the total energy requirement over the life time of a building. Choice of materials can influence operating energy requirements as well as embodied energy. For example, a high mass material such as concrete, although having a larger embodied energy than timber, has the potential for reducing HVAC energy requirements due to its good heat storing properties. In the case of glass fibre insulation, the energy savings over the building's life can be many times that of its initial energy cost (Baird, 1998). Studies on alternative building materials reveals embodied energy savings as well as reduction in heating and cooling energy requirements. The relevance and accuracy of including embodied energy in the design process when considering life cycle energy implications, forms an integral part of analyzing the total building energy (Farinola, 1999). In choosing between alternative building materials or products on the basis of embodied energy, not only the initial materials should be considered but also the materials consumed over the life of the building during maintenance, repair and replacement (Tucker, 2000). Therefore a life cycle assessment tool which includes embodied energy as well as other relevant data should be taken into consideration.

It is only recently that studies have taken a full-life-cycle approach to buildings - examining the relationship between embodied and operational energy, or the role of construction techniques an a building's ultimate environmental impact (Huberman and Pearlmutter, 2004). Life Cycle Analysis (LCA) is the technique for assessing the environmental aspects and impacts associated with a product, or service, in a life cycle perspective. Environmental impacts refer to the demand for natural resources, emissions to air, water and soil and solid waste. The life cycle consists of the processes and transport involved during raw materials extraction, refining of raw materials, production of the product, use of the product and waste management. LCA consists of four distinct phases; Goal and Scope (goal and basic definitions for the study), Inventory Analysis (data collections and calculations of input and output of the studied system), Impact Assessment (aimed at evaluating the significance of the environmental impacts using the result from the inventory analysis) and Interpretation (identification of significant environmental issues, supposed to lead to conclusions and recommendations) (Thormark, 2000).

The scenario of balancing operating energy is quite familiar and requires no further clarification. The concept of life-cycle energy balance might not, however, be quite so obvious. Here, energy inputs comprise a building's net life-cycle embodied energy plus its total operational energy inputs. The gross life-cycle embodied energy is the embodied energy of all the materials used in initially constructing the building, plus energy used in its maintenance, repair and refurbishment, including all the transport energy that that entails. It also includes the energy used to dismantle the building and transport the materials to the landfill or recycling facility. To get the net figure, the embodied energy recovered from the recycled materials must be taken away from the gross embodied energy figure. The operational energy consists of the total energy used to maintain the habitability of the building throughout its life. A figure for a building's total energy debt is found by adding together the figure for its net embodied energy and its total operating energy. Our aim then is to design buildings which will produce enough energy during their lifetime to recover this energy debt. (Storey and Baird, 1999)

Life cycle analysis at its most basic, involves looking at what goes into a process (raw materials, energy, water), what comes out (products, co-products, by-products, emissions, pollutants, wastes) and what happens at the end of the material's life (its disposal or recyclability) (Robinson 1998). LCA, as all techniques, has its limitations. One limitation is that the choices and assumptions made in LCA regarding e.g. system boundaries, data sources and impact categories may be subjective. Further, models used for the inventory analysis or to assess environmental impacts are limited by their assumptions and may not be available for all impacts. Also, the accuracy of LCA studies may be limited by accessibility of relevant data and data quality. Finally, as the weighting is based on value judgements, different weighting methods can give different results. For these reasons, it is important to be aware of the limits of the information developed in a study of this kind when assessing the result in a decision process. LCA is still at the stage of development. However, international standards have been drawn up and established regarding principles and framework, goal and scope definition and inventory analysis (ISO 14040, ISO 10041). Draft standards have been issued regarding assessment and interpretation (ISO 14042, ISO 10043) (Thormark, 2000).

3. An Evaluation of the Building Materials Used in Turkey

3.1. An Overview of Building Stock in Turkey

According to the results of a survey executed in 2000 by the Statistical Institute of Turkey (Anon, 2000) in the settlements where the number of buildings exceeds 2000, the building number in Turkey is found out to be 7.838.675. The same research concluded that 75% (5.872.808 buildings) of the buildings in Turkey are built for residential function. According to the same research, taking into account the structural system, 48% of the buildings was constructed as frame construction and 51% of buildings was constructed as bearing wall construction (1% varies). According to the type of material used in buildings constructed as bearing wall construction and frame construction, brick had the highest ratio with 60%; hollow concrete block with 18%, stone with 10%, sun dried brick with 8% and wood with 3% followed (others 1%). Comparing the results of this survey with the results of a similar research done in 1984 by the same institution, indicate that from 1984 to 2000 there has been a great tendency for the structural system of the buildings shifting from bearing wall construction to the frame construction in Turkey.

The results of this survey on building materials firstly indicate that vernacular building traditions such as bearing wall construction in Turkey is decreasing and on the other hand frame construction is increasing. Despite in the survey, material of the frame structure was not defined as reinforced concrete; we can easily speculate that because usage of steal frame system is relatively new in Turkey's building sector. Therefore the research displays that the materials mostly used in modern buildings in Turkey are concrete and brick and concrete structural system combined with brick walls represents the current construction tendency in the country.

