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Full Length Research Paper

Experımental analysıs of the thermal behavıour of mezzanıne floors ın buıldıngs wıth cavıty wall ınsulatıon

Filiz Şenkal Sezer[1*], M. Timur Cihan[2] and Şükran Dilmaç[3]

[1]Department of Architecture, Faculty of Engineering and Architecture, Uludag University, Bursa-Gorukle, Turkey.
[2]Department of Civil Engineering Corlu Faculty of Engineering, Namik Kemal University, Tekirdag-Corlu, Turkey.
[3]CEVKAK, Basaksehir, Istanbul, Turkey.

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In this study, the thermal behaviour of mezzanine beam-slab floor sections of buildings under temperate climate conditions was experimentally investigated. Data were obtained from measurements on buildings under service conditions. Heat flow density and temperatures around the thermal bridges formed by the beam and floor elements were calculated. Thermal behaviours of mezzanine floor sections made of insulated cavity wall and beam was studied. The outcome measures were the general behaviour of components within the total measurement time of about one month; differences between wall and beam temperatures in all measurements; variation of section temperatures; variation of minimum, maximum and average temperatures measured in the environment and the surfaces; heat flow through the external surface of the beam; and damping ratios.

Key words: Thermal bridges, thermal behaviour, surface temperature, mezzazine slabs, cavity walls.

INTRODUCTION

The majority of heat loss in houses materializes in building elements such as walls, flooring, roof, windows and thermal bridges. The heat loss rate that arises in these areas varies depending on the architecture of the building, its location, insulation conditions, and the features of building elements used. The rate of heat loss due to exterior walls increases higher up the building. This deems insulation for exterior walls inevitable.

Cavity wall applications are methods arising from insulation materials placed between two walls. Re-inforced concrete surfaces are not insulated by some applications of this type. In some applications, reinforced concrete surfaces are insulated in order to prevent thermal bridges.

Thermal bridges are confined zones with higher thermal transmittance than the building as a whole. Two-dimensional heat transmissions occur in these areas and cause heat losses, lower inner surface temperatures, condensation on inner surfaces, and mould formation. Thermal bridges create thermal discomfort and increase the energy consumption of buildings. Recently, thermal bridging effects have been the subject of numerous papers. Reinforced concrete or steel columns and beams constitute 15 - 25% of the external shell area of most residential buildings. These thermal bridges have thermal conductivities 5 - 6 times than those of wall materials. International standards on thermal bridges are ISO 6946/2-1986, EN ISO 13789-1999 and EN ISO 13370-1998 [Anon ISO 6946/2 (1986), Anon EN ISO 13370 (1998)]. Calculation of the parameters related to thermal bridges are explained in the TS EN ISO 10211-1 and ISO 10211-2 standards [Anon TS EN ISO 10211-1(2000), Anon ISO 10211-2 (2001)].

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 codedness of the computer software have also been examined in nume-rous papers (Al-Temeemi et al., 2003; Basak et al., 2009; Basak et al., 2010; Budaiwi et al., 1999; Dalal et al., 2005; Larbi, 2005; Lefebvre, 1997; Mao et al., 1997; Salgon et al., 1987; Van Schijndel, 2003; Wu and ching, 2010). The usability as inputs to the more etailed soft-

*Corresponding author. E-mail: filizss@gmail.com. Tel: +90 224 294 2126. Fax: +90 224 294 2128.

ware, of outputs obtained by simple software on individual building elements has also been dealt with (Childs, 1988; Deque et al., 2001; Kosny et al., 2002). There are studies in which parameters for thermal bridges used by ISO 9164 are determined, or the results obtained by the standard methods such as ISO 9164, EN 832 for different building and insulation cases are compared (Dilmac et al., 2003; Dilmac et al., 2005).

Lightweight steel construction, multilayered wall elements, insulated wall panels, wall-door thermal bridges have been examined besides homogeneous walls (Hassid, 1989; Hassid, 1990; Hens et al., 2007; Höglund et al., 1998; Matrosov et al., 1989; Schwab et al., 2005). Thermal cameras have been used for deter-mining the variation of exterior surface temperatures in buildings and the effect of section types that influence heat transmission in walls. The effects of different climate conditions (different Degree Dates) on heat losses through thermal bridges and walls have been examined too (Boland, 1997; Boland, 2002; Coldicutt et al., 1991; Csoknyai, 2001; Feuermann, 1989; Grinzato et al., 1998; Matrosov et al., 1990; Vavilov et al., 1997).

Various scientific studies carried out have outlined the properties, advantages, and disadvantages of cavity wall application. However, the number of experimental studies is inadequate; especially studies analyzing the thermal behaviour on thermal bridges are of limited number (Aviram et al., 2001; Cihan et al., 2005; Dilmac et al., 2005; Şenkal et al., 2010).

