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Increasing thermal mass in low carbon dwelling

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Abstract

The number of houses of lightweight concrete being built over recent years has increased significantly. These buildings have low thermal mass and may be subject to large temperature fluctuations and particular overheating during the summer and this problem is set to get worse with the climate change. The paper discusses the effect of lightweight concrete walls substitution for reinforced concrete walls from thermal inertia in winter and summer viewpoint. Although the issue has been discussed in the past sufficiently, it should be updated for low carbon dwellings.

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Keywords: Building materials; Low carbon dwelling; Thermal mass; Thermal inertia; Overheating; Lightweight concrete.

1. Introduction

Thermal mass offers the architect the opportunity to manage energy flows of a building to the advantage of its occupants without the use of large amounts of fuels. For building, that use intermittent heating, construction with a high accumulation capacity can slow cooling of the internal space. For buildings, that use natural ventilation as a cooling strategy, diurnal effect can be managed by mass which absorbs the heat of internal building loads during the day and the accumulated heat is flushed by cool air at night. The volume and thickness of thermal storage determines the magnitude of interior temperature swings. The time necessary for heat to be released by various thermally massive materials is called thermal lag. The effective mass thickness in a diurnal cycle can be 100 – 150 mm when one surface is used or 200 – 300 mm when both surfaces are used. The thermal lag of a material depends on the heat capacity of the material and conductivity of the material. It can be represented by this formulation:

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$$T_{lag} = \sqrt{\frac{1}{2 \cdot a \cdot \omega}} \cdot d \tag{1}$$

Nomenclature

T_{lag}	thermal lag, -
a	thermal diffusivity, $m^2.s$
ω	angular frequency, s^{-1}
d	thickness, m

The contribution from the team of authors Badurova S. – Ponechal R. [1] presents 1.78 % increase in frequency of overheating (over 25°C) between sand-lime wall with a reinforced concrete ceiling and a porous concrete construction calculated with program PHPP (Passive House Planning Package). The same comparison in the dynamic simulation program means the difference in occurrence of overheating 92.5 h/a. It was a passive building which was used for cooling in summer earth exchanger, but building presented in this paper does not use this technology.

1.1. Description of experimental low carbon dwelling house

The experimental low carbon dwelling house is situated near the town Povazska Bystrica in northern Slovakia with altitude 345 m a.s.l. It is one-storey building of a simple constructional shape with sloped roof. The composition of envelope constructions is shown in Fig. 1. The building takes full advantage of solar heat gains. Most of the windows are oriented to the southeast and southwest. Wooden windows (U_w = 0.79 W/(m^2.K)) with triple-glazing are used for fillings. They are (optionally not) protected by outer shielding, which eliminates overheating of a building in summer.

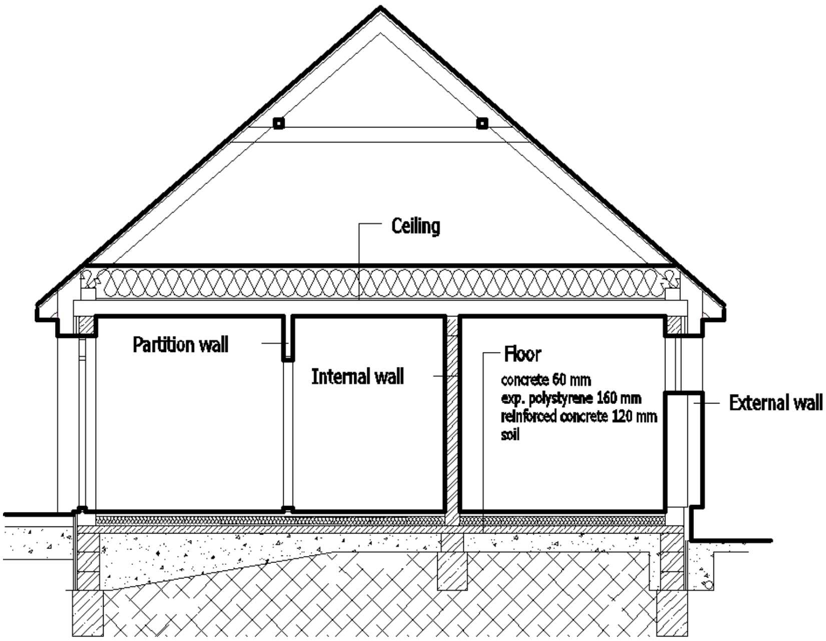

Fig. 1. The 8 zones simulation model.

