Experimental determination of thermal characteristics of lightweight building element with dual ventilated cavities

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ABSTRACT

Available time for building construction is getting shorter, therefore the number of buildings which are built with lightweight building elements (LBE) is increasing. LBEs are elements of greater dimensions with low specific weight and low thermal transmittance. Their characteristic is also low thermal stability. By upgrading LBE with dual ventilated cavities (DVC) with counter flow becomes standard LBE a thermally activated building construction with increased thermal resistance and thermal stability. It enables using of solar radiation and heat recuperation from used air. In this paper experimental analysis of transient heat transfer, solar efficiency and heat recuperation efficiency, measured on innovative thermally activated LBE with DVC will be presented. Measurements were performed on LBE with DVC with outer surface painted with spectrally non-selective and selective green paint.

KEYWORDS

Lightweight building element, thermal stability, solar collector, ventilation

INTRODUCTION

LBEs are made from two layers of thin metal sheet and a layer of thermal insulation in between. They are used as envelope elements for buildings, such as shopping centres, commercial buildings, production plants and also residential buildings. Because of low thermal stability, which determines the ability of diminishing the amplitude of transient heat flow, the heat flow varies markedly on the inner surface of an LBE as a consequence of variable meteorological conditions. This can be the reason of building overheating in summer time.

Several researches of the possibility of the heat flow reduction have been made. The influence of selected parameters on stationary heat flow through the building envelope with naturally ventilated cavity was analytically analysed by Ciampi et al. (2003). Among other things they showed that maximum heat flow reduction can be achieved with optimal distribution of thermal insulation between inner and outer surface of the cavity. Maneewan et al. (2005) analysed numerically heat flow reduction through ventilated roof without thermal insulation. In summer time the heat flow was reduced in the range from 16 to 65%, depending on meteorological parameters, compared to non-ventilated roof. Medina (2000) and Winiarski and O’Neal (1996) analysed heat flow through ventilated lightweight building construction with and without radiation barrier in summer time. They showed heat flow reduction up to 40% when radiation barrier was used.

By innovative, thermally activated LBE with DVC, new element of building envelope with increased thermal stability was developed. It combines operation of three different elements or devices (Figure 1):

- standard LBE, which represents building thermal protection;
- solar collector;
- heat recuperator.