In this study, thermal behaviour of thermal bridges in mezzanine beam slab floors are examined based on measurements performed under real conditions, on building. Thermal behaviours of sections (mezzanine floor coverings) comprising of insulated cavity wall + beam has been comprehensively studied in 6 steps:

1. General behaviours in total measurement period of about 1 month
2. Variations of differences between temperatures of wall and beam
3. Variations of section temperatures at beam and wall levels
4. Variations of minimum, average and maximum temperatures measured in the environment (ambient air) and on surfaces at wall and beam levels
5. Variations of heat flows at the beam level
6. Variations of damping ratios.

EXPERIMENTAL WORK

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 HFP01 plate model heat flow sensor. Data consisting of 15-min 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 (Dilmac et al., 2005).

The section investigated was of reinforced concrete structures made with normal conventional structural concrete and reinforcing steel bars. 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 this study.

Measurements were recorded in a building in Edirne, Turkey province on January 19 and were ended one month later (February 18). The experimental setup and wall section can be seen in Figure 1. Measurements versus date plots are given in Figure 2 and 3.

RESULTS

The thermal behaviours of section 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 4 with the least squares best fitting straight lines.

As it can be seen in Figure 4, there is no difference between the environment temperatures measured approximately 20 mm away from the surfaces of beam and wall. The two curves ($T_{indoor(beam)}$ and $T_{indoor(wall)}$; $T_{outdoor(beam)}$ and $T_{outdoor(wall)}$) coincide in all 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.

In Figure 4, exterior environment temperatures in the insulated cavity wall section varied between -7 and 18°C (T_{odmin} and T_{odmax}) throughout the measurement time (of one month), the variation in one period is about 10°C. As the interior temperatures change between (T_{idmin} and T_{idmax}) 15 - 30°C, the interior surface temperatures varied between (T_{ismin} and T_{ismax}) 13 and 25°C on the wall, and between 12 and 24°C on the beam, the variation (T_{idmax}-T_{idmin}) in one period is about 4°C. The average temperature difference between interior and exterior environments is 16°C. The time-temperature plots of the interior environment of the sections show that the peaks of exterior environment are reflected to interior environment.

In the second step, the section was compared with respect to wall and beam temperatures. Abrupt changes in the differences of wall and beam temperatures can be seen in Figure 5. As expected, the wall surface Temperatures are higher than the beam surface temperatures

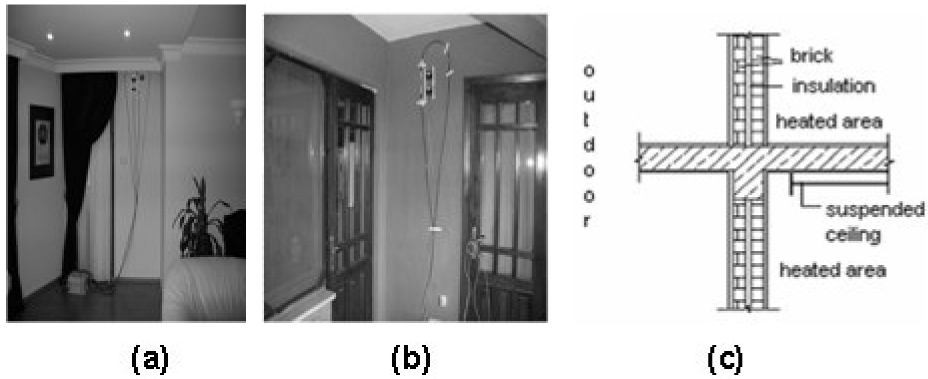

Figure 1. *In-situ* views of the data logger and the probes for single sections in building and section features; (a) inside (b) outside (c) section features.

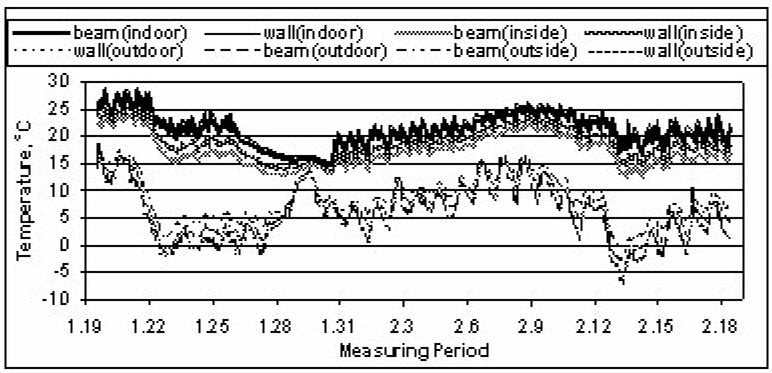

Figure 2. Surface and environment temperatures inside and outside of an insulated cavity wall building

