Energy and Buildings 158 (2018) 135–146

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# Insulation panels for active control of heat transfer in walls operated as space heating or as a thermal barrier: Numerical simulations and experiments

Martin Šimko[a], Michal Krajčík[a,*], Ondřej Šikula[b], Peter Šimko[a], Daniel Kalús[a]

[a] *Slovak University of Technology, Faculty of Civil Engineering, Radlinského 11, 81005 Bratislava, Slovakia*
[b] *Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 60200 Brno, Czech Republic*

ARTICLE INFO

*Article history:*
Received 10 July 2017
Received in revised form
10 September 2017
Accepted 4 October 2017
Available online 8 October 2017

*Keywords:*
Radiant heating system
Wall heating
Thermally activated building systems (TABS)
Thermal barrier
Thermal insulation
Heat flux

ABSTRACT

Numerical simulations and experiments were performed for a thermally active wall with pipes arranged in milled channels in the thermal insulation. The advantage of this system is its suitability for installation in both new and existing buildings in the form of precast heat insulation panels attached to their facades. The study shows that by active control of the supply water temperature, it is possible to alternate the wallís function between space heating and a thermal barrier. The wall system has the potential to significantly reduce heat loss when used as a thermal barrier. When operated as space heating, embedding the pipes in thermal insulation reduced the heating capacity by 50% as compared to systems with pipes arranged in a concrete core and by 63% for pipes arranged in a layer underneath the surface. It is crucial that pipes arranged in channels are embedded in a thermally conductive material. Failing to do so can substantially diminish the heating capacity due to the imperfect contact between the pipes and radiant surface and also due to the air gap that may form around the pipes. The thickness of the thermal insulation, spacing of the pipes, and supply water temperature also have a substantial effect on the heating capacity, whereas the thickness of the concrete core does not.

## 1. Introduction

Current trends in the design and operation of heating, ventilation and air conditioning include the increasingly frequent use of low-exergy water-based radiant systems. As opposed to all-air systems, the task of providing thermal comfort is limited to radiant systems, while the provision of ventilation is separate, i.e., the radiant system covers heat losses in the winter and eliminates heat gains in the summer, whereas fresh air is supplied by a separate air system [1–3].

Although research on radiant surfaces has mostly focused on structural floors and ceilings, evidence from several research studies suggests that radiant walls also present a potentially feasible solution for space heating (SH). Karabay et al. [4] recommend considering wall heating rather than floor heating since a better thermal performance and comfort conditions can be achieved with a lower water temperature, thereby reducing fuel consumption. Myhren and Holmberg [5] conclude that floor heating, radiators and wall heating are all capable of creating a comfortable indoor environment in a well-insulated room, although one problem with radiant systems can be the weaker counteraction of cold downflow from the air supply units. For a detached house powered by natural gas, Bojic et al. [6] indicate a preference for wall heating over both floor and ceiling heating in terms of energy and exergy consumption, destroyed exergy, $CO_2$ emissions, and operating costs as well as the nominal power of the boiler. Radiant walls are more efficient in terms of heat and cool emission than heated ceilings and cooled floors, respectively, and they have higher heating capacity per surface area than floor heating due to a wider range of permissible surface temperatures [7,8].

Contemporary research is focused on traditional wall heating solutions with pipes that are thermally insulated from the main building structure. The present study is aimed at radiant walls that work with emitting elements that are thermally coupled to the building structure and that represent a thermally active building structure (TABS) [9,10]. The major advantage of these systems is their large energy storage capacity, which permits reducing peak heating or cooling power by shifting peak loads to periods in which the system works more efficiently [11,12]. Typical examples of TABS are systems with pipes embedded in a massive concrete core

---

[*] Corresponding author.
*E-mail address:* michal.krajcik@stuba.sk (M. Krajčík).

https://doi.org/10.1016/j.enbuild.2017.10.019
0378-7788/© 2017 Elsevier B.V. All rights reserved.

## Nomenclature

*Abbreviations*

| | |
|---|---|
| E | Exterior |
| I | Interior |
| SH | Space heating |
| T1, T2 | Temperature sensors for supply and return water temperature, respectively |
| TABS | Thermally active building system(s) |
| TB | Thermal barrier |

*Symbols*

| | |
|---|---|
| $c$ | Specific heat capacity at constant pressure (J/(kg K)) |
| $d$ | Thickness of layer (m) |
| $f$ | Index denoting surrounding fluid |
| $h$ | Overall heat transfer coefficient between radiant surface and environment (W/(m$^2$ K)) |
| $l$ | Characteristic dimension (m) |
| $n$ | Index denoting a line perpendicular to surface |
| $Nu$ | Nusselt number (−) |
| $q_i$ | Heat flux to the interior (W/m$^2$) |
| $q_e$ | Heat flux to the exterior (W/m$^2$) |
| $q_t$ | Overall amount of energy transferred from pipes to wall (W/m$^2$) |
| $S$ | Internal heat source (W/m$^3$) |
| $T$ | Temperature (K) |
| $U_{\text{wall}}$ | Heat transfer coefficient of wall (W/m$^2$ K) |
| $w$ | Index denoting surface of an object |
| $\alpha$ | Convective heat transfer coefficient for the water and pipe surface (W/(m$^2$ K)) |
| $\Delta\theta$ | Difference between the surface temperature of the heating surface and the room air temperature (K) |
| $\theta_{\text{amb}}$ | Ambient air temperature (°C) |
| $\theta_{\text{i}}$ | Room air temperature (°C) |
| $\theta_{\text{op}}$ | Operative temperature (°C) |
| $\theta_{\text{sup}}$ | Supply water temperature (°C) |
| $\theta_{\text{w}}$ | Temperature of water in heating pipes (°C) |
| $\lambda$ | Thermal conductivity (W/(m K) |
| $\lambda_{\text{L}}$ | Thermal conductivity of the fluid (W/(m K) |
| $\rho$ | Bulk density (kg/m$^3$) |
| $\rho_{\text{w}}$ | Volumetric weight (kg/m$^3$) |
| $\tau$ | Time (s) |