Concrete and brick is known to have several environmental effects, therefore firstly an evaluation of the environmental effects of these in the urbanization process will be outlined. According to the researches, most of the buildings embodied energy relates to the structural system (24%) and envelope (26%). That's why lastly the embodied energy of concrete and brick in Turkey will be evaluated as they are observed to be the conventional structural and envelope systems.

3.1 Reflections on Building Materials Used in Turkey

There have been several breaking points in Turkey's building sector, but probably the most effective one can be defined as the period starting from 50's with the industrialization gaining speed. Similar to the changes undergone in most of the industrialized nations, industrialization resulted with population increase, migration to the cities and this situation lead to several transformations affecting cities in the first hand in Turkey. As the economies were developing, industry demanded new spatial formations and cities started to re-shape. Turkey as a developing country, a country willing to make progress, but still does not have adequate legal regulations; could not prevent illegal buildings; most of the people willing to make a profit took part in the building activities with the lack of relevant knowledge. That is why almost 60% of the buildings were built illegally.

When we evaluate the current situation overlooking our cities; there seems to be too many problems. With no doubt these problems are far more dependent on the economic, political and social context. However when we only evaluate these on a material selection basis, the results of the lack of information is obvious. According to Bilgin (2004) in radical modern period at the start of the formation of the Turkish Republic, it was expected that concrete material would mediate a pioneer elite role which would remove the tradition. In the populist modernization period after 1950s, this role would turn inside out and concrete would become a vehicle for populism in the construction sector. With the lack of adequate regulations, this resulted in an architecture so called "contractor-construction worker" architecture.

Figure 3 General view of Antalya from the sea (Ucar, 2004)

This situation can be clearly followed from the urbanization processes of many cities in Turkey. For instance above is a photo of Antalya (Figure 3), the biggest tourism center of Turkey along the Mediterranean coastal area. The city dates back to 2nd century BC and with its historic, cultural and environmental characteristics the city once represented one of the most peculiar places along the Mediterranean basin. However due to the unplanned development and intense urbanization, current situation of the city fairly departs from a comprehension of a livable environment. The picture below (Figure 4) represents unplanned growth of the city, ignorance of environmental conscious design principles, negative relationship with coastal and green areas, and intense urbanization on the arable lands… Besides in this intense settlement along the coastline social disintegration could also be mentioned. This example represents a general urbanization manner along with the conventional concrete and brick construction leading to environmental devastation.

Above all, the picture below also presents another sociological problem. Most of the buildings in this region are secondary residences which are used for only 3 months in the summer season. Current researches indicate that buildings either should be designed taking into their long life or simply they should be designed as taking into account the temporary implications. It is interesting here to see that these buildings despite their durable feature, are not even used effectively. Antalya, Mersin, Adana, three neighboring Mediterranean settlements, are the first three cities where there is an excess of residential buildings in Turkey. Social, political and economic processes intensively effect environmental devastation. And this situation along with inadequate information on material selection leads to serious results ignoring basic spatial needs.

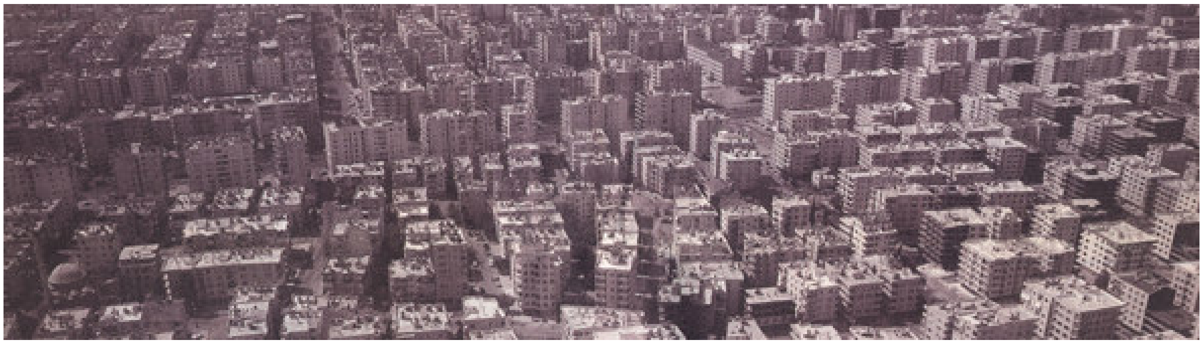

Figure 4 City center of Antalya (Ucar, 2004)

3.2 Embodied Energy of Building Materials in Turkey

In order to understand different features of the building materials, especially finding out the environmental properties of concrete and brick, a research was conducted in Turkey. The aim of the research was to identify embodied energies of building materials and underline the importance of appropriate material selection and inform the professional and the public about the environmental effects of building materials used in construction. However there were too many limitations for this research: First of all as it was too difficult to calculate all of the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, transport and administrative functions, only materials' processing energy used in the factory was aimed to be collected. Secondly as the manufacturers are not aware of the concept of embodied energy in Turkey and also as commercial sensitivity persuades manufacturers to withhold the information, it was extremely difficult to collect true data. Besides it was not possible to cross check or compare the results; for this reason due to the differences in the calculation systems it is not possible to say that preliminary results of this ongoing research presented below represent the current situation in Turkey. Still there is some data that this survey originates: Energy intensive processes of structural concrete and brick should be taken into consideration as they are the mostly used material in Turkey and also as they are consumed in great amounts in a building.

