Annex 44 - Responsive Building Elements (RBE): a State-of-the-art Review

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ABSTRACT

Responsive Building Elements (RBE), as defined in International Energy Agency - Annex 44, are building construction components which are actively used for transfer and storage of heat, light, water and air. These construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and lighting. The development, application and implementation of responsive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment. This paper will present and discuss the results of the state-of-the-art review on RBE performed during the first year of activities of the Annex 44, and highlights existing applications, availability and suitability of design tools for the estimate of environmental performance of responsive building elements.

KEYWORDS

Responsive building elements, energy saving, indoor comfort

INTRODUCTION

Research and technological innovation, over the last decade, have determined a significant improvement of performances of specific building elements like the building envelope - including walls, roofs and fenestration components - and building equipments - such as heating, ventilation, cooling equipment and lighting. Whilst most building elements still offer some opportunities for efficiency improvements, the greatest future potential seems to lie with technologies that promote the integration of “dynamic” building elements with building services. In this perspective the term “dynamic” translates into the fact that functions, features and thermophysical behaviour of such building components may change over the time and adapt to different building/occupants requirements (heating/cooling, higher/lower ventilation, …) and to different boundary conditions (meteorological, internal heat/pollution loads, …). Within Annex 44 such components have been defined as ***Responsive Building Elements (RBE)***.

A*n RBE is a building construction element that assists to maintain an appropriate balance between optimum interior conditions and environmental performance by reacting in a controlled and holistic manner to changes in external or internal conditions and to occupant intervention*.

This means that building components are now actively used for transfer and storage of heat, light, water and air and that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and lighting. The development, application and implementation of responsive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment. Examples of RBE include, among the others: façades systems (ventilated facades, double skin facades, adaptable facades,

dynamic insulation,…), foundations (earth coupling systems, embedded ducts, …), energy storages (active use of thermal mass, material - concrete, massive wood - core activation for cooling and heating, phase change materials, …), roof systems (green roof systems, …), active/passive solar systems, daylighting technologies.
In Annex 44 attention has been focused only on five specific responsive building elements, whose perspective of improvement and widespread implementation in the building sector seems to be much more promising.

ADVANCED INTEGRATED FAÇADE (AIF)

Figure 1 – V Palazzo SNAM (mechanically ventilated façade)

Figure 2 – Example of a corridor façade

An Advanced Integrated Façade (AIF) is a building envelope that exhibits adaptive characteristics that are in tune with both the physical/ climatic conditions of a particular location and the indoor environment requirements. An AIF provides the basic functions of shelter, security and privacy, while minimizing energy consumption.
The working principle of a transparent ventilated façade is to use the air gap between the two glazed panes to reduce the thermal impact on the building environment. The air gap may use natural, mechanical or hybrid ventilation schemes, or simply act as a still air buffer. AIF are the actual development of what started with passive architecture principles and evolved, originally, into Double Skin Façades (DSF) and, recently, into the intelligent skins concepts. The concept of "intelligence" associated with DSF represents a change from a static envelope to one with a dynamic behaviour and must refer to an "intelligent design" rather than just an assembly of "intelligent components".
A correctly designed AIF should make a rational use of renewable sources.
Within the state of the art review, over 200 buildings worldwide were found to be utilizing the DSF/AIF concept. The geographic distribution of the buildings that use DSF/AIF shows that a large fraction of buildings are located in Continental/Northern European countries (56.7%) and Japan (13.0%). In these countries the climate conditions are probably more suitable for the use of AIFs with cold winters and mild summers. However, as seen in a number of actual cases, habit and fashion may have a primary role in the choice of the building designer for the adoption of a DSF/AIF. The majority of buildings (more than 90%) included in the state of the art review are of the office type.
The energy savings achievable with an AIF may result from an increase in the use of daylighting on peripheral areas and from an improved thermal behaviour, than can lead to a reduction in air conditioning use. Comfort may also be improved, because the temperature of the inner glazing surfaces is closer to the indoor temperature. It has been proved that, heat load reductions between 38-52 W/m^2 may be achieved.
Barriers to DSF/AIF implementation mainly arise from: costs, fire standards and regulations, construction regulations and laws, and lack of knowledge and lack of suitable and reliable design tools. The state of the art review, showed that the technology is promising but that it is still quite young and further developments are needed before their performance become satisfactory.