1.2. Alternative constructions

According to thermal inertia some alternative designs of a low carbon dwelling house were created. Vertical and horizontal constructions were changed from lightweight to heavyweight. The outer dimensions of a building, the way of founding, surface working and the HVAC technical solution (fully convective heating) were preserved. For the material structures of the alternative constructions see Tab. 1.

Table 1. An alternative constructions.

Construction	**Layer**	**Thickness** (m*m*)
Heavy-weight concrete internal wall	Plaster	10
	Reinforced Concrete	200
	Plaster	10
Light-weight concrete internal wall	Plaster	10
	Porous Concrete Block	300
	Plaster	10
Heavy-weight concrete partition wall	Plaster	10
	Reinforced Concrete	100
	Plaster	10
Light-weight concrete partition wall	Plaster	10
	Porous Concrete Block	100
	Plaster	10
Heavy-weight concrete external wall	Plaster	10
	Reinforced Concrete	150
	Expanded Polystyrene	200
	Silicone Plaster	7
Light-weight concrete external wall	Plaster	10
	Porous Concrete Block	300
	Expanded Polystyrene	200
	Silicone Plaster	7
Heavy-weight concrete ceiling	Plaster	10
	Reinforced Concrete	200
	Glass wool	400
Light-weight concrete ceiling	Plaster	10
	Porous Concrete Block	300
	Reinforced Concrete	50
	Glass wool	400

1.3. Energy performance simulation

Numerical simulation calculations were made with EnergyPlus simulation program. The annual courses of dry bulb interior temperature and operative temperature are evaluated in model consist of 8 zones (see Fig. 2).

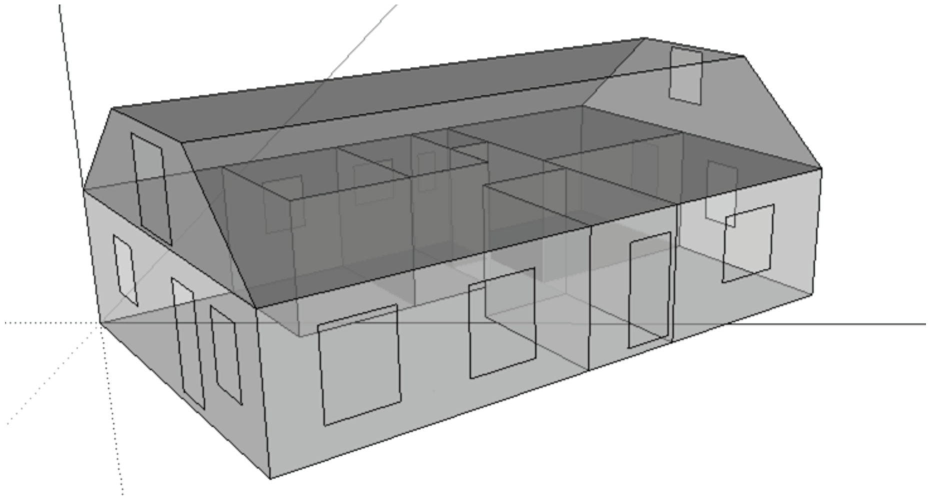

Fig. 2. The 8 zones simulation model.

For the sake of simplification of the thermal inertia evaluation, it was considered 11hour operation of the heating system (from 5:00 to 19:00) width night interruption. The sensor of dry bulb air temperature was set at 22°C for each room.

