NEW CONCEPTS FOR INCREASING THE BUILDINGS ENERGY EFFICIENCY

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Abstract: The efficient use of energy is a compulsory step towards sustainable development. Regardless the source (fossil fuel or renewable), energy consumption should be efficient to protect the resources and to lower the overall costs. This is particularly valid for buildings as worldwide over 90% of the built environment is non-efficient. This makes the already built environment one of the major concerns and raises problems that are now-a-days approached by researchers and practitioners. Old buildings need to be refurbished, to increase their energy efficiency and to reduce the exploitation costs but major barriers were identified, related to architectural and construction constraints and to the investment costs. To prevent these problems in the future, the new buildings need to be designed from the beginning as energy efficient. The paper presents a comparative analysis of several novel solutions aiming at energy efficiency in old and in new buildings. Various insulation systems are discussed (for the opaque and glazed surfaces), along with energy saving measures: for thermal energy (temperate concrete, thermal zoning of the radiant surfaces, natural ventilation, night-cooling, etc.) and for the power consumption (maximal use of natural lighting, light tubes). The implementation of new concepts of Building Energy Management Systems is also discussed, as a compulsory step in implementing renewable energy systems in energy efficient buildings.
Keywords: Energy Efficiency, Sustainable Built Environment, Building Energy Management Systems

1. INTRODUCTION

The progress of humankind is directly linked to the energy consumption. Starting with the Industrial Revolution and till the last decades of the XXth Century, industrial development was the main target of research and technology and was considered the only path identified for progress and for improving the life standards.

The consequences of almost two hundred years of development without considering the environment are now raising major concerns, that actually originate from the use of fossil fuels (oil and its derivatives, coal and gas) that are heavily supporting our energy pattern: (1) the greenhouse effect responsible for climate changes and (2) the fossil fuels depletion that leaves not only the energy problem unsolved but also the production of many common goods that use oil as raw material (e.g. plastics, rubber, synthetic fibres, etc.).

Thus, now-a-days concrete actions are formulated, aiming at mitigating the effect of human activities on the very sensitive environmental balance; during the early years that followed the formulation of the Sustainable Development concept, mainly isolated actions were implemented, e.g. by using renewables to replace the fossil-based energy production; however, these un-coordinated actions have a very slow pace and positive effect, much slower than the dynamic of the carbon-based energy pattern, thus pollution increased and its associated effects are more and more perceivable. This is why energy, raw materials and environment are now considered in an integrated approach and the concept of Sustainable Product Development is largely recognized along with an environmental tool, the Lifecycle Assessment, [1].

In this view, very common but complex products are represented by the buildings. Buildings are major energy consumers regardless their destination (industrial, public, office buildings or regular households). It is estimated that over 40% of the EU energy consumption is related to the buildings and these generate over 36% of the CO_2 emissions. There are very large variations among the

buildings and these come mainly from the energy losses; the motivation of the Energy Performance Directive in Buildings (Directive 2010/31/EU of the European Parliament and of the Council) shows that top quality buildings use three to five litres of heating oil per square meter per year, older buildings consume about 25 litres on average and some buildings even require up to 60 litres. The same document estimates that by increasing the energy efficiency in buildings the EU energy consumption can be lowered by 5…6% in affordable and feasible conditions, which corresponds to a CO_2 emissions reduction of 5%. These percentages are mirrored in huge amounts of fossil fuels that can be spared and used for much wiser purposes, like goods production, pharmaceutics, etc.

Based on these findings, with significant variations in different EU countries, the concept of *Low Energy Buildings* (LEB) was developed and adopted. There is no common definition of the LEB status and it is not likely to agree upon such a definition all over Europe, mainly because of the very different climatic conditions that can be found on our continent. This is why in Northern countries the values that define a LEB are rather high, for example 110…150 kWh/m^2/year (delivered energy) in Sweden and 150 kWh/m^2/year (net energy) in Norway, while for Germany the threshold is of 70 kWh/m^2/year (primary energy) [2, 3].