THERMAL MASS (TM)

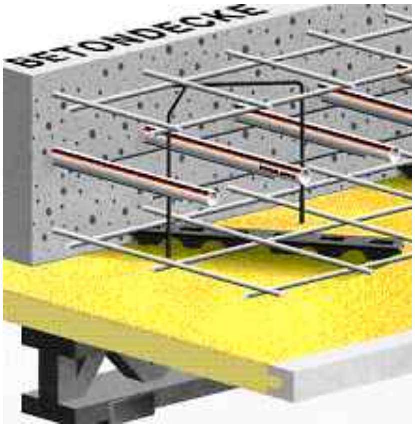

Figure 3 - cross-section of a TMA on-site constructed system (www.velta.de).

Thermal mass (TM) is defined as the mass of the building that can be used to store thermal energy for heating/cooling purposes. TM can be effectively used to reduce the wide outdoor temperature fluctuations and offers the engineers or architects a powerful opportunity to manage energy flows in the building efficiently.
Components typically adopted when the TM concept is applied include: the building envelope, the interior partition, the furnishing, or even the building structure.
According to its location, there are two basic types of thermal mass : external and internal thermal mass.
The external thermal mass such as walls and roofs are directly exposed to ambient temperature variation. The internal thermal mass such as furniture and purpose-built internal concrete partitions are exposed to indoor air temperature. Furthermore, another classification may be done based on the type of activation. Direct interaction system – when the thermal mass is directly exposed to the indoor air. Indirect interaction system – where the ambient air passes through floor voids, cores and air paths (such as for example TABS components: walls, ceilings, floors equipped with ducts for circulation of air or embedded pipes for circulation of water). Two important thermal properties of the building construction/materials should be considered when thermal mass is to be passively utilized: the heat capacity by volume and the heat-absorption rate. The first determines the ability of the materials to store thermal energy, and the second determines the ability of the element to adsorb the thermal energy. Regardless to the TM type, the surface area of the thermal mass element is a crucial design parameter.
The thermal mass concepts are applied on both residential and commercial (office) buildings. In general the application has been found to be particularly suitable for climates with big diurnal temperature variations. The most of the component applications can be observed in moderate climatic zones. Installations in cold climatic zones are limited mainly by the heating capacity of the system. Using the systems in hot and humid climate may give rise to condensation problems. A number of different solutions are commercially available, but further developments are still required specially in the field of:

- simplification of the system on-site construction,
- improvement of modeling algorithms in building energy simulation codes,
- improvements of components, with integration of TM elements with other RBEs (specially PCM),
- improvements of comfort concepts (adaptive comfort) with drifting operative temperature,
- improvements of knowledge not only on energy related issues, but also about the construction and running costs of building and system.

EARTH COUPLING (EC)

The basic principle of the Earth Coupling (EC) is to ventilate air to the indoor environment through one or several buried ducts, in order to exploit the seasonal thermal storage ability of the soil. This enables a cooling effect of the hot summer air and a heating effect of the cold winter air.
The ground’s large thermal capacity is, therefore, used to preheat or pre-cool the ventilation air, resulting in energy savings for the building. Frequently, this technology is also addressed as “Earth To Air underground Heat Exchangers”.
In buildings with required indoor air temperatures between 20°C to 26°C, EC is primarily used for cooling purposes, since soil temperatures are usually below the indoor air temperature most of the time. However, EC can also be used for winter heating, when the

