ENERGY DEMAND REDUCTION TO ENSURE THERMAL COMFORT IN BUILDINGS USING ALUMINIUM FOAM

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Abstract
The high energy efficiency of buildings can be achieved if energy needs are almost entirely covered by the supply of renewable energy sources obtained directly on the building or in its immediate vicinity. The technology providing efficient storage of the heat at a time of excessive sunlight is necessary if a returns of investment for the construction of small houses with zero energy balance should be less than 10 years. The regular alternation of day and night cycle resulting in continuously changing amount of sunshine falling on the building roof causes even though a small but very well usable potential. The concept presented in this contribution is based on the storage of energy obtained through the aluminium foam roof and facade cladding, which are capable of absorbing the desired, or even take away the excess energy to the surroundings if necessary. The energy effectively generated by this way is by means of piping system distributed by heating liquid medium/coolant to interior ceiling heat exchangers made of aluminium foam enabling due to filling by Phase Change Materials (PCMs) to store the energy required for heating/cooling for a period of at least several hours. This progressive technology, therefore, contributes significantly to reducing of energy demand and thus also the prices of future not only large buildings but also small family houses that are able to achieve the optimal thermal comfort by extremely low costs. Possibility to manufacture facade, as well as the interior panels of aluminium foam, is a good prerequisite for ensuring that these structural components could be in the nearest future made from fully recyclable aluminium alloys. This fact indicates large potential chance for long-term sustainable further development of above-mentioned advanced technologies.

1 Introduction
The energy systems providing supply to future buildings will be surely based on entirely CO_2-free energy production. The development of energy supply and storage technologies should lead to an economy focused totally on emission-free and inexhaustible energy sources, such as a solar, wind or geothermal. However, it is true that the electricity and the energy efficiency to produce it will play still quite a long time an important role in fulfilling constantly growing global energy demand. The challenges of sustainability, such as climate change, diminishing natural resources and further negative environmental effects necessitate a transition from power production based on the use of limited energy sources obtained from fossil fuel combustion to the more efficient energy systems

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with significantly lower emissions. The future economy will utilize solar energy either directly as solar power or heat or indirectly as hydro, wave and wind energy, bio-energy and geothermal heat. The future eco-cities will be surely based on smart grids with eco-efficient construction utilizing exclusively ecological engineering materials, sustainable methods of energy production, transportation and storage as well as various advanced energy efficient heating/cooling solutions. The Zero-Energy Buildings (ZEBs), which will be in the nearest future the unavoidable benchmark for all new buildings, have a total annual sum of zero exergy transfer across the building district boundary in a district energy system, during all energy transfers that are taking place in a certain period of time. The energy needs for ZEBs are greatly reduced through such efficiency gains that the balance of energy needs can be covered by energy supply from renewable sources. ZEBs optimally combine commercially available renewable energy technologies with the state of the art energy efficiency construction techniques. There are no fossil fuels consumed in ZEBs and its annual energy consumption therefore do not exceed annual energy production [1].

2 Heat storage in future zero-energy buildings

The thermal energy can be stored in standard buildings into massive inserts (i.e. clay bricks, stones, granite, sandy clay, quartz sand, etc.), but only sensible heat can be stored and the massive materials evolve this heat only in hand with continuous change of their temperature in this case. The sensible heat can be stored also if the Phase Change Materials (PCMs) are used for this purpose. However, their most important property, which is very well applicable in the building industry, is the phase change solid-liquid and vice versa at the temperature range between 23°C and 28°C. During this change, a lot of latent heat is evolved or absorbed at almost constant temperature. The utilization of PCMs in larger volumes is strongly limited because of its low thermal conductivity. In this case solidification starts on the surface creating thus an isolating solid crust. That is why there is a need to combine PCMs and porous materials with higher thermal conductivity. Small empty pores can be filled with PCMs what ensures phase change in the whole volume without the creation of the isolating solid crust.