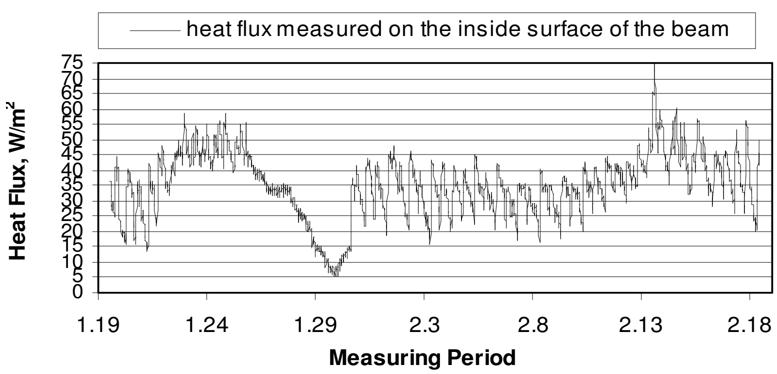

Figure 3. Heat flow measured on the interior surface of a beam in an insulated cavity wall building.

in interior environment and lower in exterior environment. It should be noted that the amplitudes of wall – beam temperature differences exhibit daily periodic character. The periodic character of wall – beam temperature difference is especially pronounced in exterior surface temperatures. The data obtained, not given herein for sake of briefness, show that the exterior wall – beam temperature differences increase during nighttime, the beam surface temperatures being much lower than those of wall, the difference increasing also with the advance of night. During the daytime, the beam surface temperatures were closer to wall temperatures, in some days the

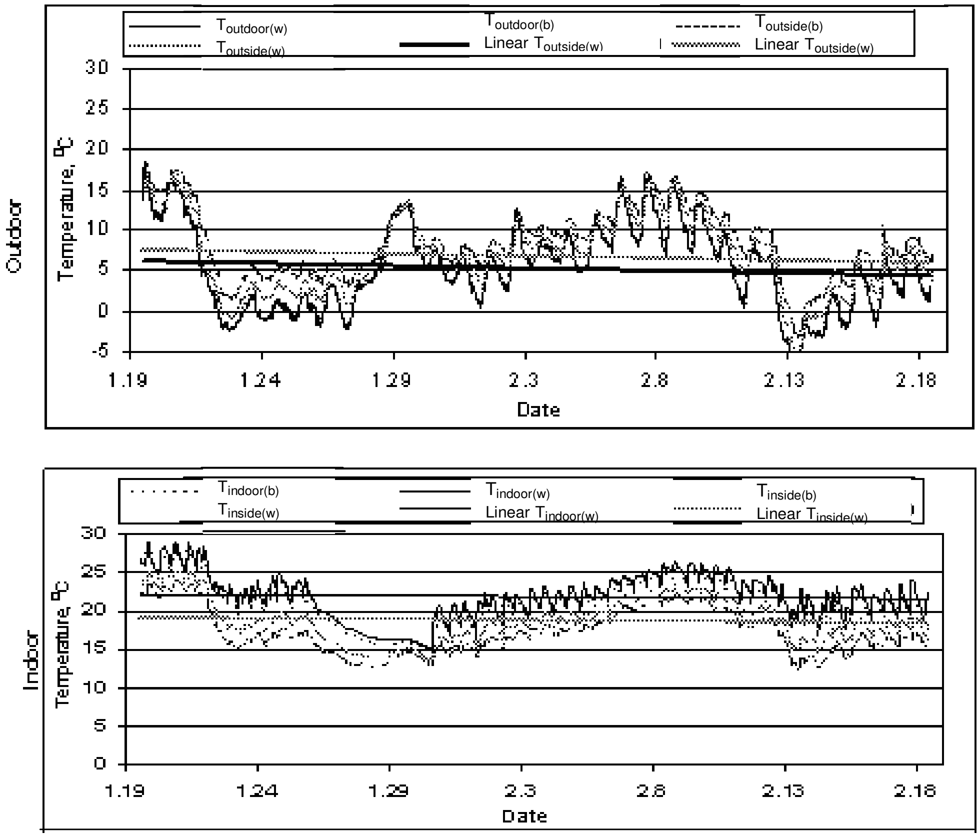

Figure 4. Environment and surface temperatures (15-min average) of the sections.