outdoor air temperature is much lower than that of the soil, but additional heating systems are usually needed in this case.
The state of the arte review revealed that most existing EC systems are installed in mechanically ventilated buildings. However, recently, to reduce the fan energy consumption, some hybrid and naturally ventilated buildings have also been designed and built (these solutions have the drawback of requiring larger duct sections).
EC's application seems not to be restricted to a particular building type. Examples of application comprise greenhouses and livestock houses, as well as residential and commercial buildings. The working principle makes it suitable for a wide range of different climate conditions, provided that a sufficiently large temperature difference between summer and winter and between day and night are available. Advantages of EC systems are: potential energy saving for winter heating and summer cooling, suppression (or at least reduction) of use of mechanical cooling systems, improvement of the indoor thermal comfort, possible passive moisture control for the supply air, air filtration effect, low maintenance and operational costs.
Limitations are mainly due to: space availability (systems are cumbersome), difficulties in excavations for some soil types (rocks), difficulties for retrofitting building and HVAC systems, presence of radon gas in the soil, potential access for insects and small animals, risk of moisture condensation, poor air quality (due to a risk of fungal and microbial growth in the airways). Furthermore, there is a general lack of easy-to-use design methods. Existing modeling methods are not easily accessible for designers and training programs need to be promoted. In some cases, the initial investment for installing an EC system might be higher than a traditional air conditioning system. However, it should be noted that an EC system has a very long lifespan and that the energy saving potential can determine conditions for a competitive solution.
From the results of the state of the art review EC systems seem to be promising in buildings with the following features: moderate cooling loads, low ground temperature, large daily outdoor air temperature swings, relatively low requirements for indoor environment (use of adaptive comfort).

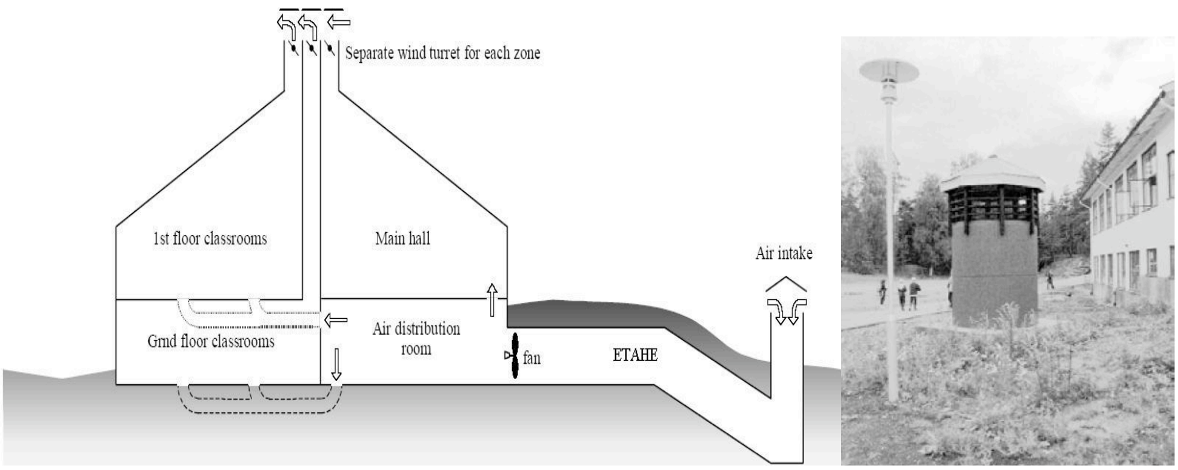

Figure 4 - Example of an EC system - schematic cross section of Jaer School (NO).

DYNAMIC INSULATION WALLS (DIW)
The concept of Dynamic Insulation Walls (DIW) combines the conventional insulation with the heat exchange characteristics of an outer wall. The system allows an effectively pre-heating of the ventilation air. DIW are regarded as one possible method for reducing building envelope heat losses while achieving better indoor air quality.
One of the most promising existing technology is represented by the so called “Breathing Wall” (BW). A BW is a suitably designed wall which let an air transfer through a permeable insulation layer. The system can act as a contra-flux mode heat exchanger and it usually

consists of two main sub-layers: an external envelope (this could be a prefabricated reinforced concrete slab or a perforated metal sheet) - through which the ventilation air can be introduced from the bottom or top - and a dynamic insulation sub-layer (which may consist of layers of breathing, porous materials). The air flow through the wall is, usually, assured by means of mechanical ventilation, but “natural” systems have also shown encouraging performances.
It has been proved that it is preferable to have dynamic insulation using materials which are inherently good insulators. However, masonry material with a higher thermal capacity can also be used to produce a composite permeable wall with a low dynamic U-value and high thermal capacity.
Crucial points in the design of DIW are: the air flow rate, that needs to be in a suitable range, the insulation thickness. It is necessary, in fact, to supply adequate fresh air - to promote the heat exchange between air and insulation and to decrease the risk of condensation - but the flow rate must not be too high in order to avoid excessive convective heat losses.
Until now, no special design tools for the design of dynamic insulated wall have been reported. However, concerning the thermal performance, some commonly used building energy analysis tools could be modified to incorporate dynamic insulation elements.
Dynamic insulation has the potential to be implemented in most climate conditions, however, even though the concept has been developed more than 30 years ago, dynamic insulation has not yet really been implemented in building design, because of its specific problems and uncertainties. These are, in particular:

- risk of too low indoor wall temperatures (leading to discomfort conditions),
- difficulties in predicting and controlling the uniformity of the air flow over the surface of the wall,
- moisture transport and condensation,
- lack of proper guidelines for DIW design,
- accumulation of dust and other particles trapped in the insulation, that might prompt the growth of bacteria (a DIW works as an air filter),
- additional electrical energy may be required to drive fans (as the overall energy saving by dynamic insulation has been quantified in about 10%, DIW concepts are less attractive if a fan needs to be operated continuously).

Moreover, DIW thermal models are not yet integrated in commonly used design tools and building designers are still unfamiliar with the concept of dynamic insulation.

PHASE CHANGE MATERIAL (PCM)

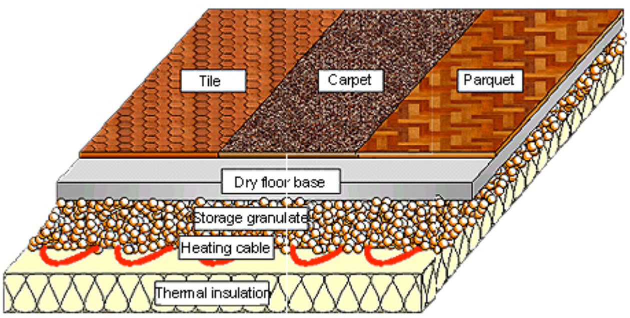

figure 5 – Example of an under floor heating and cooling system with PCM (Rubitherm).

PCM are suitable materials that, at the atmospheric pressure, undergo a phase change around the ambient temperature. The basic principle is to exploit their capability of storing large amount of heat at temperatures close to their melting point. In fact, as long as the phase change is under way, heat is stored and released without any sensible temperature variation of the medium. This property can be used as a means of increasing the thermal inertia (thermal mass) of the building components and, therefore, to smooth and shift the cooling/heating loads. The energy storage capacity of PCM per unit mass is much greater than that of usual building materials, like concrete or brickwork. For this reason, PCM are often used in case of lightweight constructions. Different applications are possible:

- integration of PCM in external wall structures,
- thin layered latent heat fiber boards or granular PCM placed in internal partitions

- PCM plaster to be applied on ceiling/walls indoor surface,
- under floor applications,
- Air (or water) heat exchanger with PCM energy storages (combined with traditional AHU).

The adoption of PCM in external walls allows for a better control of thermal fluxes and also increases the potential of exploiting solar energy (that is stored during daytime and utilized/discharged during nighttime). Thanks to the PCM, temperature fluctuations and peak heat loads are reduced and shifted in time. The same effects may be achieved by using PCM integrated in internal partitions and under floor. In particular, in this last case, thanks to the relevant solar flux directly hitting the surface, an efficient control of the solar loads may be achieved. In the end, the adoption of air exchangers with PCM provides a low cost solution for a sustainable passive air conditioning.

Thanks to the smoothening and the time shift of the heat loads, smaller HVAC appliances can be installed, and, as a results, lower investment and operational costs may be achieved using PCM components.

Barriers to application and limitations to a widespread use of PCM are mainly linked to the difficulty of properly designing and sizing the components making use of PCM (type of materials, layer thickness, quantity, melting point, …) and to the durability of the PCM available on the market so far. As far as the climatic conditions are concerned the two main issues that could limit the effective use of this technology are: the night outdoor air temperature (it has to be sufficiently lower then the daytime value) and the heat transfer coefficients between the air and the element encapsulating the PCM.

CONCLUSIONS

Results of the state of the art review have highlighted that, frequently, even though RBE's are not completely new concepts, having been developed some years ago, their application is still quite limited. Potentialities in term of energy saving and indoor comfort seem to be highly promising, but a number of barriers and limitations have to be removed to assure a proper and widespread use of these technical solutions. Barriers and limitations are mainly due to a lack of proper design tools and to an insufficient technological knowledge.

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