Experimental Study on the Effects of Wall Materials on the Thermal Behavior of Mezzanine Floors

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Abstract: The authors of this paper want to investigate the effect of location of thermal insulation on the thermal behavior of mezzanine floor beam slab element sections of buildings under temperate climate condition was investigated by experimental methods. Data obtained from measurements on buildings under service conditions were used. Thermal behaviors of mezzanine floor sections comprising of un-insulated brick wall + beam and un-insulated autoclaved aerated concrete wall + beam were studied in 3 steps. These steps are general behavior of components within the total measurement time of about one month, variation of section temperatures at beam and wall levels, and heat flow through the external surface of beam. Finally, the differences between the two types are discussed.

Keywords: Thermal bridges • Thermal insulation effect • Thermal behaviour • Heat flow • Surface temperature

INTRODUCTION

Thermal bridges are limited confined zones with higher thermal transmittance than the overall average of the buildings. As two dimensional heat transmission that occur in these areas, cause extra heat losses - lower inner surface temperatures - condensation on inner surfaces - mould formation, it has unfavorable influence on thermal comfort and energy consumption of buildings. Recently, thermal bridging effects have been the subject of numerous papers, because reinforced concrete or steel columns and beams, as major thermal bridges, constituting 15%-25% of the external shell area of residential buildings, have thermal conductivities at least 5-6 times those of wall materials.

A significant number of these studies deal with comprehensive software by which steady-state or time dependent one, two and three dimensional heat transmission problems can be solved taking into consideration also the vapour and air transfer. The accuracy, repeatability, user friendliness and open coddness of the computer software have also been examined in numerous papers [1-6]. The usability as inputs to the more detailed software, of outputs obtained by simple software on individual building elements has also been dealt with [7,8].

Other studies, which are of limited number, concentrate on some special subjects. There are studies in which parameters for thermal bridges used by ISO 9164 are determined [9], or the results obtained by the standard methods such as ISO 9164, EN 832 for different building and insulation cases are compared [10]. There are studies on the minimization of [11,12] thermal bridges in windows, modeling heat transmission in thermal bridges [13,14] numerical [15] solutions for thermal bridges formed by wall blocks. There are also searches for methods in which numerical [16,17] analytical [18,19] and analytical numerical solutions are used together for the solution of heat transmission problems [20,21]. Multilayered wall elements, insulated wall panels, wall-door thermal bridges have been examined besides homogeneous walls [22-24]. Thermic cameras have been used for determining the variation of exterior surface temperatures in buildings and the effect of section types that influence heat transmission in walls [25,26]. The effects of different climate conditions (different Degree Dates) on heat losses through thermal bridges and walls have been examined too [27-29]. There are studies in which thermal behaviors of thermal bridges on reinforced concrete beam slab in different insulation systems, are examined using finite element methods [9,30,31].

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374

The aim of the study is to find out the effect of wall material on thermal behavior of thermal bridges in mezzanine beam slab floors are examined based on measurements performed under real conditions, on buildings in service. Thermal behaviors of sections (mezzanine floor coverings) comprising of un-insulated brick wall + beam and un-insulated autoclaved aerated concrete wall + beam have been comprehensively studied in 3 steps.

- General behaviors in total measurement period of about 1 month.
- Variations of section temperatures at beam and wall levels.
- Variations of heat flows at beam level.

MATERIALS AND METHODS

Environment and surface temperatures were measured at points 50 mm from the wall-beam interface. Environment temperatures in inner and outer environments were measured using Campbell scientific Inc 108-L environment temperature sensor, surface temperatures on interior and exterior environments were measured using ENERCORP TS-PL-R-100 plate surface temperature sensor. Heat flows were measured only on the inside surface at points 50 mm away from the beam-wall interface with HUKSEFLUX HF151 plate model heat flow sensor. Data consisting of 15-minute averages of measurements taken with one minute interval were stored in Campbell Scientific Inc CR200 model data-logger.

Before starting the experiments, trial measurements were made. Deviations from each other of the temperature probes for the same temperature, the accuracy of heat flow measurements, the effect of type of installation of the probe on the surface temperature measurements and adequacy of the data logger for recording were tested [9].

The sections investigated were of reinforced concrete structures made with normal conventional structural concrete and reinforcing steel bars. There is a wide variety of choices for the location of insulation. In this study, insulated cavity wall buildings and exterior insulated buildings are examined. Surface and environment temperatures were measured both for beam and wall, approximately on the same horizontal line perpendicular to the surfaces, on interior and exterior sides. Heat flow values were measured only on beams’ interior side. Sections where measurements were taken, measurement dates, place of building, figures of measurements and graphics of measurement values are shown in subchapters below.