Fully convective heating was simulated in this study. The predicted dry bulb and surface temperatures are strongly dependant on surface convective heat transfer coefficient of used model, therefore the variation 10 – 15 % are commonly allowed. The TARP - variable natural convection based on temperature difference model (Walton) was used in this study. The simulation used Standard International Weather for the Energy Calculation (IWEC) climate file for the Ostrava city.

The annual calculations were done with casual heat gains 3.0W/m^2. For heating season the uniform infiltration air exchange number n = 0.3[1/h] was used for alternative without recuperation unit and n = 0.09[1/h] was used for alternative with recuperation unit. In summer the uniform infiltration air exchange number vary from n = 1.0[1/h] in daytime to n = 3.0[1/h] at evening and night.

2. Thermal inertia in winter

To verify the lowest drop in temperature in winter was evaluated period 21. November - 25. November. At that time it was mostly cloudy and dry bulb temperature in the climate data set ranged between -4 ° C and +1 ° C. It can say that this is a typical winter day, which is dominated by winter.

Simulation represents a fully convective heating system. The control was set to dry bulb temperature 22 ° C, while from 19:00 to 5:00 was a break in heating. The dry bulb temperature after the break had a very rapid start-up. Heating power at start-up was not limited (see Fig. 3. and Fig. 4.).

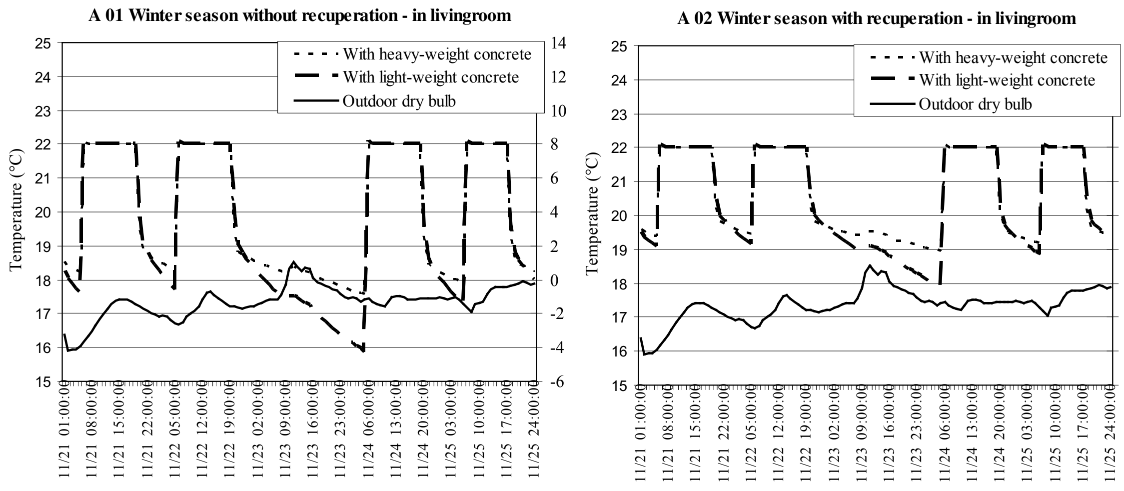

Fig. 3. Graph of air temperature in the living-room in winter (21. November – 25. November).