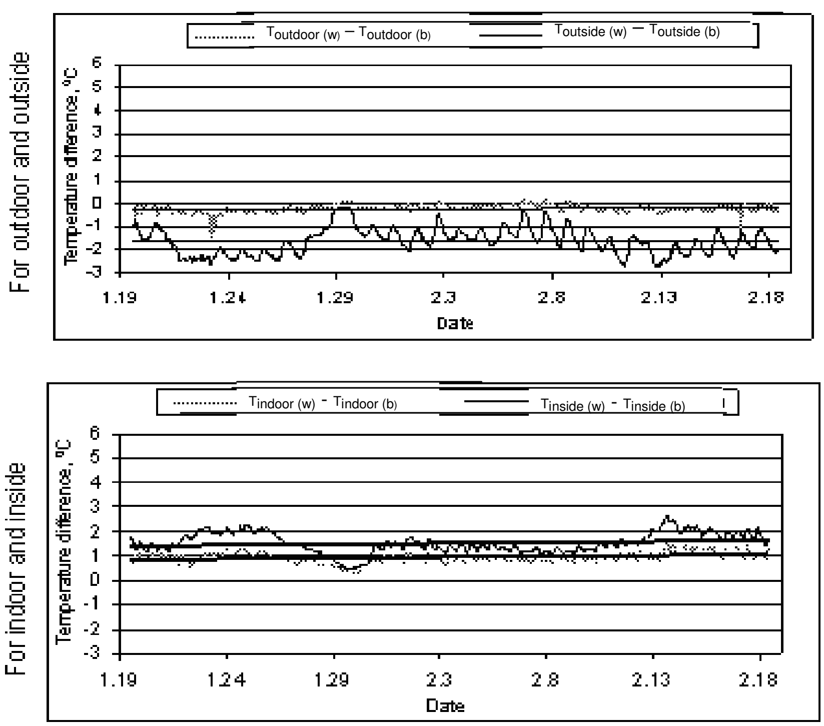

Figure 5. Variations (15 min average) of differences between temperatures of wall and beam

Table 1. Comparison of wall and beam temperatures.

Section features	Outdoor*	Indoor*	Outside*	Inside*
Insulated cavity wall	Wall < Beam (ΔT very small)	Wall > Beam $\Delta T \cong 1$ °C	Wall < Beam $\Delta T \cong 1.5$°C	Wall > Beam $\Delta T \cong 1.5$ °C

*: $\Delta T \equiv T_{wall}-T_{beam}$

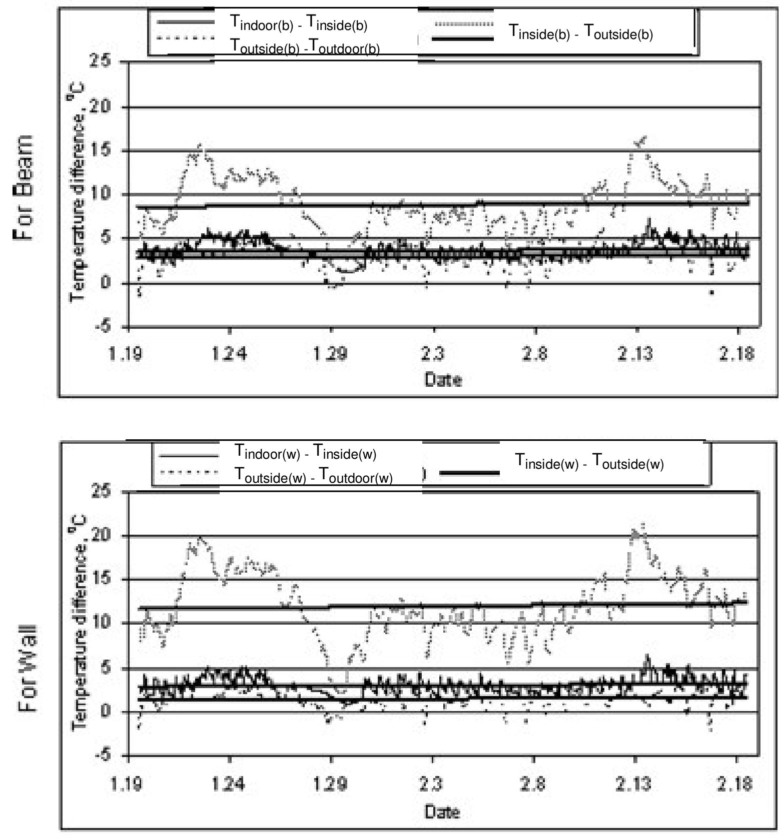

Figure 6. Variations of (15 min average) temperature differences: Interior environment - interior surface, interior surface - exterior surface and exterior surface - exterior environment.

beam surface temperatures were even higher than wall surface temperatures. As observed in Figure 2.5, in the insulated cavity wall section, the environment temperature measured in front of wall is 1°C higher than that in front of beam (Table 1).

In the 3rd step, section was 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 6.

In section, one the temperature differences between wall surfaces is always higher than temperature differences between beam surfaces. However, the differences ($T_{indoor/outdoor}$-$T_{inside/outside}$) between environment and surface temperatures are smaller at wall levels, these are expected, because the thermal transmittance of beam is higher allowing 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.

In Table 3, the averages of surface and environment temperature differences at wall and beam levels in sections are compared. The difference between the environ-

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

Section features	Wall outside		Wall inside		Difference		Average amplitude difference between interior and exterior surfaces / average surface temperature difference
	Average temperature (℃)	Amplitude (min-avrg-max) (℃)	Average temperature (℃)	Amplitude (min-avrg-max) (℃)	Temperature (in-out) ℃	Amplitude (in-out) (min-avrg-max) (℃)	
Insulated cavity wall	7	0.9 - 2.4 - 5.9	19	0.3 - 1.1 - 2.8	12	0.6 - 1.3 - 3.1	0.11

Table 3. Comparison of surface and environment temperature differences at wall and beam levels.