Brick Wall: Measurements were recorded in a building province on October 28 and were ended December 02. The experimental setup and wall section can be seen in Figure 1. Time (date) versus temperatures and heat flux plots are given in Figure 2 and 3.

Autoclaved Aerated Concrete Wall: Measurements were recorded in a building from December 02 to January 13. Experimental setup and wall section are seen in Figure 4. The temperatures and heat flux values versus date plots are given in Figure 5 and Figure 6.

![Fig. 1: In-situ views of data logger and probes for a section in an un-insulated brick walled building](image-url)
Fig. 2: Surface and environment temperatures measured inside and outside in un-insulated brick walled building.

Fig. 3: Heat flow measured on interior surface of beam in un-insulated brick walled building.

Fig. 4: 3D views of data storage units and probes in an insulated autoclaved aerated concrete walled building.
TEST RESULTS AND DISCUSSIONS

The thermal behaviors of sections were compared first based on the trends observed throughout the whole measurement time. Instantaneous changes (of 15 min averages) of environment and surface temperatures in sections are shown in Figure 7 with the least squares best fitting straight lines.

As it can be seen in Figure 7, there is no difference between the environment temperatures measured approximately 20 mm away from the surfaces of beam and wall. The two curves (T_{inside(beam)} and T_{inside(wall)}; T_{outside(beam)} and T_{outside(wall)}) coincide in sections. The surface temperatures of beam and wall (T_{inside(beam)} and T_{inside(wall)}; T_{outside(beam)} and T_{outside(wall)}), as expected, differ from each other. The differences between beam and wall surface temperatures are higher on the interior side than those on the exterior side.

Exterior environment temperature of section with brick as the wall material in Figure 7a varied between about 0°C to 25°C (T_{outside(minimum)} and T_{outside(maximum)}). Variation within one period (one day) was about 5°C (T_{outside(minimum)}-T_{outside(maximum)}). The interior environment temperatures (T_{inside(minimum)} and T_{inside(maximum)}) varied between 23°C to 26°C, the interior surface temperatures (T_{inside(minimum)} and T_{inside(maximum)}) varied between 20°C to 25°C on wall surfaces and between 19°C and 25°C on beam surfaces. Variation in one period of a day (T_{inside(minimum)}-T_{inside(maximum)}) was about 2°C. Average temperature difference between interior and exterior environments is 13°C. In the date-temperature plots, no peaks in interior environment records appear due to the damping effect of walls. The divergence of curves of the beam interior surface and the wall interior surface temperatures is quite little.

Exterior environment temperatures in the section with autoclaved aerated concrete as the wall material in Figure 7b varied between -5°C and 20°C (T_{outside} and T_{inside}). The variation in one period (of a day) is about 3°C (T_{outside}-T_{inside}). The environment temperatures varied...
a. Brick wall

b. Autoclaved aerated concrete wall

Fig. 7: Environment and surface temperature plots (15 min average) of the sections

Fig. 8: Variations of (15 min average) temperature differences: interior environment - interior surface, interior surface - exterior surface and exterior surface - exterior environment

Brick wall

Autoclaved aerated concrete wall

Fig. 9: Variations of daily minimum, average and maximum heat flows through interior surface of beams
### Table 1: Ratios of reflections of effect of exterior environment on the interior environment for the sections and variation of difference between beam interior surface temperature and interior environment temperature

<table>
<thead>
<tr>
<th>Section Features</th>
<th>Ratio of variation range of interior surface to exterior surface temperatures</th>
<th>Average difference, between beam interior surface and interior environment temperatures, °C</th>
<th>Average difference between wall interior surface and interior environment temperatures, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick wall</td>
<td>5/25 = 0.20</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Autoclaved aerated concrete wall</td>
<td>8/25 = 0.32</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 2: Comparison of temperatures and their changes on interior and exterior surfaces of walls

<table>
<thead>
<tr>
<th>Section Features</th>
<th>Wall outside</th>
<th>Wall inside</th>
<th>Difference</th>
<th>Average amplitude difference between interior and exterior surfaces</th>
<th>Average surface temperature difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average temperature (°C)</td>
<td>Amplitude (min-avg-max) °C</td>
<td>Average temperature (°C)</td>
<td>Amplitude (min-avg-max) °C</td>
<td>Temperature (in-out) °C</td>
</tr>
<tr>
<td>Brick</td>
<td>12</td>
<td>0.9-25-49</td>
<td>21</td>
<td>0.3-0.7-1.1</td>
<td>9</td>
</tr>
<tr>
<td>Autoclaved aerated concrete</td>
<td>0.5</td>
<td>0.9-3.9-9.3</td>
<td>215</td>
<td>0.5-1.2-2.4</td>
<td>13</td>
</tr>
</tbody>
</table>