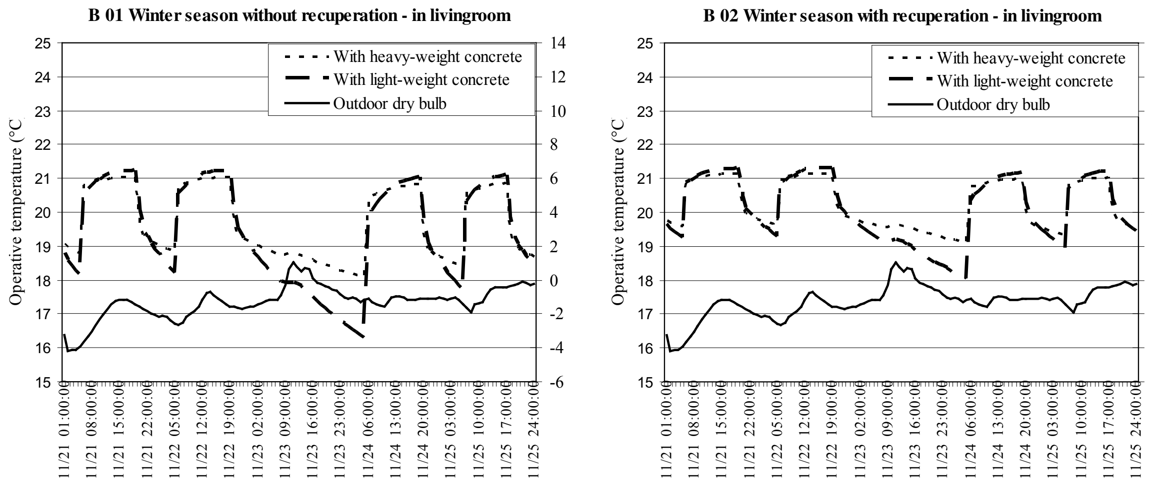

Fig. 4. Graph of operative temperature in the living-room in winter (21. November – 25. November).

3. Thermal inertia in summer

To verify the maximum daily internal temperature rise were selected days of extreme dry bulb temperature (over 30 ° C). Especially critical it is when there is hot days just one after the other. Such days occur in the climate file between 3.8 and 7.8.

The resulting absolute values of dry bulb temperature in the interior are very strongly dependent on the internal heat gains. There have been considered with uniform distribution heat gain in time and space (3 W / m^2). It could be that just in the time of the highest dry bulb exterior temperature is somewhere greater source of heat gains (eg, cooking lunch, visit a bigger, etc.). In this case, the results might be different than those which are presented in Fig. 5. and Fig. 6.

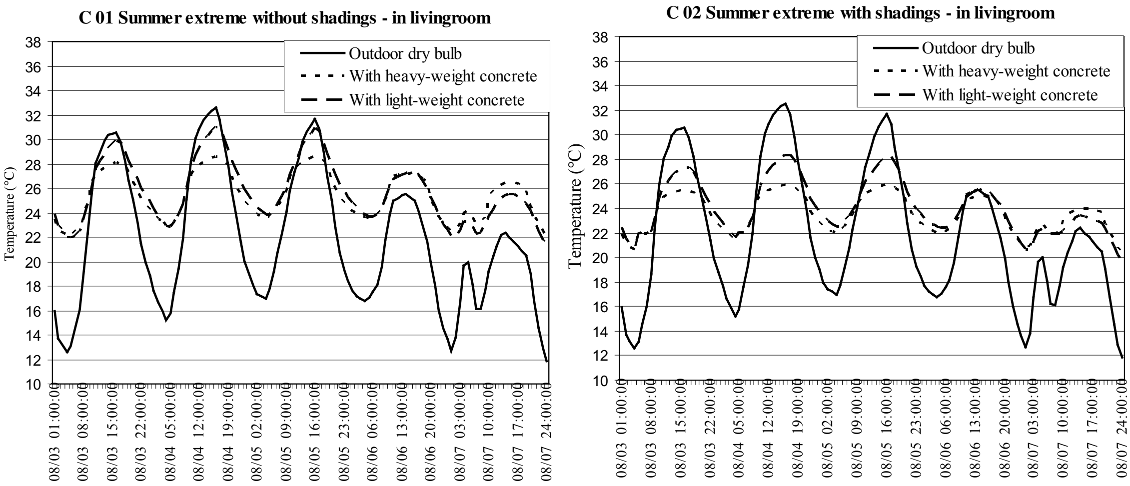

Fig. 5. Graph of air temperature in the living-room in summer hot period.

