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A CONCEPT OF A THERMAL COMFORT SYSTEM WITH ENERGY STORAGE IN STRUCTURE OF THE BUILDING

Key words

Phase change material, thermal comfort, energy storage.

Abstract

The manuscript presents concept of system for keeping thermal comfort in low-energy buildings with the use of the energy storage in the structural elements of the building. The system uses both the daily fluctuations of outdoor air temperature as well solar energy, respectively, to remove the heat gains during summer and compensate heat losses during winter. In order to achieve the required heat capacity with the low temperature difference, it is necessary to provide the sufficiently large heat transfer area and an efficient energy storage system. An effective system capable of providing thermal comfort conditions in a building with acceptable cost requires maximizing heat capacity and heat transfer conditions as well as an enlarged heat transfer area. Providing an acceptable payout time also requires the use of typical structural elements of the building as energy reservoirs. Therefore, it was assumed that the accumulation

of the energy should be provided by modified gypsum plasterboards used for drywall construction. Ventilated, multichannel wall plates made of gypsum modified by an admixture of the phase change material (PCM) with a melting point close to the temperature of thermal comfort in residential buildings provide a large heat capacity and a relatively stable temperature during processes of energy absorption and emission.

Introduction

Energy consumption by buildings (to heat, cool and prepare hot water) currently reaches 40% and accounts for the largest contribution among key sectors of the economy and generates approximately 36% of greenhouse gas emissions in Europe [1]. Therefore, attempts at cutting energy consumption of buildings at the stage of both construction and operation are a principal area of research and innovation in global and, particularly, European economies. This is reflected in directives and international programmes of economic growth. Currently known systems using air-handling units provide the reduction of energy consumption, but those systems cannot provide the building goal of zero energy use [2–5].

The project is part of actions to achieve the goal set by the Directive of the Parliament and the Council of Europe 2010/31/UE of 19 May 2010 on energy characteristics of buildings [6], which binds Member States to assure all new buildings are facilities of 'nearly zero energy consumption' by the end of 2020. The 15% reduction of the demand for energy required to maintain thermal comfort envisaged by the project is a significant contribution towards attaining the goal. The proposed solution, which combines night ventilation and solar energy based heating with smart controlled and efficient energy storage in modified building elements, is a complex undertaking aimed at the reduction of energy consumption in existing and new buildings. The planned testing to define parameters of the future solution will help to fulfil the directive's requirements, which obliges the EU Member States to introduce an independent system for verifying certificates of building energy characteristics and reviews of heating and air-conditioning systems.

1. State of the art

Nowadays, energy storage systems use night ventilation, which is an inexpensive method of cooling building space using low the temperature of outside air during the night [7]. This method uses heat the capacity of the building materials. However, the main disadvantage of night ventilation is the low heat transfer area. A small area of heat transfer results in the heat transfer with higher temperature difference. Thus, intensive ventilation of the building space is needed to compensate this drawback. This makes the method impossible to use in residential buildings because of noise and draft. Application of PCM into the walls increases thermal the capacity of building structures, but without improving the heat transfer conditions, the efficiency of the system is poor because expensive material is used inefficiently [8–10].

2. Project assumptions

The developed system will minimize one of the most important drawbacks of the systems based on renewable energy to maintain thermal comfort in the buildings, which is the lack of the synchronization in time between energy demand and the availability of the required energy density in a certain period. To develop an effective system capable of providing thermal comfort conditions in buildings with acceptable cost, maximizing heat capacity and heat transfer conditions (Nusselt Number) and enlarging the heat transfer area are required. It is also crucial to minimalize the temperature difference in heat transfer processes.

Providing an acceptable investment return requires the use of typical elements of the building as thermal energy reservoirs by avoiding additional heat exchangers and piping systems. Therefore, it was assumed that the accumulation of the energy in the system will be provided by commonly used building elements (modified gypsum boards used for drywall construction) and PCM. The phase change material (PCM) with a melting point close to the temperature of thermal comfort in residential buildings will increase the heat storage capacity.

Contrary to the flat surface of the typical plates used for drywall construction, a ***flat surfaces combined*** with a set of ***grooves*** are included ***in the system for construction.*** Covering the walls with a double layer of modified plates will allow forming a thermal energy storage system of large heat capacity, where grooves serve as the multichannel structure for air transport, which significantly improves heat transfer by forced convection.

The air distribution system will be located in the false ceiling of the room. The airflow will be arranged from top to bottom through one layer of supply channels (grooves), and it would go to the top through the second layer of return channels (grooves). Such a flow arrangement allows installing the air distribution system in the false ceiling without reducing the usable space of a dwelling.

The gypsum board used to build the system, in addition to their primary function, which is wall surface finishing, would be the active element of the heating and air-conditioning system. As a result of using the air as the heat transfer medium, the wall plates would not lose their typical functionality. The thickness of double plate will be approx. 6 cm; therefore, it would be possible to mount furniture and other equipment on the wall. Moreover, since the heat transfer is mostly driven by forced convection, there is no restriction in use of the wall surface. A number of channels, the dimension of which have been initially estimated at 10 × 20 mm divided by 10 mm thick material, would provide proper conditions for heat exchange and temperature distribution ensuring efficient use of the storage material. Considering the system as a heat exchanger, the surface-to-volume ratio of the internal channels of grooved gypsum boards is about 300 m^2/m^3. The air is supplied at low velocities (V_{max}<1m/s), which reduce pressure loss and minimalize acoustic disturbance.