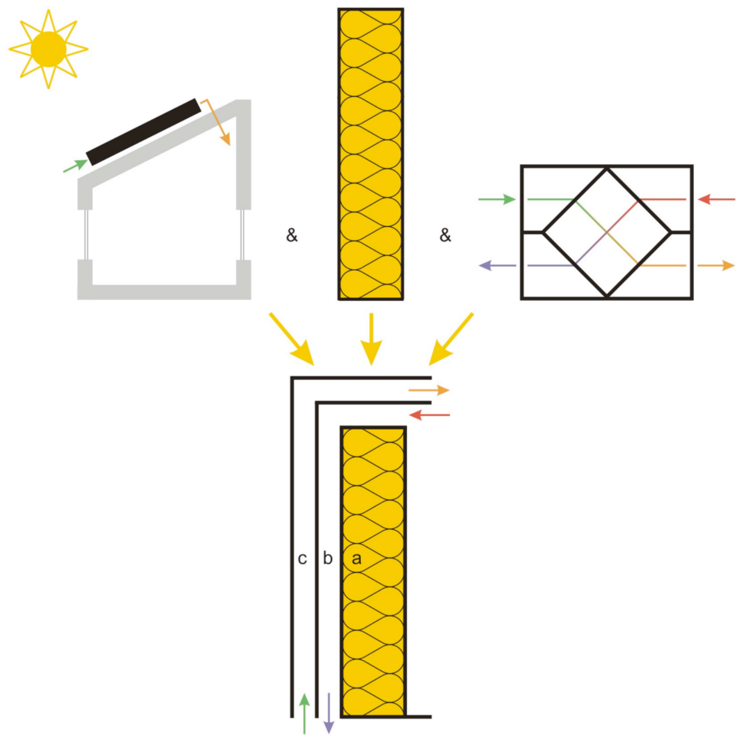

Figure 1: Scheme of LBE with DVC structure and operation

LBE with DVC is composed from standard LBE (a) with two ventilated cavities with counter flow on the outer side of the LBE. In the inner cavity (b) enters used air from the building which thermally activates the LBE. Due to thermal activation the temperature difference between inner and outer side of the LBE is essentially smaller then the temperature difference between the inner side of the LBE and ambient. Therefore, the transmission heat losses in winter and transmission heat gains in summer are reduced. Fresh air for building ventilation flows in the outer cavity (c) where it is preheated due to heat recuperation from used air in the inner cavity. Fresh air is also preheated due to absorbed solar radiation on the outer surface of the LBE with DVC. Ventilation heat losses are therefore reduced.

EXPERIMENTAL SETUP

Thermal performance of LBE with DVC was determined by measurements of temperatures, heat flows, air flows and meteorological parameters. Height and width of experimental LBE with DVC were 3 and 1 m, respectively. The thickness of LBE was 80 mm. Experimental element was set up vertically and oriented 20° southwest. Measurements of thermal performance of LBE with DVC painted with spectrally non-selective green paint (NP) took place between March and May 2005, while measurements of thermal performance with surface painted with spectrally selective green paint (SP) took place between July and December 2005. Optical properties of spectrally non-selective paint are α_s = 0,84, ε_{ir} = 0,91, while for the spectrally selective paint the properties are α_s = 0,84, ε_{ir} = 0,36 (Černe and Medved 2005a). During the measurements the air flow through both cavities was equal and in the range between 70 in 97 m^3/h. This air flow would be sufficient for ventilation of fictive space behind LBE with DVC where up to 3 persons would be present (Slovenian regulation 2002). Fictive space behind LBE with DVC is a space with arbitrary depth and the same width as experimental element. Air flow was assured with two DC fans with low nominal power (P_e = 5 W). Figure 2 shows experimental LBE with DVC painted with spectrally non-selective green paint (left) and spectrally selective green paint (right) and Figure 3 shows scheme of innovative element with locations of temperature and heat flow measurement.

Figure 2: Thermally activated LBE with DVC painted with spectrally non-selective (left) and spectrally selective (right) green paint

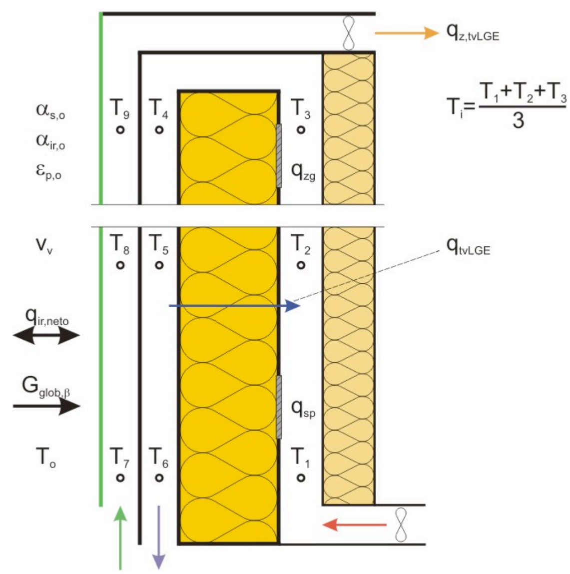

Figure 3: Scheme of experimental LBE with DVC and locations of temperature and heat flow measurement