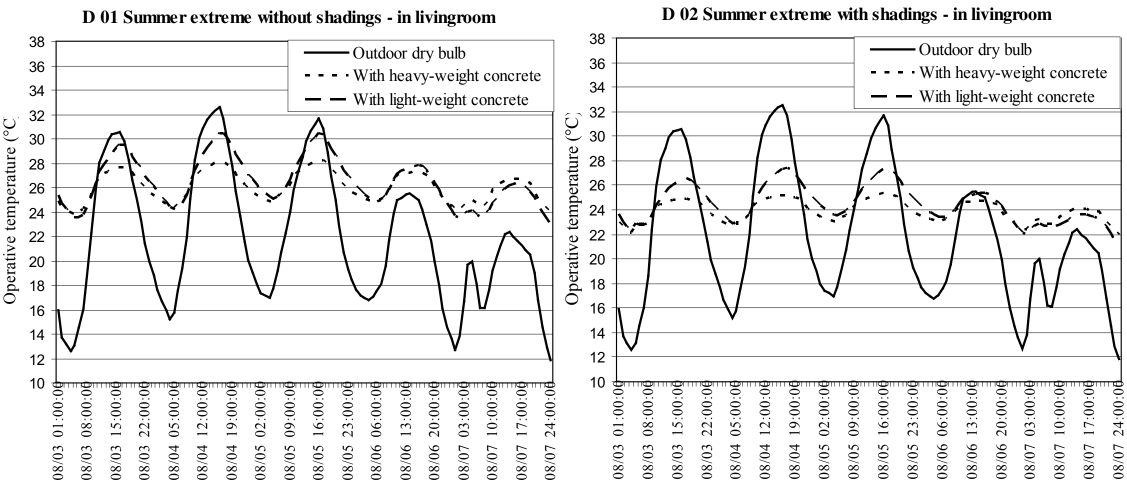

Fig. 6. Graph of operative temperature in the living-room in summer hot period.

4. Discussion

The dry bulb temperature during night breaks in heating decreases by 3.5 K with massive concrete structures, and 4 K with porous concrete structures. The difference represents 0.5 K. This difference is not a big man and difficult noticeable. When reducing the heat loss caused by ventilation, i.e. using heat recovery is a drop in temperature during night breaks in heating 2.5 K with massive concrete structures and 3 K with porous concrete structures. 0.5 The difference remains the same as before without heat recovery.

The dry bulb temperature during a prolonged periods of heating inactivity (35 h) decreased by 4.5 K with massive concrete structures, and 6 K with porous concrete structures. The difference represents 1.5 K. When reducing the heat loss caused by ventilation, i.e. using heat recovery a drop in temperature during 35 h break in heating is 2.5 K with massive concrete structures and 3 K with porous concrete structures. 0.5 The difference remains the same as before without heat recovery.

Increasing thermal mass in low carbon dwelling results in an operative temperature drop of only 2 K. The operative temperature was returned to the original state at 21 ° C for the heavy-weight concrete constructions more quickly like for light-weight concrete constructions. Heavy-weight concrete constructions not manage to cool down during a break as much as porous concrete.

Without the usage of effective external shading it can not be assured comfort in naturally ventilated low carbon dwelling. The dry bulb temperature reaches in dwelling without shading and with heavy-weight constructions 29 °C, the operative temperature reaches 28 °C. It does not meet the requirements of standard STN 73 0540 [2]. By using external shading can ensure summer thermal comfort conditions in the low carbon dwelling with heavy-weight constructions (dry bulb temperature below 26 °C and operative temperature below 25 °C. By using light-weight concrete construction 2 - 3 K higher temperatures is expected.

The external shading does not change differences between the maximum temperatures with increasing thermal mass, it affect only the temperature maximum. A similar regularity than at higher gains from the sun would apply even at higher internal heat gains.

Acknowledgements

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