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Critical thinking in teaching sustainable architecture

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ABSTRACT: The authors of this article champion critical thinking on conventional teaching of sustainable design to architecture students at Slovak University of Technology in Bratislava, Slovakia. Teaching is closely related to building practice, responding to ever-tightening standards on the thermal protection and energy efficiency of buildings. Requirements for the building envelope are progressing towards a nearly zero energy standard and do not take into account the wider context of sustainability. Contrary to this trend, a number of studies prove the economic, ecological and social aspects of the conventional solution. Holistic concepts based on the principle of dynamic building envelopes respond to changes in the surrounding environment, as well as the user's changing demands, with renewable energies, decentralised energy generation or collective infrastructure management in a neighbourhood. The main challenge in educating future architects is to outline the wider view concerning sustainable design, to give students critical insight into evolving trends and direct them towards a deeper understanding of the subject.

INTRODUCTION

Sustainability in architecture and construction is the principal contemporary topic discussed within the discipline. Meeting the requirements of the paradigm of sustainability in design and building technologies by architects and civil engineers is inextricably linked with an adequate professional knowledge and expertise [1]. In teaching, often encountered is an approach that suggests only a building that is energy-efficient during operation is sustainable. The common argument is that by applying more thermal insulation, higher energy savings result, and thus the building is more environmentally friendly. However, this approach does not take into account many other aspects, such as saving resources and the energy needed to produce building (insulation) materials. The life cycle assessment (LCA) is a method to assess product life cycles and is already well known but still not frequently applied in architecture design teaching and practice. There are also more aspects which must be considered regarding this topic.

Buildings provide weather protection for people. They basically compensate the fluctuations between the parameters of external environment and the surface of the human body. Naturally, this flux depends on geographical location. One of the most basic human needs is warmth, which is required for a comfortable indoor environment. Because of the climate conditions in Europe, in earlier times the open fire was included in the interior of shelters. As a result, the sense of subjective well-being has evolved, while demands have increased on the quality of indoor spaces. Space tempering by methods of trial-and-error and intuitive perception of well-being laid the groundwork for the first energy calculation methods. Here is also found the first discussions on thermal protection issues in science and teaching. The current situation is based on calculations connected to the philosophy of lifestyle sustainability. Education is becoming more and more complex and lots of diversified disciplines affect the architectural profession.

The advisability of building thermal insulation has been discussed by the general and professional public for several years. Unfortunately, building practice often has negative examples. Reducing energy losses and improving a building's energy balance comes at the expense of architectural expression or charm of craftsmanship. Where is the limit to this *energy madness*? Environmental sustainability should go hand in hand with cultural sustainability. Does the current trend represent the right way? What are the boundaries for building thermal protection? Is an *obese* architecture that does not allow direct sunlight into its bowels, the architectural style of today? This is certainly not an attribute of a healthy and sustainable architecture - a building culture that is an indicator of the state of modern society.

The goal of modern education for future architects is to teach them to design buildings that are environmentally and resource user-friendly. *An architect is the one who can produce a construction other than in a utilitarian form* [2]. Besides the architect, the participation of many other people in the construction process - as an engineer or craftsman - gives each building a distinctive visual expression. Headless *polystyrene wrapping* of the buildings from the past or present era covers this crafty piece of work. Usually, the accompanying phenomenon is a colourful cacophony. Among the biggest promoters of *anti-polystyrene culture* in Slovakia are architects Pavol Paňák and Martin Kusý (BKPŠ studio).

HISTORICAL BACKGROUND

The 19th and 20th Century industrial revolution brought uncontrolled extraction of raw materials, which contained the required energy potential. In 1972, concerns already were being raised through the Club of Rome about exponential population growth [3], which resulted in the assessment of the impact of human activity on the environment through reducing the energy demands of a building, developing new technologies and the thermal insulation of buildings. Energy evaluation started with calculations for heat losses through the building envelope and heating loads. Even in the 1970s, the thermal insulation standard in Slovakia was represented by the 45 cm full brick, which was later replaced by the 37.5 cm thick air brick.