The system is meant for flat inner walls, which do not contain window and door openings. In the case of walls that include window and door openings, it can be installed on a part of the wall.

3. Project concept

The aim of the project is to develop the system for maintaining thermal comfort in buildings using energy accumulation in parts of the building materials. The results of the project enable one to minimize one of the fundamental problems that impedes the efficient use of renewable energy in buildings, which is the lack of synchronization between the demand for energy

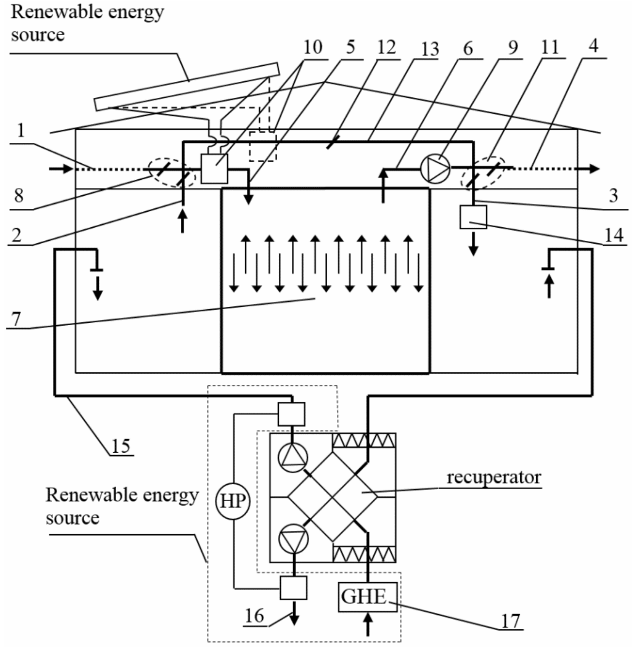

Fig. 1. The scheme of energy-efficient system for maintaining thermal comfort inside a building: 1 – outside air duct, 2 – outflow duct air, 3 – supply air duct, 4 – extract air duct, 5 – air supply to energy storage element, 6 – air extracted from energy storage element, 7 – thermal energy storage board (TESB), 8, 11, 12 – valves, 9 – fan, 10, 14 – heat exchanger (coil), 13 – by-pass, 15, 16 – ventilation system with heat recovery unit, 17-ground heat exchanger, HP – heat pump

and the availability of the required energy density. The system uses daily fluctuations of outside air temperature and solar energy in order to lower the heat gain in the summer and cover the heat loss during the winter. The system achieves the required energy efficiency with low energy use of factors for the transport of heat by providing a sufficiently large heat transfer surface and effective utilization of the thermal energy storage board (TESB). The system (TESS) is composed of the elements shown in Fig. 1. Figure 2 provides an illustration of an example of a system installed in a dwelling.

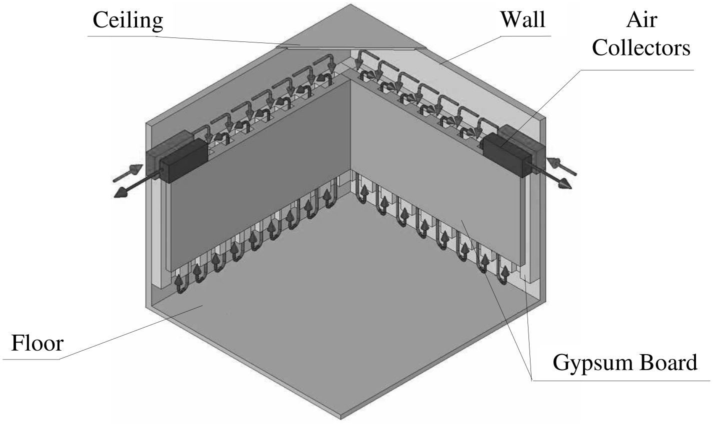

Fig. 2. An example of a drywall thermal energy storage system installed in a dwelling

During summer conditions, the system uses the low, nighttime outdoor air temperature typical for a temperate climate zone. During the day, the air flows through the TESB, removing heat gains and accumulating the energy in the mass of the TESB and the walls. During the night, the working mode of the system is switched on in order to increase the intensity of the ventilation of the TESB with the low temperature of outdoor air. The analysis of the meteorological data indicates that the temperature in a moderate climate zone usually decreases by approx. 10ºC during the night and stabilizes at this level for several hours. Therefore, it is possible to cool the TESB below the temperature of the phase change of the paraffin waxes. Cooling the storage mass of TESB below the phase change temperature of the paraffin maximizes its thermal performance and enables keeping the indoor air temperature during the day at thermal comfort levels.