Buildings energy efficiency is thus a quantifiable property that mainly depends on the implementation location and materials that are used in construction, including insulation. While the implementation location does not register massive variations in the climatic profile (especially in the outdoor temperature values), the building as such is subject of continuous deterioration as result of aging. Therefore, old buildings represents actually the major problem that has to be solved for two reasons: (1) from the beginning their construction was done with little concern for reducing the energy losses and (2) during aging, the buildings efficiency is decreased. Surprisingly, extended studies showed that buildings developed during the past 30 years or buildings older than 100 years are more efficient than the rest, thus the problem is represented by the buildings dating from 1920 till 1985, and these represent over 80% of the entire building stock [4].

Increasing the energy efficiency of an old building is possible but limited by objective constraints: spatial orientation, mechanical resistance, etc. These constraints do not exist when developing a new building, when combined solutions for energy efficiency can be complementary integrated.

Developing energy efficient buildings solves only one part of the problem; additionally the future should also consider the energy embedded in the construction materials, and the avoiding of critical materials, i.e. materials that are scarce, toxic and/or strategic (e.g. oil).

This paper reviews the main problems related to the buildings' sustainability and presents a comparative analysis of the passive and active solutions for increasing the buildings energy efficiency in old and in new buildings, along with the comments on the environmental impact of these solutions.

2. PASSIVE SOLUTIONS FOR ENERGY EFFICIENT BUILDINGS

Passive solutions for increasing the energy efficiency in buildings aim at making use of the local climatic resources for reducing the thermal and electrical energy demand. This includes the South orientation of the largest glazed walls for reducing the lighting consumption and for increasing the greenhouse effect of the solar radiation for indoor heating during transient and cold seasons. One example is the R&D Institute of the Transilvania University of Brasov that consists of 12 low energy buildings, South-oriented (despite the fact that this orientation does not follow the road line), Figure 1.

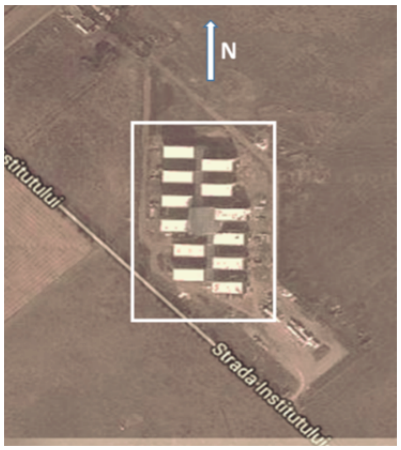

Fig. 1. The S-N orientation of the R&D Institute of the Transilvania University of Brasov (ICDT).

The distance between the buildings is calculated to avoid reciprocal shading even during winter (when the sun "is low" and the shadows are long). Shadowing calculations are done for the worst case scenario - the winter solstice.

The South orientation of large curtain walls has a significant drawback during summer, when it supports indoor (undesired) heating through the glazed surface (with less performant thermal resistance as compared to the opaque walls). This drawback can be mitigated by controlled shading; traditional Romanian houses are representative examples for this, having a shading plateau positioned as to reflect the summer solar rays and to leave the winter radiation inside the house. If this type of shading does not represent a viable option (e.g. in high buildings), other types of solar shades can be mounted or glazing with controlled thermal transmittance can be used. The latest option was adopted in the ICDT buildings, with triple glazed windows having controlled optical parameter both on the indoor and outdoor sheets. Regularly, these double Low*E* windows are of polymeric type (thus using basically oil as raw material) but recent alternatives propose temperate inorganic glass, obtained using sand as raw material. Inorganic glass is a highly energy intensive material but is fully recyclable, thus in a lifecycle assessment its contribution is not extreme. For high buildings and for buildings with special destination (schools, hospitals etc.) the safety regulation impose special glass restrictions which hardly can be fulfilled by inorganic glass thus a compromise solution implies a triple glazing combining polymer and inorganic sheets [5]. Oppositely, the Northern part of the building is always exposed to lower temperatures, thus large areas of compact walls are recommended, to mitigate the energy losses during the cold seasons. Thus, the ratio of glazed/opaque surfaces in the building envelope is an important passive solar feature and has different values on the differently oriented walls of the building.

The major passive contribution to the building energy efficiency is related to the insulation which can significantly limit the thermal energy consumption both in the cold seasons (by reducing the heat losses) and during the warm seasons by decreasing the heat gain in the building (thus reducing the cooling demand). Various insulation solutions are now-a-days on the market, mainly involving cellular polymers (polystyrene, polyurethane) that are used as such or in composites with metal sheets. Their efficiency is directly related to the volume fraction of voids (where the insulating air is trapped) and with the thickness of the material.