The aluminium foam panels made by foaming of foamable precursor with stainless tubes embedded in the structure of the foam are therefore the most promising solution for energy efficient heating and cooling of walls/ceilings in interiors of buildings. The huge application potential mainly in the building and shipbuilding industry is expected thanks to their quick response to temperature changes due to excellent heat conduction of porous aluminium structure, lightweight design, self-supporting capability as well as shape and surface flexibility. The large active surface of foamed panels with extremely quick response to temperature changes enables to use heating/cooling fluids with the temperature nearly the same as is the achieved and maintained room temperature of the interior air. This allows utilize various available alternative energy sources such as solar or geothermal energy very effectively for heating during winter, or even simply cold air during summer nights for cooling. The ceiling panels made of aluminium foam (**Fig. 1**) supplemented with a system containing the heat storage reservoir enables significantly to increase energy efficiency of interior heating and cooling. Moreover, this system enables to spend or release into the interior certain amount of heat at constant temperature in the case that aluminium foam is filled with PCMs melting or solidifying at desired temperature. This feature makes possible in combination with smart temperature control systems further energy cost savings for heating/air conditioning systems of future ZEBs.

The main disadvantage of lightweight building structures is their very low thermal mass. They are currently built mainly due to savings of the expenses related in particular to the huge amount of

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energy required for the production of cement and thus also costs of concrete in the market are very high. That is why the modern lightweight buildings tend to have high-temperature fluctuations in the interiors resulting in high heating and cooling loads. Using PCMs in such buildings can smooth out the temperature variations by the greatly effective way.

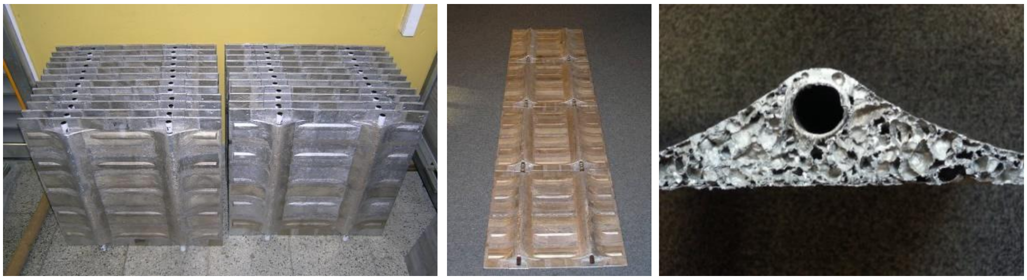

Fig. 1 Aluminium foam ceiling panels for heating/cooling of building interiors

The PCM impregnated in the surface layer of interior ceiling heat exchangers is capable of capturing a large proportion of the solar radiation incident on building roof or facade in the case that active interior panels are interconnected with roof cladding or facade system via circulating heating liquid medium. On the other hand, during hot summer days, this same system of active interior ceiling heat exchangers impregnated by PCM is capable of removing excess heat from the interior during whole day long and to dissipate this undesirable heat during nights through the facade to surrounding of the building. Because of the high thermal mass of PCM impregnated in the ceiling heat exchangers, they are also capable of minimizing the effect of large fluctuations in the ambient temperature on the inside temperature of the building. They can very effectively to shift the heating and cooling load to off-peak energy periods. However, the main obstacle is the low thermal conductivity of both the PCMs and the conventional porous building materials (e.g. gypsum wall boards, aerated concretes, etc.). The best technical solution to avoid this lack is to use novel advanced heating/cooling aluminium foam ceiling panels able to distribute homogeneously heat to/from the interior via heating/cooling liquid medium. These panels developed recently by scientists of Institute of Materials & Machine Mechanics SAS in Bratislava have been successfully tested in the pilot application in 260 m^2 open space office room (**Fig. 2**).