The introduction of energy standards occurred as a reaction to the energy crisis that caused rising energy prices in the 1970s. The primary goal was to save energy on heating, and thus abate energy bills by reducing the heat loss of structures through building insulation. The envelope of the building was dimensioned according to the required heat demands. Similar building concepts have been observed at the same time in different locations around the world, as follows:

- *passive house* type (Dr Feist);
- *zero energy house*, the Technical University of Denmark in Copenhagen (physician Vagn Korsgaard);
- *super-insulated houses*, the University of Illinois (Professor Wayne Shick);
- *Saskatchewan conservation house* (William A. Shurcliff) [4].

The Le Corbusier *Machine for Living* was brought to perfection: man becomes a *slave* of his dwelling that represents a highly sensitive and liable system able to react quickly to minor changes. The requirements on building structures are increasing as a response to a continuous tightening of energy standards. What was considered energy efficient yesterday does not meet the necessary requirements today. This development resulted in a new paradigm of education.

Later, aside from thermal insulation as a means to reduce heat energy, the efficiency of heating systems and sources of energy also has been taken into account. In Germany, for example, the energy savings ordinance (EnEV) combined the thermal insulation ordinance and the heating system ordinance into one document. The main output of the EnEV energy calculation is the annual primary energy needed to cover the energy consumption of a building. Although this ordinance set up the maximum values of heat transfer coefficients of structures and conditions on how to meet them (the proper thermal insulation of the building is necessary), the priority is given to the energy source, and especially to the use of renewable resources [5].

The main goal of a *passive house* concept (according to Dr Feist) is saving the energy required for heating by reducing the building ventilation and transmission heat losses (five principles of the passive house: air tightness; thermal insulation; insulating triple glazing; eliminating thermal bridging; and heat recovery ventilation), while the maximum allowed primary energy of 120 kWh/m^2 per year is a relatively high value [6].

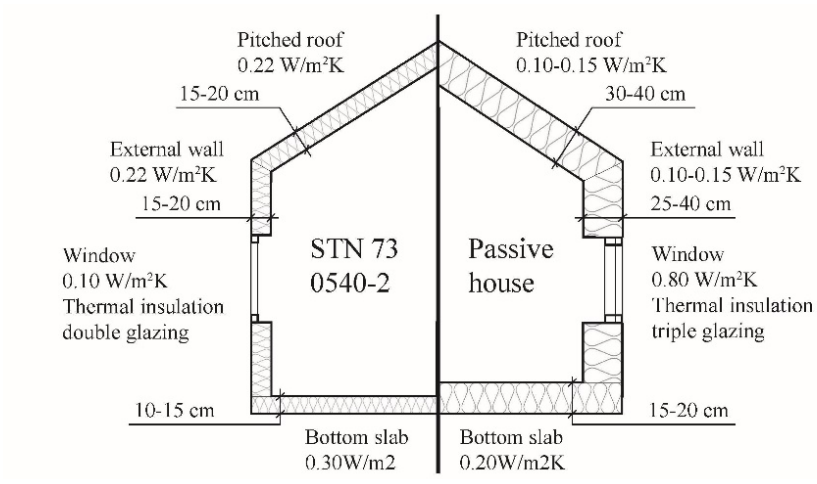

Figure 1: The passive house.

Figure 1 shows the comparison between the heat transfer coefficient and thickness of the thermal insulation in accordance with the present Slovak thermal insulation standard STN 73 0540-2: 2012 (valid from 1.1.2016) and the *passive house* requirements. Standardised values partially reach the values of the *passive house*, i.e. maximum. The allowed value of the heat transfer coefficient for the flat roof is 0.1 W/m^{2}K, which in practice means 40 cm of thermal insulation [7].