(a) (b)

Fig. 2. LEB in the R&D Institute of the Transilvania University of Brasov:
(a) Southern and S-W facade; (b) Northern facade.

Implementing these concepts was done in the ICDT buildings, with the opaque part of the envelope of this type, with a metal sheet covering a 20 cm cellular polyurethane with a large fraction of very small voids (micro- porous); the thermal transmittance of this panels deposited on a regular concrete wall (total thickness of 30 cm on the Northern part, Fig. 2) is very low and allowed reaching the LEB status, confirmed during one year of monitoring: the total energy demand is 90 MWh/year; by reporting this value to the total floor surface (1350 m^2) a specific energy load of 66.69 kWh/m^2/year is obtained, divided as follows: 57.8 kWh/m^2/year for heating, 5.75 kWh/m^2/year for cooling and 3.14 kWh/m^2/year for domestic hot water, [6].

Although efficient these insulation solutions have a high (and negative) environmental impact due to the use of polymers (oil based) and steel (energy intensive). More sustainable solutions are using natural materials (plaster) as matrixes in composites with natural fibres or micro-insulators with controlled porosity [7]. Highly efficient but less cost effective are the advanced insulation solutions based on phase change materials, [8]. These latest solutions are feasible also for refurbishing historical buildings, as they can be shaped respecting the architectural *patina*.

Last but not least, the shape of the building can significantly support the decrease in the thermal energy consumption: surfaces with rounded shape, avoiding as much as possible rectangular angles, will support inner air flow circulation, that allows the warm/cold air layers to exchange supporting the natural ventilation for cooling during summer and for heating during the cold seasons, [9]. The Solar House in the Transilvania University of Brasov has such a particular passive solar architectural design with an egg shape, Figure 3.

Fig. 3. The Solar House in the Transilvania University of Brasov, Campus Colina with passive solar architecture.

A synthesis of all these options is presented in Table 1. As the findings in Table 1 show, refurbishing implies increased costs to implement energy efficient solutions, thus supporting incentives should be adopted to increase the acceptance. By applying these recommendations in refurbishing, the energy efficiency will significantly increase in any building but the initial financial effort must be well balanced by the payback time, as result of lowering the energy consumption.

Table 1. **Passive solutions for increasing the energy efficiency in buildings**

Solution	Applicability for refurbishing buildings	Applicability for new buildings
S – N Orientation	*Impossible*, as the buildings has an initial given position in the implementation locations	*Possible* but efficient only if shading is avoided (from the neighbouring constructions or architectural objects or vegetation) *Cost*: no additional costs, if there is enough available construction ground
S-facing curtain glazing / N-facing compact walls	*Possible*, according to the mechanical resistance of the building and to the architectural constraints *Cost*: additional refurbishing costs	Possible, as a solution implemented in the initial building design *Cost*: not additional costs if considered from the design phase
Environmental friendly glazing	*Possible*, (partially) using inorganic glass, respecting the safety regulation *Cost*: additional refurbishing costs	Possible, (partially) using inorganic glass, respecting the safety regulation. *Cost*: not additional costs if considered from the design phase
Composite insulating materials	For regular buildings and blocks of flats, insulating layers covered with cellular concrete of metal sheets. For historical buildings, mainly as dispersed insulator in a base material. *Cost*: additional refurbishing costs	Insulating composite materials: as layers protected with metal sheets or cellular concrete plates or advanced solutions based on micro-dispersed insulators in concrete or in natural-based binders. *Cost*: not additional costs if considered from the design phase
Solar architecture	*Impossible,* as the building already has a given shape of the envelope (usually rectangular)	Possible, as a solution implemented in the initial building design *Cost*: not additional costs if considered from the design phase

Usually, calculations are done considering the current costs of the electrical and thermal energy but, a correct approach should consider the short and middle term scenarios that predict increased costs for the energy obtained from fossil fuels as a combined effect of the decrease in the reserves and penalties applied for environmental pollution. In Romania for example, the short term projection

shows significant increase in the thermal energy costs, thus the most simple action – envelope insulation, is well justified; another issue is the need for a professional design of insulation, and more generally of the combined measures, in agreement with the implementation location and the actual quality of the old building, estimated by on-site measurements.