During winter, the system is supplied by a renewable energy source, for example, solar collectors. The energy from the collectors is transferred to the system by a heat exchanger in order to warm the air pumped through the TESB to the room.

During autumn and spring, the TESB operates in the heat accumulation mode in which the cooling of the room will be provided directly by outside air. Heat transfer at minor variations in the temperature range protects the system in a natural way against condensation of the water in the channels. Additionally, in order to avoid condensation in the channels, the control system keeping the temperature of air in channels above dew point is needed.

The heat is transferred to the room space mainly by forced convection in the board channels and natural convection and radiations by the surface from the room side of the TESB. The second mechanism of the heat transfer always operates when there is a temperature difference, but its capacity is relatively low. The forced convection is the main mechanism of the heat transfer and allows one to control charging and discharging of the stored energy by means of variable airflow. The system provides a large volume of the storage material; nonetheless, it does not (significantly) limit the space of the dwelling. The gypsum plasterboards used for building the system, in addition to their regular function as the active element of the system, also provide the desired finish of walls.

The use of room walls as the energy reservoirs and air as an energy carrier reduce the cost of the system compared to the energy storage systems based on an intermediate medium like water or glycol. The operating mode of the system during summer is the advanced development of the method used for nighttime ventilation. A preliminary study shows that increase of the heat transfer area and the improvement of the heat exchange conditions will significantly increase the effectiveness of the system used for room cooling based on the low temperature of the air occurring during the night. Separation of the storage mass from the room space will allow the application of the system in residential buildings where the standard night ventilation would not be acceptable (because of noise).

4. The thermal energy storage board

The application of grooved multichannel gypsum boards enlarges the heat transfer area and the Nusselt Number, and it creates a type of regenerative heat exchanger with surface-to-volume ratio about 80 m^2/m^3.

The project will develop a system of maintaining comfort in a building based on energy storage in grooved gypsum plasterboards, which enable effective exchanges and storage of energy. So far, grooved gypsum plasterboards that form channels for air-circulation have not been implemented in the construction industry. The gypsum boards used to construct the system, apart from their principal function of surface finishing, will be the active elements of heating and ventilation systems.

Therefore, the system focuses on the increasing effectiveness of heat transfer between the air and building elements used for energy storage ensuring a more effective utilisation of the heat capacities of materials, and, in this way, it minimizes the quantity of expensive material, i.e. PCM to be added. Preliminary research has indicated [11–14] that the improvement of heat transfer effectiveness can have a great contribution to the enhancing total energy effectiveness of the system.

Summary

The project is a response to the market demand for zero-emission buildings. The application of the developed solutions will increase the innovation capacity of companies in the construction sector by integrating solutions such as 3D CFD modelling, new building materials, and building design. Furthermore, the simplicity of the solution makes it promising in terms of real market needs.

The developed heat storage system will allow for year-round thermal comfort in residential or office buildings located in a temperate climate with minimal use of non-renewable energy sources. An important advantage of the developed solution is the use of the elements of the building for energy storage (grooved gypsum boards), which form a multichannel structure that significantly improves heat transfer. Therefore, it is not necessary to install a separate energy storing modules. The heat transfer between the storage and the building will be mostly by forced convection in the channels located in the modified elements of drywall.

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Koncepcja systemu do utrzymywania komfortu cieplnego w budynku wykorzystującego magazynowanie energii w strukturze budynku

Słowa kluczowe

Materiał zmiennofazowy, komfort cieplny, magazynowanie energii.

Streszczenie

Artykuł przedstawia koncepcję systemu utrzymującego komfort cieplny w budynku energooszczędnym wykorzystującego magazynowanie ciepła w strukturze obiektu budowlanego. System wykorzystuje dzienne wahania temperatury

i energię słoneczną do usuwania zysków ciepła latem i kompensowania strat zimą. W celu osiągnięcia wymaganej pojemności cieplnej systemu przy niewielkich zmianach temperatury, konieczne jest zapewnienie wystarczającej powierzchni wymiany ciepła i wydajnego systemu magazynowania energii. Efektywny system, umożliwiający uzyskanie komfortu cieplnego przy akceptowalnym okresie zwrotu, wymaga zmaksymalizowania pojemności cieplnej, współczynnika wnikania oraz powierzchni wymiany ciepła. Zapewnienie możliwie krótkiego czasu amortyzacji systemu wymaga również wykorzystania typowych elementów konstrukcji budynku jako magazynów energii. W rozwiązaniu przyjęto, że akumulacja energii jest zapewniona przez zmodyfikowane płyty gipsowe wykorzystywane do suchej zabudowy. Wentylowana, wielokanałowa płyta ścienna wykonana z gipsu zmodyfikowanego przez dodatek materiału zmienno-fazowego (PCM – ang. *Phase Change Material*) o temperaturze topnienia zbliżonej do temperatury komfortu cieplnego w budynku mieszkalnym, zapewnia wymaganą pojemność cieplną, dużą powierzchnię wymiany ciepła i niewielką różnicę temperatury podczas pochłaniania i oddawania energii.