On the one hand, there is a Slovak standard that requires the fulfilment of basic hygiene health protection requirements in the design of building structures and buildings with a specified indoor environment. Such requirements take into account different levels of energy efficiency of buildings, i.e.: a) energy-efficient building; b) a low energy building; c) an ultra-low energy building; and d) nearly zero energy building (target for the recommended value) [7].

> *Slovak standard STN 73 0540-2: 2012 after 1st January 2016 requires a shape factor of family houses close to 0.7 1/m, at the same time using mechanical ventilation with heat recovery and designing details with zero influence of thermal bridges on the building's heat losses. Failure to comply with any of the above conditions results in - in an attempt to follow the standard - an extreme increase in the thermal insulating properties of the family houses' envelope significantly above standard values* [8].

On the other hand, there are claims supported by different strategies, documents or architectural approaches through which the limits have been reached of increasing the thermal insulation properties of building structures (thickness of thermal insulation, glazing). At present, the balance calculation method increasingly is being applied: energy demand → renewable energy sources → energy storage appliances → e-house-e-car concept → residual fossil fuel demand (see Figure 2). The goal is to reduce the last factor in this sequence. New concepts are emerging for the active energy contribution to the overall energy balance of a building. There are some shining examples when the object produces more energy than it consumes. They represent models of energy independence: the smart island energy systems (SMILE) and decentralised energy production at the point of consumption, thus avoiding or reducing losses down the line.

In the context of the necessity to use the building surface to generate energy, the current requirement should be reassessed of the shape factor of a building. The paradigm of the smallest surface for a given volume apparently shrinks from the surface size optimised for conversion of solar energy.

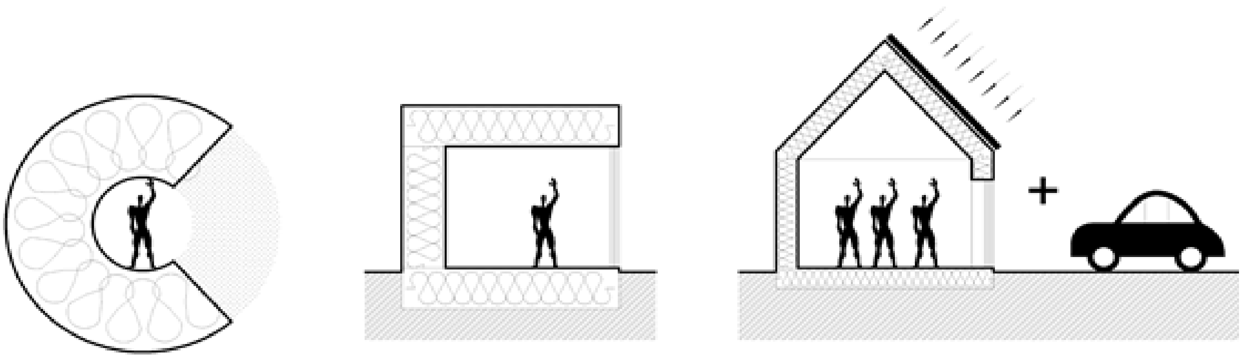

Figure 2: The thermal insulation of buildings as a trend leading to extremism and to objection in the architectural creative expression is gradually replaced by concepts based on decentralised renewable energy generation, combined with electro mobility (e-house-e-car).

REASONS FOR CHANGING MINDSETS

In education it is important to proceed with particular caution. On the one hand, there is critical thinking based on rational consideration. On the other hand, there occurs environmental enthusiasm and the euphoria of young people. So as to achieve a balance between rationality and often emotionally motivated euphoria, the authors of this article try to generate a specific direction in critical thinking. Sustainable and energy-efficient architecture is still associated with too many myths. The main role of education lies, among other things, in explaining these myths and in their gradual elimination (for example, W. Friedel's dissertation thesis which discussed the one-sided sustainability of Dr Feist's *passive house*).

> *The great enemy of the truth is very often not the lie, deliberate, contrived and dishonest, but the myth, persistent, persuasive and unrealistic* (John F. Kennedy).