On the other hand, careful and smart design of the new buildings can lead to buildings with increased energy efficient, without too high initial investment. To extend the implementation of sustainable energy buildings requires knowledge at the professionals' level (architects, civil engineers) and at the beneficiaries' level. When selecting the solutions, obviously the beneficiary will firstly consider the costs, without too many thoughts on environmental protection. This is why policy regulation should be formulated to make distinction among the sustainable and the un-sustainable construction materials, by e.g. awarding incentives proportional with the overall environmental impact of the new building (considering the construction and the exploitation phases).

By implementing these type of measures, passive solar buildings can be developed. An almost unanimously accepted indicator, defines a building as passive solar house if the heating energy demand is less than 15kWh/m^2/year.

3. ACTIVE SOLUTIONS FOR ENERGY EFFICIENT BUILDINGS

Active solutions for increasing the energy efficiency are related to the energy production and consumption in the building.

Most of the buildings are grid-connected, thus electrical energy production is done in centralized systems (mainly coal and gas based),therefore the production cannot be influenced at the building level. Decreasing the electrical energy consumption can mainly done at the consumption level, particularly by implementing low energy consumers for:

- Lighting, e.g. by replacing the regular incandescence light bulbs with LED lighting that can decrease by four up to ten times the energy consumption;
- Computers and multimedia by using "green" solutions, already existent on the market;
- Household appliances. The A…E energy efficiency ranking of most of the domestic electrical devices was well advertised and is part of the common knowledge at consumers level, which are educated to purchase energy efficient devices even if the initial cost is higher.

Thermal energy is used in buildings for domestic hot water (DHW) production, for heating and (less often) for cooling. Thermal energy is usually produced at the building's level or in communities (district heating). There are pros and cons for both alternatives and the discussion cannot give a unique solution. On-site heating is comfortable but implies an initial investment that can be convenient for public, office and industrial buildings but is less convenient for individual households or apartments; additionally on-site heating implies a large number of point-pollution sources emitting CO_2. District heating is convenient only if the distribution network is well insulated and limits the losses; from an environmental point of view, community or district heating has the major advantage that it allows the implementation of units able to treat the gases resulted during burning fossil fuels, thus their environmental impact is much, much lower.

In each situation, energy efficient burners must be used, adapted to the type of fuel (oil, gas, Diesel, biomass, coal, etc.), also including systems that recuperate the condensation heat of water.

In a temperate climate, thermal energy consumption amounts about 15% for DHW, 20% for cooling (if any) and the rest is used for heating, [10]. This makes heating the most important target that must be addressed to reduce the thermal energy consumption, and the focus is actually on reducing the losses.

Obviously, the larger the temperature of the heating source is, the larger are the losses; this is why, heating with lower temperature (enthalpy) sources is one of the main paths in reducing the losses and insuring indoor thermal comfort and the usually developed solution is represented by floor heating [11]. Floor heating requires a thermal agent no warmer than 30…32^{o}C and insures uniform heating of the entire space. To be effective, floor heating requires a not too high insulated floor surface, thus the old, thick wooden floors are not recommended; actually massive wood is not recommended at all, as the continuous heating leads to an extensive drying and to cracks. Recommended solutions imply therefore thin wood laminated structures (where the wood is thermally treated) or ceramic tiles. Unfortunately, the most cost-effective solutions in the market are based on polymeric composites, with very low (or no) wood insertions which, although effective, raise the

common problem of plastics (the raw material is oil) and additionally, can emit in time volatile organic compounds of average toxicity. This solution is implemented in the Solar House in the Transilvania University of Brasov, using ceramic tiles as floor.

Similarly to floor heating other large surfaces, like the walls can be used.