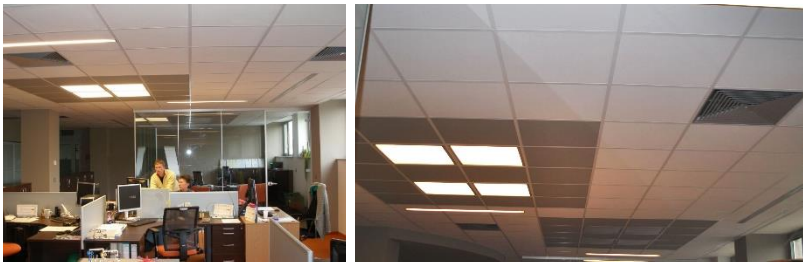

Fig. 2 The ceiling heating/cooling panels made of aluminium foam in the open space office area 260 m^2 in the company Sapa Profily a.s. in Ziar nad Hronom, Slovakia

The low heat capacity of aluminium foam allows changing the temperature very quickly, whereas the temperature of the entire foam volume is always very uniform due to excellent thermal

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conductivity of aluminium cell walls. The heat is dissipated by foam using foamed-in tubes, which are completely embedded in the foam, keeping excellent contact to cell wall aluminium. The excellent thermal conductivity of the foam results in a short length of embedded tubes, what is beneficial for low flow resistance and consequently also the energy consumption of pumping system is considerably reduced. The foamed panels can be partially impregnated at facing side by appropriate plaster, which improves the appearance and also serves as an absorber of potentially condensed air humidity. The developed panels provide an excellent alternative for large built-in ceiling radiators for efficient heating or cooling of rooms using low potential energy resources.
The main benefit of using these panels is that the porous structure created by thermal conductive aluminium pore walls is characterized by pores interlinked by microcracks in pore walls. These open cell structure of aluminium foam with extremely low permeability allows to impregnate porous structure by PCMs and thus to achieve the significantly improved thermal conductivity of resulting composite material.

3 Efficient utilization of solar gains

The direct solar gain hitting the surface of building roof or facade cladding is the heat retained by the thermal mass of building construction. It can be, as contemporary builders nowadays often do, also avoided with reflective materials. However, the direct solar gain is important for any site that needs heating, because it is the simplest and least costly way of passively heating a building with solar heat gain. Avoiding direct solar gain is also important in hot sunny climates.
In many climates, much more heat gain is desired in the winter, when the sun is low, while less or none is desired in the summer. Likewise, it is usually desired more in the morning, but less or none in the late afternoon. Sunlight can heat a space through the solid walls or roofs of the envelope. Sunlight also enters the space through windows and heats interior surfaces. Part of solar energy is long-wavelength radiation, which is called the heat. Moreover, the light of any wavelength absorbed by surfaces turns into heat in those materials. These materials then warm interiors by conducting heat to them directly, by warming air, or more effectively warming water, which carries heat by convection as well as by radiating of accumulated heat.
In this regard, the use of the active surface heat exchangers made from aluminium foam forming the inclined roofs and vertical facades seems to be highly beneficial. The significant cost savings for optimal maintenance of thermal comfort inside buildings during winter as well as summer operation can be achieved primarily if the facade system is interlinked with interior panels by an appropriate heating/cooling liquid medium and if the heat can be stored also in the form of latent heat of phase transition of PCMs impregnated in the aluminium foam structure of interior panels. It is important to manage this system properly by an intelligent control software during winter and summer operation mode.

4 Conclusions

The aluminium foam panels provide an excellent alternative for large built-in ceiling radiators for efficient winter heating and summer cooling of building interiors using low potential energy sources. The porous structure of aluminium foam allows absorbing or dissipating latent heat very homogeneously at almost constant temperature if PCMs with phase transition temperature in the range between 23°C and 28°C are used for storage of the heat obtained from renewable energy sources. These features of aluminium foam panels in combination with smart temperature control systems allow reducing significantly the energy consumption of heating/air conditioning systems

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of future zero-energy buildings characterized by very low investment as well as operating costs. The heat storage systems based on PCMs with enhanced thermal conductivity seem to be unavoidable in order to have return-on-investment period below ten years especially in the case of energy efficient small family houses.

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