The continuously changing role of the architect affects education, and therefore conservative/traditional school models cannot follow the pace of development of the extra-academic environment.

> *Architectural education should be subjected to constant modification. New ways of designing, especially the so-called integrated design methods, have introduced innovative systems of cooperation between various participants of creative processes leading to the construction of buildings. Another crucial aspect of the ongoing changes in this regard are new building technologies, which come so rapidly that practising architects are rarely capable of becoming familiar with them in a reasonably short time* [1].

In architectural education, critical thinking represents one of the primary pillars, especially in the current time of dynamically developing trends, standards and positions of sustainability. In architecture, the *condicio sine qua non* of sustainability is beauty. Passive thermal protection of buildings is often counterproductive in this matter.

Several studies exist that are critically concerned with the increase of thermal insulation properties of a building envelope. A critical approach in terms of wider contexts and implications also should be applied in architectural education.

Didactic Approach to Building Costs

One specific Finnish study dealt with the optimal thickness of thermal insulation of a one-storey family house (150 m^2) respecting the local climate and economic aspects [9]. As a result, the standardised heat transfer values were quite strict and caused a 15% increase of total costs, calculated over 40 years, compared to optimal values (cost-effective solution). The most advantageous was calculated to be the heat recovery (ventilation) combined with heat pump (heating). In this case, the optimal heat transfer values were up to 50% higher compared to the required local standard.

The achieved data calculations confirmed that the optimal thickness of thermal insulation depends on the type of building, heating and cooling system, heat recovery and local energy prices. Energy cost savings were achieved by thermal insulation and mostly by heating appliances. The energy costs of a house with ventilation and a renewable energy heating system were low, which resulted in reduced demand for additional thermal insulation protection in the building. One of the main findings was that reducing heat losses through ventilation with heat recovery has a higher impact on energy savings than does additional thermal insulation. Improved thermal insulation caused the interior to overheat in summer so additional investments were needed for external shading and cooling systems. It was also confirmed that the shorter the operation period of the building (20, 40 and 50 years), the less economical is the effect of thermal insulation.

Didactic Approach Considering Energy Savings for Heating

Several studies (for example, a study about the effective thermal protection of different brick exterior wall structures performed by Fraunhofer Institute Holzkirchen in 1983-1984 [10] or the research analysing heat energy demand in existing residential houses carried out by the GEWOS Institute in 1995 [11]) showed that highly insulated structures with a low level of heat transfer values did not achieve the expected low energy consumption. Besides the thermal resistance of the perimeter structures, other factors, such as thermal bridges, solar radiation, shape factor, direction to cardinal points, surface colour and albedo, weather conditions, interior conditions (air temperature, ventilation, etc), HVAC system, user behaviour, and so on influenced energy demands and, consequently, the energy savings for heating.

Didactic Approach Considering Building Physics

Building physics, along with thermal protection, includes other fields, such as: moisture protection; overheating protection during summer; fire protection; acoustics; noise protection; weather protection; natural and artificial lighting. These types of protection, respectively physical effects, such as moisture or overheating, represent the biggest problem in over-insulated and airtight buildings. The selected insulation material and its position (external, internal insulation) are most important as well. The interior climate of the insulated buildings is changing as the perimeter structures are not *breathing* and there is no self-exchange of air. This feature reduces the air quality in the room and can cause the spreading of bacteria or water vapour condensation at critical points in the structures. More frequent ventilation or mechanical ventilation can deal with this issue.

Another common effect is the presence of mould and algae on façades. The reason is that a thermal insulation surface requires a longer drying time which causes humidity maintenance, allowing easy multiplication of these organisms. Another problem of an over-insulated building is that of spaces overheating during summer. Once the warmth from the sun enters the interior, it is difficult to cool it down naturally. To eliminate the physics problems in buildings in the multi-layer construction (resulting from connection of materials with different physical characteristics) or very airtight construction, monolithic elements with improved thermal insulation properties could be a solution.