(Fig. 1a) and systems with capillary mats embedded in a layer on the inner surface (Fig. 1b) [13]. In this study an alternative design is investigated, where a system of pipes arranged in milled channels in thermal insulation is attached to the bearing structure of a building in the form of precast insulation panels (Fig. 1c) according to a patent [14]. The advantage of this solution is its potential suitability for installation in existing buildings as a part of retrofitting. If the bearing structure has enough storage capacity, the system will behave as a TABS.

Besides SH, it is also possible to use a wall system as a thermal barrier (TB) to reduce transmission heat losses. An example of a wall system designed to serve as a TB is shown in Fig. 1d [15]. The system acts as a TB when the temperature of the fluid in the pipes is lower than necessary for heating, but is still high enough to reduce the heat loss. As an option, an additional absorption layer can be arranged on the insulating layer to collect thermal energy during the summer months (Fig. 1e) [15]. Doležel [16] estimates that in a passive house [17], the heat loss is lower for a wall with a TB than for a conventional external wall when the ambient temperature drops below −2.5 °C for pipes arranged in a concrete layer (Fig. 1f), below 6.3 °C for pipes embedded between bricks and thermal insulation (Fig. 1g), and below 9.6 °C for pipes between an OSB plate and thermal insulation (Fig. 1h). Despite the high thickness of the thermal insulation used in [16], the main advantage of TB is a reduction of the thickness of the outer insulating layer, which should permit the total thickness of the wall to be less than the insulation of a conventional highly insulated exterior wall [15]. Thus, together with aerogel [18,19] and vacuum insulation panels [20,21], TB presents an alternative to conventional insulations made of, e.g., mineral wool or polystyrene, which allows for a lower thickness of a wall due to its ability to actively control the heat transfer.

Compared to traditional insulation methods, TB requires a fluid of a certain temperature to circulate in the pipes. To ensure that the energy to heat the water in the pipes and the auxiliary energy does not exceed the energy-saving benefits, it is recommended that the energy is harvested by renewable energy sources such as a solar roof or collectors and that the excess is fed to an underground reservoir as soon as the outdoor temperature exceeds the indoor temperature. During the winter, the building can be fed from this reservoir [15,22]. Krzaczek and Kowalczuk [22] showed that combining TB (Fig. 1i) with geothermal energy storage and fixing its temperature close to 17 °C all year round can help reduce the heat losses through external walls to one third as compared to traditional insulated walls. Xie et al. [23] showed that for a building envelope structure consisting of two brick layers (Fig. 1j) supplied from a low-grade energy source, a TB in a hot climate can decrease the heat transfer from outside to the interior space to almost zero and thereby reduce the energy consumption significantly.

Existing research has indicated the insulation potential of TB. However, the heat transfer in a TB has not been fully explored, and a detailed comparison with SH is lacking as well. Furthermore, the existing studies focus on systems specifically designed to serve as TB intended for new buildings. Systems that can serve both as SH and a TB and are intended for use both in new and in existing installations have not been previously investigated.

This paper studies the possibilities of the active control of heat transfer by insulation panels in walls operated as SH or TB as shown in Fig. 1c. The main contributions are summarized as follows:

1. (1) The originality of the proposed system is its potentially universal use as either TB or SH, depending on the systemís configuration and operating conditions. Unlike previously investigated systems, this solution is suitable for installation in both new and existing buildings.
2. (2) The proposed TABS wall presents an alternative to the more common floor and ceiling TABS. It is also an alternative to the more typical TABS solutions shown in Fig. 1a and b. The heat transfer in the proposed TABS wall is explored and compared to a typical TABS wall.
3. (3) To facilitate the design of this system, the effect of different parameters, such as the supply temperature, the thickness of the concrete and insulation, the spacing of pipes, and the thermal conductivity of the material surrounding the pipes, on the heating capacity is investigated.
4. (4) Published scientific studies on TB are scarce. This study adds to the existing knowledge and explores the insulation potential of a particular TB design. The TB is researched and compared with a traditionally insulated wall and with a SH in terms of heat transfer.

## 2. Cases investigated and methodology

The heat flux, surface temperatures, and other parameters necessary to describe the heat accumulation and discharge process of a wall were investigated by numerical simulations using dedicated software and by experiments performed on a wall fragment