An advanced solutions for large-surface, low-temperature heating is represented by the temperate concrete, where the tubes for the heating agent are implemented in the middle of the concrete platform that separates the building's stores (the solution is called "temperate concrete"). This has the immediate advantage of simultaneously providing floor and ceiling heating along with the "*in situ*" storage of the heat in the thermal mass represented by the concrete plate. This solution was implemented in the buildings of the R&D Institute of the Transilvania University of Brasov and a comparative monitoring of the specific energy consumption in these buildings and in the Solar House outlines the advantages of temperate concrete for multi-store buildings. Both solutions for large surface heating are significantly reducing the thermal energy consumption as compared to rooms where regular heating bodies are installed (about 30%).

Both floor heating and temperate concrete have the additional advantage of being able to support cooling. On sustainable solution that allow both heating and cooling is represented by heat pumps use; if the heat pumps are operated in direct and reverse circuit, both heating and cooling can be reached and the heat pumps have high performance coefficients (COP = 5 or higher).

According to their destination, the rooms in a building require different temperatures, thus have different specific thermal energy demands. This can be easily solved by adapting the meander tubing for the heating agent (in floor or temperate concrete solutions) for each room, providing the required energy. But for large rooms, of open space type, one possible solution is thermal zoning, that gives full value to the passive heating (e.g. through large glazed envelopes South – oriented) and actually heats only the parts that are less supported by the passive energy efficiency solutions. This solution was applied in the buildings of the R&D Institute of the Transilvania University of Brasov, [6], where a large open office (150m^2) is dedicated to the desks of the researchers and Ph.D. students, Fig. 4.

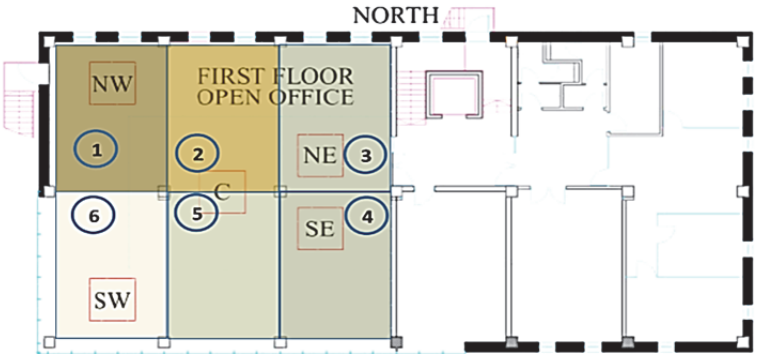

Fig. 4. Thermal zoning in an open office (R&D Institute of the Transilvania University of Brasov).

The thermal zoning implies six different meander tubes circuits that can be differently commanded, to give an almost even indoor temperature; in the absence of thermal zoning, differences as high as 6^{o}C could be registered during winter between zone 6 (where passive solar heating is maximum as result of the orientation and glazing) and zone 1. These differences can be compensated through differently heating the 1….6 zones. An automation is responsible for this.

Last but not least, reducing the energy consumption can be done by simply using the energy only when needed. This is a matter of behaviour (and education can well contribute) but not only, if inhabitants comfort is also considered. This is why Building Energy Management Systems (BEMS) were developed, with different complexities at the level of the hardware infrastructure (sensors, data loggers, control systems) and at the algorithm and software levels [12].

The first attempts referred to saving electrical energy by implementing motion sensors but in the past decade more sophisticated systems were developed, involving the thermal energy consumption (including thermal zoning), e.g. by switching on/off the heating/cooling by a web-based command or through a pre-defined time schedule. Implementing BEMS raises the building standard to "intelligent building", although the building intelligence concept is now-a-days more complex, involving also the sustainable waste management and emissions control [3].

A synthesis of the analysed active solutions for increasing the buildings' energy efficiency is presented in Table 2.