### Table 3: Comparison of beam and wall surface temperatures

<table>
<thead>
<tr>
<th>Section Features</th>
<th>Beam (°C)</th>
<th>Wall (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick wall</td>
<td>Tbeam(min) - Tbeam(max)</td>
<td>Twall(min) - Twall(max)</td>
</tr>
<tr>
<td>Autoclaved aerated concrete</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 4: Change of heat flow on beam level in section from which measurements was taken

<table>
<thead>
<tr>
<th>Section Features</th>
<th>Average heat flow W/m²</th>
<th>Average temperature difference between surfaces °C</th>
<th>Average heat flow per 1°C temperature difference between surfaces, W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick wall</td>
<td>30</td>
<td>9.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Autoclaved aerated concrete</td>
<td>35</td>
<td>10.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

between (T_{beam(min)} and T_{beam(max)}) 16°C and 26°C, the interior surface temperatures on the wall surface varied between (T_{wall(min)} and T_{wall(max)}) 18°C and 25°C and on the beam surface between 15°C and 22°C. Change in one period is about (T_{beam(max)} - T_{beam(min)}) 4°C. Average temperature difference between interior and exterior environment is 17°C. The time-temperature plots show that the peaks in interior environment decreased significantly, but the general trend persisted. The range of divergence of curves is more than that of brick wall.

In Table 1 column 2, (Figure 7) the unitless ratios of interior to exterior temperature ranges are given as basis for comparison of the sections studied. This was done by dividing the interior surface temperature variation ranges to that of the exterior surface temperature variation ranges within the measurement period. The smaller the ratio the better the section absorbs the effects of exterior environment, which is an advantage for the section.

In the second step, sections were compared with respect to the variation of section temperatures at beam and wall levels. Abrupt variations in interior environment - interior surface, interior surface - exterior surface and exterior surface - exterior environment temperature differences calculated from measurements taken at beam and wall levels can be seen in Figure 8.

These are expected, because the thermal transmittance of beam is higher allowing for more energy transmission from interior to exterior, resulting in smaller temperature differences between its interior and exterior surfaces, whereas the temperature differences between the wall surfaces are higher.

In Table 2 the differences between the amplitudes of temperature variations of interior and exterior surfaces per 1°C average temperature difference between interior and exterior surfaces of the walls are given. Average surface temperatures are computed from temperature measurements.

In Table 3, the averages of surface and environment temperature differences at wall and beam levels in sections are compared (Figure 8). Temperature differences between interior and exterior surfaces are higher at wall levels than at beam levels.

In the third step, the sections are compared with respect to heat flow at beam level. In Figure 9 the variation of daily minimum, average and maximum heat flow through interior surface at beam level given. In Table 4, the heat flow values per 1°C surface temperature difference are given (Figure 9).
CONCLUSIONS

Thermal behaviors of sections composed of uninsulated brick wall + beam and un-insulated autoclaved aerated concrete wall + beam are evaluated using the experimental data obtained in this work. The environment temperatures measured at a distance of 20 mm from the surfaces in front (at the level) of beam or walls were equal. However, the surface temperatures of beam and wall were different as expected. The differences between surface temperatures of beams and surface temperatures of walls were higher in interior environments than those of exterior environments in all sections.

Throughout the measurement periods, the ratios of temperature variation range (amplitude) of interior surface to temperature variation range of exterior surface were the smaller in the section with brick wall. Only 20% of variations of exterior environment were reflected into the interior environment in this section making them the better (Table 1). In terms of the average temperature difference between interior surface and interior environment in front of beam, the section with autoclaved aerated concrete wall ranked the worse with 4°C difference (Table 1). In terms of difference between the surface temperatures of wall and the surface temperatures of beam per 1°C difference between the environments, autoclaved aerated concrete insulated section the worse.

The temperature differences between the environments determined at wall and beam levels are very small in two sections. The surface temperature differences at wall and beam levels were, of course, significantly different. In two sections, the temperature differences between interior and exterior surfaces of walls are higher than those of corresponding beams. Divergence of temperature differences between wall and beam surfaces in a given section type is an indication of different thermal behavior and is undesirable (Table 2 - Table 3).

In terms of average heat flow per 1°C temperature difference between the surfaces of two sections has showed closed results (Table 7).

The overall total ratings of uninsulated sections with brick and autoclaved aerated concrete as the wall material are similar. A section that is inadequate in terms of one feature might be better in terms of another. The improvement comes out to be significant in section with brick wall.

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REFERENCES