Section features	Beam (°C)				Wall (°C)			
	$T_{indoor(beam)}$-$T_{inside(beam)}$	$T_{inside(baem)}$-$T_{outside(beam)}$	$T_{outside(beam)}$-$T_{outdoor(beam)}$	($T_{indoor(beam)}$-$T_{inside(beam)}$)-($T_{outside(beam)}$-$T_{outdoor(beam)}$)	$T_{indoor(wall)}$-$T_{inside(wall)}$	$T_{inside(wall)}$-$T_{outside(wall)}$	$T_{outside(wall)}$-$T_{outdoor(wall)}$	($T_{indoor(wall)}$-$T_{inside(wall)}$)-($T_{outside(wall)}$-$T_{outdoor(wall)}$)
Insulated cavity wall	3.5	9	3	0.5	3	12	1.5	1.5

ment and the surface temperatures is higher in the interior (T_{indoor}-T_{inside}) than it is in exterior ($T_{outside}$-$T_{outdoor}$) at the beam level. Similar condition is also valid at the wall level, but the differences are closer to each other in interior and exterior environments. The differences at beam levels are higher than those of wall in all sections. Temperature differences between interior and exterior surfaces are higher at wall levels than at beam levels.

In Table 4, per 1℃ difference between environment temperatures, the ratio of the difference between wall surface temperatures to the difference between beam surface temp-eratures are given. As the difference increases the section becomes unfavourable in terms of thermal comfort. Nevertheless, it should be kept in mind that variation of interior surface temp-eratures is a more important factor for thermal comfort. In the 4th step, the sections are compared in terms of daily minimum, average and maximum temperature variations are measured at beam and wall levels, as can be seen in Figure 7.

The differences of average, minimum and maximum temperatures for the environment and the surfaces are given in Table 5. In insulated cavity wall section the temperature difference between environments at wall level is 1.2℃ higher than that at beam level. In contrast to the above, the temperature differences between interior and exterior surfaces ($\Delta T_{wall(inside/outside)}$ and $\Delta T_{beam(inside/outside)}$) at beam and wall levels, are significant, as expected.

The temperature difference between surfaces of wall and beam per 1℃ temperature difference between the two environments, diverging from each other is an evidence of different and unfavorable thermal behaviour in the section. The unfavorable situation is seen in insulated cavity wall section. Even though the wall is insulated, the intermission of insulation on beam surface increases the difference. In the 5th step, the section is compared with respect to heat flow at beam level. In Figure 8 the variation of daily minimum, average and maximum heat flow through interior surface at beam level, and in Table 6 the heat flow values per 1 °C surface temperature difference are given.

In the 6th step of evaluation, the section is compared with respect to their damping ratios at beam and wall levels. In Figure 9 plots of daily damping ratios at various locations of the section, and in Table 7 rating of the section with respect to the ratios of interior to exterior amplitudes are given. In Table 7, in addition to average damping ratios and standard deviations, the thicknesses and U values of sections are also given. Figure 9 show that damping ratios take various values. This variation is due to the substantial deviation of the exterior environment temperatures from being regularly periodic (Figure 4).

In the insulated cavity wall section, the damping ratios determined for wall-environment, beam-

Table 4. Ratio of the differences between wall surface temperatures and beam surface temperatures per 1°C temperature difference between the environments.

Section features	$(T_{inside(wall)}-T_{outside(wall)}) - (T_{inside(beam)}-T_{outside(beam)})$ (°C)	T_{indoor} (°C)	$T_{outdoor}$ (°C)	$T_{indoor}-T_{outdoor}$ (°C)
Insulated cavity wall	3	21.5	5.5	16