Didactic Approach Considering the Implementation of Insulation Materials

Natural and regional (within 40 km) insulating materials are easy and suitable for use. Relatively low energy is required to mine, manufacture and transport them to the building site. There are fewer emissions, compared to other man-made materials, for instance polystyrene. They also do not have a great negative impact on the environment; they can be easily recycled or brought back to nature. Because of the physical features use of these materials can help to regulate interior climates. On the one hand, there can be a construction made of straw boles with clay plaster that is cost-effective, as well as environmentally and user-friendly, and characterised by very good thermal insulation properties. On the other hand, there is polystyrene that was declared hazardous waste in spring 2016, because of a widely used flame-retardant hexabromocyclododecane (HBCD) banned throughout the world. It releases styrene emissions, so polystyrene may be marketed after four weeks of storage. If a fire occurs, polystyrene burns by formation of toxic combustion gases that can form highly toxic dioxins and furans [12].

Shown in Figure 3 are comparisons between the primary energy and CO_2 emissions from producing a number of exterior wall structures.

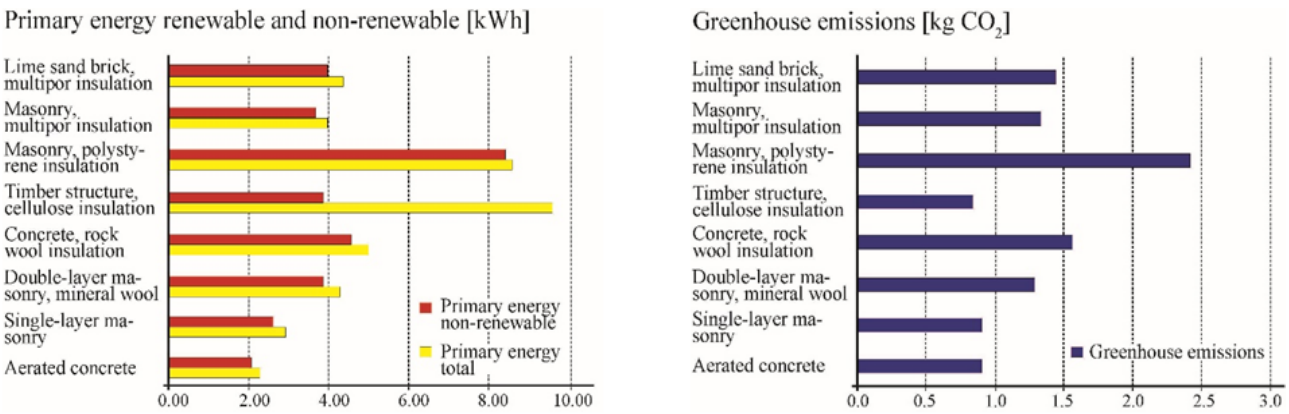

Figure 3: Comparison of primary energy and CO_2 emissions from production of eight different exterior wall structures, per 1 m^2, U = 0.2 W/m^2K, according to the Swiss study made by GIBBeco - Genossenschaft Information Baubiologie [13].

From the compared constructions, the largest consumption of non-renewable primary energy and the release of emissions is a brick wall with polystyrene insulation; the most environmentally friendly is the monolithic structure made of aerated concrete, as well as a wooden structure with thermal insulation from cellulose.

Didactic Approach Considering the Broader Point of View

This didactic approach involves the comparison of the fuel consumption of a building operation with mobility and equalisation of fuel consumption with insulation surface/surface of active energy generation. Table 1 shows a comparison of fuel consumption of a *3 litre house* and a *passive house* with the fuel consumption of a car and airplane. This has shown that, apart from saving energy in the operation of homes, it is much more important to deal with the energy savings in mobility, especially in air transport. It is not possible to save fuel by adding a few centimetres of thermal insulation, so it needs to be offset in another way.

Table 1: A comparison of fuel consumption of a *3 litre house* and a *passive house* with the fuel consumption of a car and airplane.