EXPERIMENTAL RESULTS

Thermal performance of the LBE with DVC was determined separately for day-time and night-time. Day-time is time between sunrise and sunset, while night-time is time between sunset and sunrise of the following day. Analysis results are presented as a function of a difference between average day-time or night-time indoor temperature and average day-time or night-time equivalent temperature. Equivalent temperature is determined by equation 1 (Černe and Medved 2005b):

$$T_{ekv} = T_o + \frac{\alpha_{s,o} \cdot G_{glob,\beta} + \alpha_{ir,o} \cdot q_{ir,do} - \varepsilon_{p,o} \cdot \sigma \cdot T_{p,o}^4}{h_{konv,o}}$$

where T_o is ambient temperature, $G_{glob,\beta}$ is solar radiation, $q_{ir,o}$ is upward longwave radiation, $q_{ir,do}$ is downward longwave radiation, σ is Stefan-Boltzmann constant, $T_{p,o}$ is LBE outer surface temperature.

Transmission heat flow

Experimentally determined transmission heat losses and gains during day-time or night-time through the LBE with DVC were compared with calculated transmission heat losses and gains through standard LBE at the same meteorological parameters and indoor temperature. By using experimentally determined and calculated values relative decrease of transmission heat losses and gains through LBE with DVC was determined. The results are presented on Figure 4. In the area of positive values of temperature difference T_i - T_{ekv}, the heat flows through the element to the ambient (heat losses) while in the area of negative values of temperature difference T_i - T_{ekv}, the heat flows into the building (heat gains). It is evident that the decrease of transmission heat losses and gains through LBE with DVC is practically independent of temperature difference and amounts on average 90%. In the area of temperature difference T_i – T_{ekv} close to zero higher deviation from average value can be noticed. Higher deviation is a consequence of negligible heat losses and gains when the temperature difference T_i – T_{ekv} is close to zero and the definition of relative decrease.

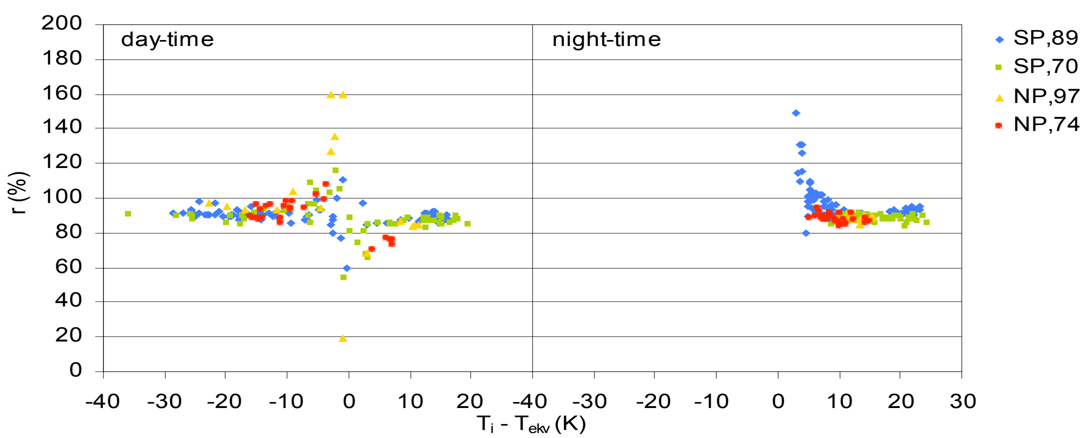

Figure 4: Relative decrease of transmission heat losses and gains through thermally activated LBE with DVC compared to standard LBE. Numbers represent volume air flow in m^3/h. Each point represents one day or night.