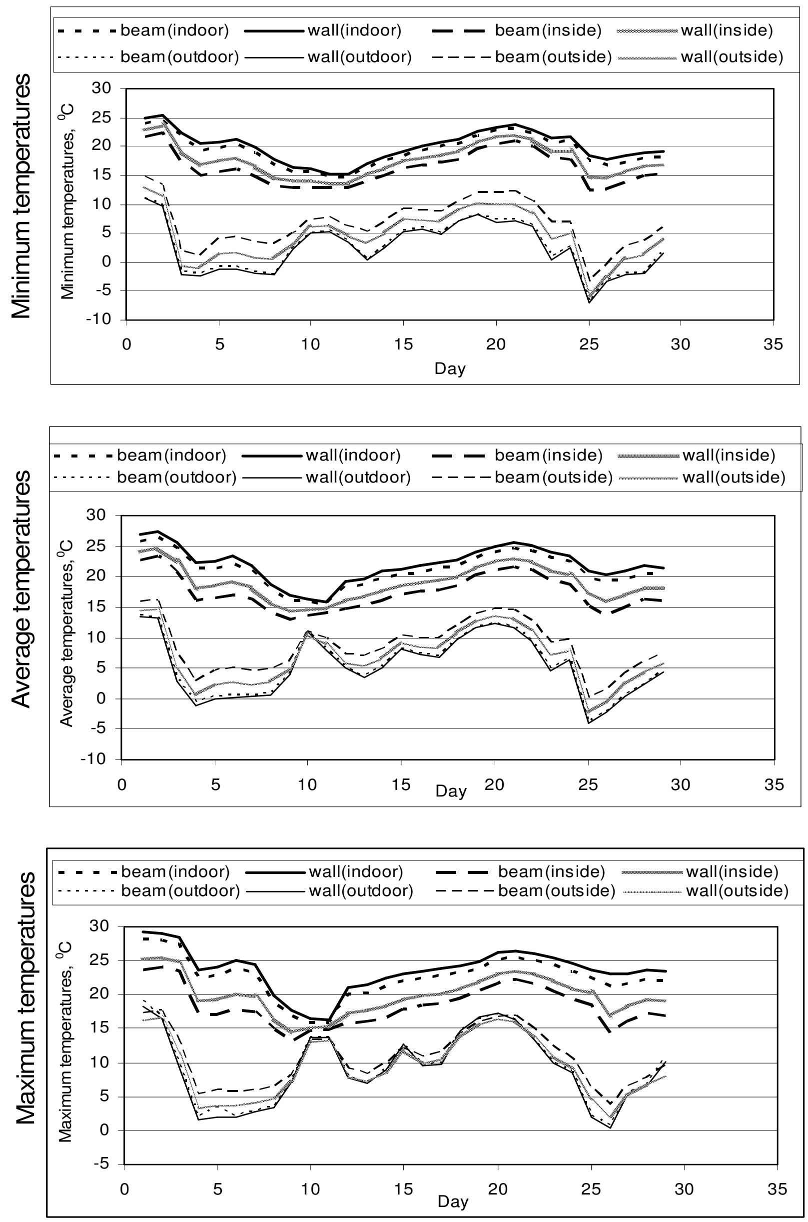

Figure 7. Daily change of minimum, average and maximum temperatures beams in section from which measurements was taken

environment and beam-surface are significantly greater than expected. As it is known, smaller damping ratios indicate that the section tolerates exterior environment conditions better, a desirable property.

DISCUSSIONS

Thermal behaviours composed of insulated cavity brick wall + beam is evaluated using the experimental data

Table 5. Comparison of differences of minimum, average and maximum temperatures measured at wall and beam levels.

Section features		Variations of Average temp.	Variations of Minimum temp.	Variations of Maximum temp		
insulated cavity wall	$\Delta T_{wall(indoor/outdoor)}$	16.7	22.2	10.9	$\Delta T_{indoor/outdoor}$=16 °C	
	$\Delta T_{beam(indoor/outdoor)}$	15.5	21.5	21.5		
	$\Delta T_{wall(inside/outside)}$	12.0	8.9	8.9	$T_{inside/outside}/\Delta T_{indoor/outdoor}$ 0.75	
	$\Delta T_{beam(inside/outside)}$	8.8	15.7	6.5	$T_{inside/outside}/\Delta T_{indoor/outdoor}$ 0.55	0.20
	$\Delta T_{beam(inside/outside)}$	2.5	16.2	-24.9	$T_{inside/outside}/\Delta T_{indoor/outdoor}$ 0.54	

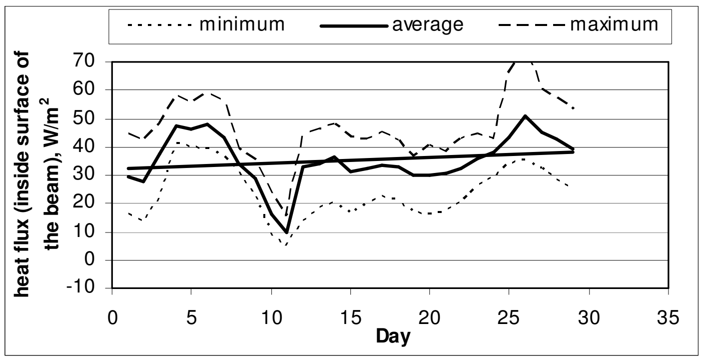

Figure 8. Variations of daily minimum, average and maximum heat flows through interior surface of beams.

Table 6. Change of heat flow on beam level in section from which measurements was taken.