3 litre house			
Fuel consumption 3 l/m^2a	Floor area 100 m^2	Household consumption 300 l / 100 m^2a	1-5 persons
Passive house			
Fuel consumption 1.5 l/m^2a	Floor area 100 m^2	Household consumption 150 l / 100 m^2a	1-5 persons
3 litre car (basically an illusion), daily route 27.4 km = 1 year of heating in 3 litre house, daily route 13.7 km = 1 year of heating in passive house			
Fuel consumption 3 l / 100 km	Daily route 27.4 km = 10,000 km/a	Car consumption 300 l / 10,000 km.a	1-5 persons
	Daily route13.7 km = 5,000 km/a	Car consumption150 l / 5,000 km.a	
Airbus A380, 1 flight from Bratislava to Bangkok and back, two persons = 3 and half years of heating in 3 litre house or 7 years of heating in passive house			
Fuel consumption 3.12 l / 100 km.person	Route 8,400 km x 2 = 16,800 km	Flight consumption 1,048 l / 16,800 km 2 persons	2 persons
Airbus A380, 1 flight from Bratislava to Sydney and back, two persons = 6.4 years of heating in 3 litre house or 12.8 years of heating in passive house			
Fuel consumption 3 l / 100 km.person	Route 16,000 km x 2 = 32,000 km	Flight consumption 1,920 l / 32,000 km 2 persons	2 persons

Table 2 shows that to compensate the annual 10,000 km car fuel consumption of 1 l / 100 km through the house thermal insulation (exterior wall and roof only) the energy saving in a house with floor area of 100 m^2 needs to reach 10 kWh each m^2.

Table 2: Energy savings to compensate for annual 10,000 km car fuel consumption of 1 l / 100 km.

Consumption	35 $kWh/m^2.a$	25.1 $kWh/m^2.a$	15.5 $kWh/m^2.a$
U-value of exterior structure (homogeneous polystyrene)	0.23 W/m^2K	0.12 W/m^2K	0.01 W/m^2K
Polystyrene thickness	13 cm	25.5 cm	300 cm *

* In the case of the requested reduction in energy demand per m^2, other measures or combinations of several solutions would be applied. This was calculated for a 10 x 10 x 3 m model cube, with triple glazed window U_w = 0.54 W/m^2K in all cases

CHANGE IN APPROACH THROUGH NEW TECHNOLOGIES

The authors of the article have explained to their students the primary question of lifestyle. Passive thermal protection of buildings has reached its physical limits. Nowadays, the crucial task is to optimise the ratio of cost-performance and environmental impact. Human behaviour remains at the centre of this thinking, in comparison to traffic - travelling to work - energy consumption.

Other aspects that need to be considered are the combination of insulation and use of alternative energy sources (solar, wind energy) in regards to the decrease in prices of energy generated from renewable sources. Buildings also can serve as energy generators, which means they can produce more energy than they need for operation.

Another concept, suitable especially for cultural monuments, when traditional insulation is usually impossible to use, represents the smart grid or energy co-operativeness among buildings. It means that an energy-positive building provides its surpluses to buildings with high energy demands. This approach to the preservation of such monuments without thermal isolation from the 20th and 21st Century for future generations is significant for cultural sustainability. The main goal is not to save energy but to save *primary* energy.

Transparent thermal insulation represents another solution that enables the solar gains in winter periods and through which the thermal protection of a building can be performed. It does not influence the architectural expression of the building, and is suitable mainly for monument restoration. The construction industry offers a large number of materials such as *aerogel, vacuum insulation* or thermal insulation plaster characterised by low thickness. Unfortunately, these materials are quite expensive and have an adverse effect on the environment linked with their production (e.g. *aerogel* insulation). Therefore, further research in this field is required. Another option is insulation made from capillary or honeycomb panels applied by architect Thomas Herzog in the project of a *semi-detached house in Pullach* in 1989.