Ventilation heat gains

Ventilation heat gains of LBE with DVC due to absorbed solar radiation (during day-time) and heat recuperation (during day-time and night-time) were compared with ventilation heat losses when no heat recuperation is used in the building ventilation system. The amount of heat, which can be transferred into the building when ventilating with LBE with DVC can exceed ventilation heat losses. In this paper we will analyse only heat gains which do not exceed ventilation heat losses. Therefore the excess of heat gains is not used or stored. For such an operation mode relative decrease of ventilation heat losses is presented on Figure 5. It is evident that during day-time three areas of relative decrease can be determined. In the first area (1) are the days with clear or mostly clear weather. In this area relative decrease is constant because the excess of heat is not used and amounts to 78% for LBE with DVC painted with spectrally non-selective paint and 82% when spectrally selective paint is used. In the second area (2) are the days with partly cloudy weather. In this area relative decrease of ventilation heat losses depends on the temperature difference T_i - T_{ekv}. Bigger the temperature difference, smaller is the relative decrease. In the third area (3) are the days with cloudy weather. Due to small influence of solar radiation heat recuperation prevails in this area. Therefore the relative decrease is comparable with relative decrease during night-time. During night-time the difference in spectrally non-selective and selective paint can be seen. By using spectrally non-selective paint relative decrease between 15 and 30% can be achieved and between 30 to 40% when spectrally selective paint is used.

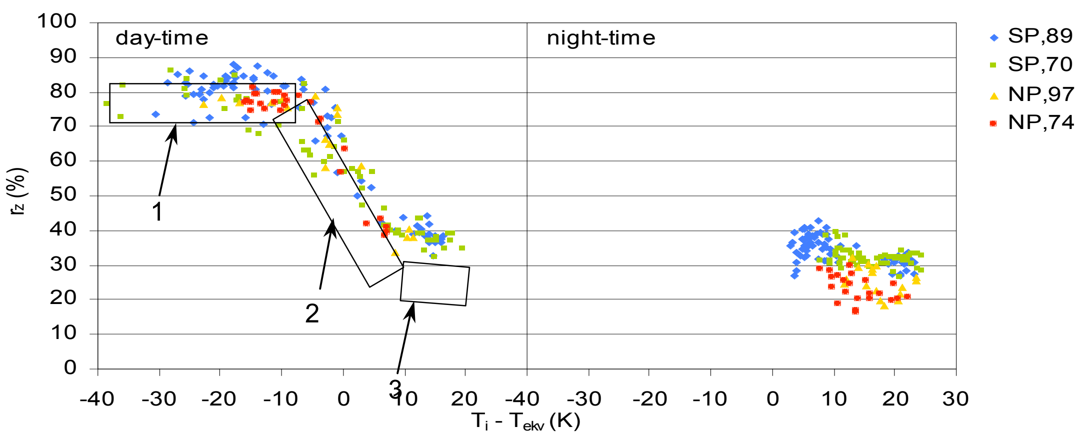

Figure 5: Relative decrease of ventilation heat losses when LBE with DVC is used for building ventilation and no excess heat is used or stored. Numbers represent volume air flow in m^3/h. Each point represents one day or night.

CONCLUSIONS

In the paper innovative thermally activated LBE with DVC, which operates as dynamic insulation of building envelope, uses solar radiation for heating ventilation air and enables heat recuperation from used air to fresh ventilation air. Thermal performance of such element was determined experimentally for LBE with DVC painted with spectrally non-selective and spectrally selective green paint. Transient heat transfer, solar efficiency and heat recuperation efficiency was analysed.

Transmission heat flow through the LBE with DVC is decreased by 90%, therefore smaller thickness of standard LBE is needed for achieving appropriate thermal transmittance of building envelope. Influence of spectrally selective paint compared to non-selective paint on transmission heat flow is not clearly evident.

Based on performed experimental analysis relative decrease of ventilation heat losses was determined. During day-time up to 78% decrease can be achieved when spectrally non-selective paint is used and up to 82% decrease when spectrally selective paint is used.

Using of night-time longwave radiation heat loss for cooling of fresh air in summer is not reasonable because heat transferred by recuperation from used to fresh air prevails over longwave radiation heat loss from the surface of the LBE with DVC. Cooling of fresh air by longwave radiation heat loss would be possible only in the case of closed inner cavity.

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