Table 1 Preliminary Results of an Ongoing Research on Embodied Energy of Building Materials in Turkey

Material	Specification	Data	Units	Source of Data
Timber	Pine	0,144	MJ/kg	Manufacturer
Concrete	Used in infrastructure and urban pavements	18	MJ/m^3	Manufacturer
Concrete	Structural walls (in 19x39x9cm blocks)	1541	MJ/m^3	Manufacturer
Brick	Fired brick	1,9	MJ/kg	Manufacturer
Metal	Curtain Wall (structural system)	0,018	MJ/kg	Manufacturer

The importance of conducting an extensive research on embodied energy of building materials in Turkey is obvious. As the building sector depends on only few materials having energy intensive processes, it would be a wise step to complete this survey, and constitute an embodied energy coefficient for building materials. According to Alcorn and Wood (1998), this coefficient should include:

- The country of origin of the data
- The country where a material or ingredient is produced
- The size of the organization producing the data

• Political or market forces affecting the organization producing the data

• Market or other factors influencing the period in which the data was gathered

• The relative size of the organization producing the data

• The completeness of the data

• The completeness of records from which the data is drawn

• The reliability of records from which the data is drawn

• The age of the data

• The relevance of the time period of the data

• The consistency of time periods for different pieces of data

• The level of detail of the data

• The representativeness of the factory or plant producing the data

With this relevant information and a life cycle analysis approach, it is possible to attract attention to the energy intensive processes accounted with the building materials.

4. Conclusion

The research presented here, on the materials used in building sector in Turkey indicates that current building stock mostly depends on only few materials. Apart from traditional buildings which represent almost half of the building stock, most of the modern buildings are of concrete structure and brick walls which consume great amounts of energy and have negative effects on the environment. This conventional building system along with political and governmental inadequacies on urbanization seems to be preparing the collapse of the cities.

On the other hand environmental issues seem to be on the agenda of every level of the society from the governmental degrees to the professionals and the public. However despite the efforts that most of the devoted people make, little progress has been made. The reason for this is that neither professionals nor the public want to change their consumerist attitude. Architects, decision makers, clients, users (under effect of the intense political pressures) do not question whether the buildings have any environmental impacts. The researches are mostly focused on reducing the operational energy of the buildings because clients and users demand energy savings. However the energy intensive use and environmental devastation that is made to erect a building is often ignored. That's why this article is focused of embodied energy of the building materials, which equals almost half of the operational energy that a building needs during its entire life. Identifying the embodied energy as a greater proportion of the total energy used by the building during its lifetime and realization of energy intensive processes to produce some materials, reducing Greenhouse Gas Emissions by using less energy intensive materials and processes are intended to stress on.

Therefore what is intended to underline in this article is that the importance of material selection. With no doubt energy intensive processes of the building materials is much more related to heavy industrial processes. Architects selecting appropriate materials alone can not be a solution to this overall problem; there should be attempts for the industry of building materials shifting to appropriate and green technologies. However we are at most times seized to styles and isms of the current practices. And what we should be aware of is that there are alternatives and our task is not to simply apply the conventional one but to seek for new possibilities.

The aim of this article is not to propose the usage of specific materials and prohibiting specific materials in the building sector but instead it is written to provoke awareness among all levels of the society. Today it is evident that appropriate material selection relies on many characteristics of the material: inherent pollution, thermal performance, toxicity, capacity to recycle and reuse, embodied energy. To calculate and asses embodied energy and directly constitute appropriate relationships between materials and their contribution to operational energy of the buildings, life cycle analysis is needed. Designers should not forget that some aspects of the process are quite sophisticated (especially the thermal energy efficiency aspects) and getting it properly environmentally responsible is a delicate balance as there are always dilemmas. Looking for opportunities to re-use and recycle materials is of great concern. With no doubt we should provoke using recycling in every level of the society but most important we should develop ways for recycle and reuse in building sector.

First step towards a livable future could be conducting an extensive survey on embodied energy of building materials; afterwards an informative process could be initiated and the results as well as assessment tools should be announced to the professionals and public. As the issue is complex enough an intermediate approach allowing people to take a combination of quantitative and qualitative information to help make reasonable decisions is needed. The lack of information on material selection along with other social and political aspects is shaping many settlements throughout the world; it would be a wise step to attract an overall awareness related to the issues on building materials' environmental effects. And specifically an overall activism among professionals along with accurate political and governmental support which will lead to revival of the cities should be initiated.

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