Nowadays, there exist many interactive concepts for façades that dynamically react to changing conditions in the surrounding environment. To mention a few: sun protection panels; segments generating power from solar energy during the winter period; gathering rain water in reservoirs. Thus, they can be adapted effectively to different conditions during changing seasons or during the day and night. Such concepts are based not only on preventing heat transfer from buildings, but they also allow permeation of direct solar radiation into the spaces of the building during winter.

At the *Energy Forum* in October 2014 in Bressanone, Italy [14], many advanced building skins were discussed, such as the façades named *active, adaptive, solar* (for example the *Trombe wall*), *responsible, dynamic, multifunctional* and *green,* as well as *wallboard-integrated phase-changing materials (PCMs)* that can store thermal energy and also prevent heat from passing through temperature-controlled areas, such as walls or roofs.

Other concepts included those where the building envelope is also an active energy source, such as the *smart building envelope, cyber-physical systems for cognitive building skins*, and so on. Many inventions and developments in information technologies are pushing boundaries in this area of thermal protection.

Many studies have proven that even less-insulated buildings (mostly monolithic structures), with efficient use of renewable energy for heating, are much more economical, ecological and socio-cultural friendly, and thus more sustainable in the long term. It is important to find the right compromise that depends on several factors. The most important factor is access to renewable resources for construction (e.g. natural insulation material) and after that, renewable sources for covering energy demand of the building with the possibility of storing energy. When having sufficient access to renewable energy sources covering its consumption and with the possibility to store it, the amount of energy consumption becomes secondary. Therefore, decentralised energy production is growing more important. Hence, architects must try to integrate energy generators into buildings and their façades, create energy-efficient building clusters and reach a symbiosis within a building neighbourhood.

> *The more the proportion of photovoltaics (PV) for power generation increases, the more important is that more PV devices are integrated into the building envelope. Today, according to the largest solar yield, the PV devices are oriented to the south with an angle of about 30°, in the future, due to the all the day current demand, the important PV devices will be oriented in all directions. East-facing photovoltaics will be needed to produce the maximum current in the morning, or west-facing devices reaching their peak in the afternoon. But also PV devices on the façades that reach their maximum in winter when the sun shines low over the horizon, or which are orientated towards the north and produce more current in the summer in the morning and in the evening, will provide an important contribution to the changing current load profiles* [15].

Figure 4 below shows the Stavros Niarchos Foundation Cultural Centre (SNFCC), Athens, architect Renzo Piano. The energy canopy with a dimension of 100 x 100 metres covers the building of the Greek National Opera; it is one of the largest energy canopies in Europe. The declared volume of energy generated from the photovoltaic roof is about 2 GWh/a, which contributes to the goal of zero CO_2 emissions [16].

Figure 4: Stavros Niarchos Foundation Cultural Centre (SNFCC), Athens.

DISCUSSION AND CONCLUSIONS

Sustainable architecture requires a large number of factors and external impacts to be considered. Hence, it is necessary to think critically about the matter. For this reason, the teaching of sustainable architecture should replace the *training* method with the *education* method, in which students are forced into a deeper understanding of the subject, helping them to choose from a wide range of information and apply the knowledge learned by means of practical exercises. Modern teaching is not about providing the theoretical facts that are available to the wider public by means of digital media. As a part of education, the authors of this article suggest it is necessary to explain all terminology, to ensure students are not misled. Interaction with other professions and students from other faculties can teach students to handle different points of view, and apply knowledge and approaches from various disciplines.

There is no universal approach to designing sustainable architecture. Building practice is constantly changing based on new knowledge, changing standards or users' requirements and preferences. Holistically, buildings should be considered complex. In the design process, students must deal with many inputs, such as the lifecycle of the building, energy savings during the operation of the building, extraction of raw materials and their conversion to building materials, construction itself and subsequent building operation. In general, in the very first stage of the project students and architects must determine the preliminary time of the building's operation, because this aspect is crucial for the proposed measurements.

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