Section features	Average heat flow (W/m^2)	Average temperature difference between surfaces (°C)	Average heat flow per 1°C temperature difference between surfaces, (W/m^2)
Insulated cavity wall	35	9.0	3.9

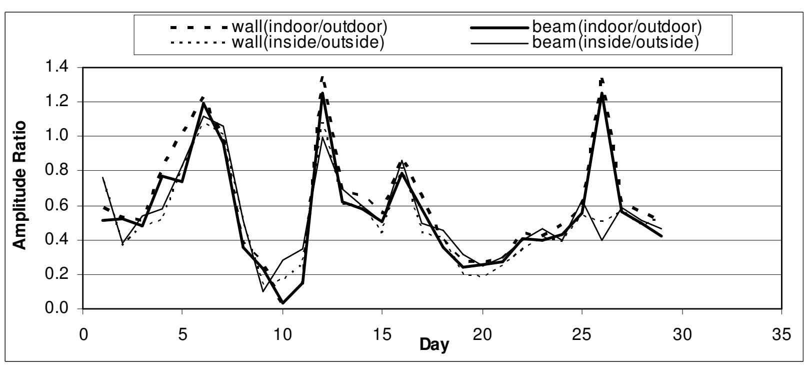

Figure 9. Variation of daily damping ratios.

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. In terms of average temperature difference between interior surface and interior environment at the wall level, the insulated cavity wall

Table 7. Thermal features of the section investigated.

	Damping ratio	Standard deviation	Difference of damping ratio (beam-wall)	Difference of damping ratio ((indoor-outdoor)/ (inside-outside))	Thickness, m	U-value, W/m^2K
Wall indoor/outdoor	0.60	0.34	-0.15	0.09	Beam = 0.24	Beam = 3.21
Beam indoor/outdoor	0.55	0.31		0.00		
Wall inside/outside	0.51	0.26	0.04		Wall = 0.24	Wall = 0.64
Beam inside/outside	0.55	0.24				

section emerges with 3°C difference. Again, the insulated cavity wall section is undesirable per 1°C difference between interior and exterior surfaces of the wall in terms of difference bet-ween temperature amplitudes in interior and exterior surfaces.

In the insulated cavity wall section, the temperature differences between the environments determined at wall level is 1.2°C higher than that at beam level. The surface temperature differences at wall and beam levels were, of course, significantly different.

In section, 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 behaviour and is undesirable. This undesirable situation was seen in insulated cavity wall section.

In terms of average heat flow per 1°C temperature difference between the surfaces, again the exterior insulated section was desirable. In terms of the damping ratios and the standard deviations, the insulated cavity wall section being undesirable.

Because the insulated wall is placed between reinforced concrete structural elements, and the reinforced concrete structural elements are left un-insulated, the section with insulated cavity wall qualifies as the worst in total rating. The advantage imparted by the insulation in the walls and, thus, U value of the wall being much smaller than un-insulated sections, is lost due to interruption of insulation on the beam surface, making it worse than un-insulated sections.

Nowadays, insulated cavity wall applications are still been used even though they contain significant deficiencies. In recent years, in the hope of resolving these problems, the concern has become insulating the inner surface of beams as well. Interior surface temperature is an important variable in terms of thermal comfort. In this respect, the insulated cavity wall applications and the insulation of the interior surface of the beam increases the interior surface temperature of the insulated element as well as causing an increase of heat loss in areas where the elements are joined. As a result, conditions that are more adverse arise at the lowest interior surface temperatures.

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REFERENCES

Al-Sanea SA (2003). Finite-volume thermal analysis of building roofs under two-dimensional periodic conditions, Build. Environ., 38: 1039-1049.

Al-Temeemi AA, Harris DJ (2003). The effect of earth-contact on heat transfer through a wall in Kuwait. Energy. Build., 35: 399-404.

Aviram DP, Fried AN, Roberts JJ (2001). Thermal properties of a variable cavity wall. Build. Environ., 36(9): 1057-1072.

Basak T, Roy S, Sharma PK, Pop I (2009). Analysis of mixed convection flows within a square cavity with linearly heated side wall(s). Int. J. Heat. Mass. Transfer., 52(9-10): 2224-2242.

Basak T, Roy S, Singh SK, Pop I (2010). Analysis of mixed convection in a lid-driven porous square cavity with linearly heated side wall(s). Int. J. Heat. Mass. Transfer., 53 (9-10): 1819-1840.

Boland J (1997). Simplifying the solution of the differential equations which describe heat flows in domestic dwellings. Build. Environ., 32: 479-484.

Boland J (2002). The analytic solution of the differantial equations describing heat flow in houses, Build. Environ., 37: 1027-1035.

Bridges A, Clarke J, Sussock H (1981). Computer graphics for building energy analysis. Advances in Engineering Software. 3 (2):84-88.

Budaiwi I, El-Diasty R, Abdou A (1999). Modelling of moisture and thermal transient behaviour of multi-layer non-cavity walls. Build. Environ., 34(5): 537-551

Childs KW (1988). Analysis of seven thermal bridges identified in a commercial building. American Society Of Heating, Refrigerating And Air-Conditioning Engineers (ASHRAE), Annual Meeting, Ottawa, INCONNU, pp.1776-1792.