Table 2. **Active solutions for increasing the energy efficiency in buildings**

Solution	Applicability for refurbishing buildings	Applicability for new buildings
Using low power consumers	*Possible*, by replacing the old consumers for lighting and household appliances with low energy consumers *Cost*: additional cost but not very high, as most of the powered devices are anyway replaced each 5…15 years	*Possible*, from the design step *Cost:* additional costs as compared to the traditional devices but with acceptable payback time
Thermal energy production	*Possible* on-site or at community level if reducing the losses during transportation and distribution *Cost*: on-site additional costs for replacing the traditional burners with energy efficient burners	*Possible* on-site or at community level if reducing the losses during transportation and distribution *Cost*: no additional costs if energy efficient burners are integrated in the design phase
Floor heating	*Possible*, by replacing the traditional wooden floor with thinner composites, wood- or ceramics-based *Cost*: additional refurbishing costs	*Possible*, from the design step *Cost*: no additional costs if the solution is implemented in the design step
Floor and ceiling heating using temperate concrete	*Impossible* through simple refurbishing	*Possible* if implemented in the design phase *Cost*: similar to the usual floor heating
Thermal zoning	*Impossible* through simple refurbishing	*Possible* if implemented in the design phase *Cost*: quite high as it requires specific automation
BEMS	*Possible*, in any situation *Cost*: additional sustainability costs	*Possible*, in any situation *Cost*: additional sustainability costs

Similarly to the passive solutions, the active solutions that support energy efficiency can be easily implemented in new buildings. However, there are solutions that suitably match also the refurbishing process. It is to mention that all the active solutions hereby described (and many others) are effective if passive solutions were already implemented. Of course, the active solutions are not directly linked to the passive ones (as Table 1 and 2 show) but the payback time makes cost-effective the active solutions only if the energy consumption was already reduced through passive measures (at least insulation).

4. CONCLUSIONS

The path towards sustainable development implies to reduce the fossil fuel consumption and eventually to replace these by renewable energy sources. Until a fully green energy pattern is reached, significant actions must be *now* taken, to mitigate the global warming and this implies to increase the efficiency of the energy used in all the applications.

Buildings are major energy consumers, therefore the energy efficiency in buildings represent a multi-facet topic, very much investigated at research but also at technology development levels.

Increasing the energy efficiency of a building has not a unique solutions: the answer depends on objective factors: the implementation location, the type of building (industrial, public, office, family buildings, and blocks of flats), the age of the building (new or needing refurbishing), etc. The answer also depends on subjective factors: costs (thus affordability in a given economical context), professionals' training, inhabitants' level of education (directly influencing the market request), etc.

Passive and active solutions must be complementary considered to significantly increase the energy efficiency in a building, by preserving or increasing the indoor comfort, at an affordable cost.

Once a building is energy efficient (and reaches the LEB status) it can be further developed towards sustainability by implementing renewable energy systems.

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NOI CONCEPTE PENTRU CLĂDIRI EFICIENTE ENERGETIC

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Rezumat: Utilizarea eficientă a energie reprezintă o componentă obligatorie a dezvoltării durabile. Indiferent de sursă (combustibili fosili sau energii regenerabile), consumul de energie trebuie să fie eficient pentru a proteja resursele şi pentru a scădea cheltuielile globale. Acest aspect este pregnant atunci când se abordează mediul construit, pentru care estimările la nivel mondial indică un procent de peste 90% ca fiind ineficient din punct de vedere energetic. Acest fapt face ca mediul construit să reprezinte una dintre principalele probleme actuale iar problematica ridcată reprezintă subiectl de interes atât pentru cercetătorii ştiinţifici cât şi pentru practicieni. Clădirile vechi trebuie reabilitate pentru a creşte eficienţa lor energetică şi pentru reducerea costurilor de exploatare dar s-au identificat o serie de bariere greu de trecut, referitoare la restricţiile de inginerie civilă şi arhitectură ca şi referitor la costurile de investiţii. Pentru a preveni escaladarea acestor probleme în viitor, clădirile noi trebuie proiectate de la început astfel încât să fie eficiente energetic. Lucrarea prezintă o analiză comparativă a unui set de soluţii noi, vizând eficienţa energetică in clădirile vechi şi noi. Se discută diferite sisteme de izolaţii (pentru suprafeţele opace şi pentru cele vitrate), alături de măsuri de economisire a energiei pentru: energie termică (beton temperat, zonare termică a suprafeţelor radiante, ventilaţie naturală, răcirea de noapte etc.) si pentru energia electrică (utilizarea la maxim a luminii naturale, tuburi de lumină etc.). Implementarea de noi concepte de tipul Sistemelor de Management al Energiei în Clădiri este de asemenea discutat, ca un pas necesar în implementarea sistemelor de energii regenerabile în clădiri eficiente energetic.

Cuvinte cheie: eficienţă energetică, mediu construit sustenabil, sisteme de management al energiei în clădiri.