Cihan T, Şenkal Sezer F, Dilmaç Ş (2005). Evaluation of thermal bridges formed by reinforced concrete beams at the cavity walls applications in Turkey. University of Uludag J. Faculty. Eng. Architect., 10(2): 33-47.

Clark MR, McCann DM, Forde MC (2003). Application of infrared thermography to the non-destructive testing of concrete and masonry bridges. NDT. E Int., 36(4):265-275.

Coldicutt S, Williamson TJ, Penny REC (1991). Attitudes and compromises affecting design for thermal performance of housing in Australia, Environ. Int., 17(4): 251-261.

Csoknyai T (2001). Surface temperature a thermal bridges. J. Build. Phy., 25(1): 67-81.

Dalal A, Das MK (2005). Laminar natural convection in an inclined complicated cavity with spatially variable wall temperature. Int. J. Heat. Mass. Transfer., 48(18): 3833-3854

Deque F, Ollivier F, Roux JJ (2001). Effect of 2D modelling of thermal bridges on the energy performance of buildings numerical application on the Matisse apartment, Energy. Build., 33(6): 583-587.

Dilmaç Ş, Cihan MT, Güner A (2004). Comparison of energy productivity of terrace roofs. (in Turkish). J. Design. Const., 226: 68-77.

Dilmaç Ş, Alamut Ö (2003) Comparison of ınternational thermal analysis methods of thermal bridges. Proceedings of The First İnternational Energy, Energy And Environment Symposium, İzmir, Turkey, pp. 781-786.

Dilmaç Ş, Guner A, Can A, Kaygusuzoğlu G, Cihan MT, Senkal Sezer F, Kartal S, Kalpak Ö (2005). Determination of parameters for the calculation of the side heat losses at floorings. Construction and Environmental Technologies Research Grant Committee. Project No: İÇTAG – 1242, TÜBİTAK, pp. 1-79.

European Committe for Standardization (1998). EN ISO 13370 Thermal performance of buildings, Heat transfer via the ground, calculation methods, Brussels.

Grinzato E, Vavilov V, Kauppinen T (1998) Quantitative infrared thermography in buildings. Energy. Build., 29: 1-9.

Hassid S (1990). Thermal bridges across multilayer walls: An integral approach. Build. Environ., 25(2): 143-150.

Hens H, Janssens A, Depraetere W, Carmeliet J, Lecompte J (2007). Brick cavity walls: a performance analysis based on measurements and simulations. J. Build. Phy., 31(2): 95-124.

International Organisation for Standards (1986). ISO 6946/2: Thermal insulation, Calculation methods, Part 2: Thermal bridges of rectangular sections in plane structures, Geneva.

International Organization for Standardization (2001). ISO 10211-2: Thermal bridges in building construction, heat flows and surface temperatures, Part2: Linear thermal bridges, Geneva.

Kosny J, Kossecka E (2002). Multi-dimensional heat transfer through complex building envelope assemblies in hourly energy simulation programs. Energy. Build., 34(5): 445-454.

Larbi AB (2005). Statistical modelling of heat transfer for thermal bridges of buildings. Energy. Build., 37: 945-951.

Lefebvre G (1997). Modal-based simulation of the thermal behaviour of a building: the m2^{m} software. Energy. Build., 25: 19-30.

Mao G, Johannesson G (1997). Dynamic calculation of thermal bridges. Energy. Build., 26: 233-240.

Matrosov YA, Butovsky IN (1989). U.S.S.R. experience in thermal design of building envelopes with improved thermal properties. Energy. Build., 14(1): 31-41.

Matrosov, YA, Butovsky IN, Childs KV (1990). Results of comparing solutions of calculation problems of enclosing structures with thermal bridges by Soviet and American methods. Energy. Build.,14(4): 303-311.

Salgon JJ, Neveu A (1987). Application of modal analysis to modelling of thermal bridges in buildings. Energy. Build., 10: 109-120.

Şenkal SF, Yeşilyurt N (2010). The Comparative Analysis of Thermal Bridges In Cavity Walls Applications In Turkey And In European Countries. University of Uludag J. Faculty. Eng. Architecture. (in press).

Turkish Standards Institution (2000). TS EN ISO 10211-1: Thermal bridges in building construction, heat flows and surface temperatures, Part 1: General calculation methods, Ankara.

Van Schijndel AWM (2003). Modeling and solving building physics problems with FemLab, Build. Environ., 38: 319-327.

Vavilov V, Kauppinen T, Grinzato E (1997). Thermal characterization of defects in building envelopes using long square pulse and slow thermal wave techniques. Res. Nondestructive. Eval., 9(4): 181-200.

Wu W, Ching CY (2010). Laminar natural convection in an air-filled square cavity with partitions on the top wall. International J.Heat, Mass. Transfer., 53(9-10): 1759-1772.