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PERFORMANCE ANALYSIS OF THE EXTERNAL WALL THERMAL INSULATION SYSTEMS APPLIED IN RESIDENCES

Neşe DİKMEN
Süleyman Demirel University, Department of Architecture, 32260, Isparta, Turkey, nesdikmen@gmail.com

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Abstract: Additional or retrofitted thermal insulation systems of existing buildings appeared as the most straightforward way to achieve almost immediate improvements in heating energy consumption. Insulation reduces fuel consumption, undesirable emissions from the burning of fossil fuels, and increases thermal comfort by minimizing heat losses from buildings. The thermal performance of four residences with different external wall systems, which are located in the Unikent Housing Complex in Isparta, was analyzed in this study. The users of three residences applied additional insulation layers to the wall system. One of these buildings had no insulation system, one had internally applied insulation, and the remaining two residences had externally applied insulation systems. One of the residences with an externally applied insulation system had an enclosed balcony. Dataloggers were placed in the bedrooms, which have the same sized windows and look towards the same direction and are located on the second floor of each building, to obtain the temperature and humidity values of these spaces. The buildings with insulation were found to exhibit better performance when compared with the uninsulated buildings. According to the study conducted, the building with internal insulation behaves like an uninsulated building during the period when no heating is applied. Nonetheless, during the period when heating is applied, the internally insulated building permits less exposure against external atmospheric conditions since the materials used in the internal surface of the wall store the heat. Additionally, an externally insulated building with an enclosed balcony shows better performance than the other externally insulated building with a lower U wall value. The balcony, enclosed by using glass material, did increase the heat savings and enabled the maintenance of the inner temperature of the related room.
Keywords: Internal thermal insulation, External thermal insulation, Sunspaces, Thermal performance.

KONUTLARDA UYGULANAN DIŞ DUVAR ISI YALITIM SİSTEMLERİNİN PERFORMANS ANALİZİ

Özet: Isı yalıtım sistemlerinin ısıtma enerjisi tüketimindeki en hızlı iyileşme için en basit yol olduğu söylenebilir. Yalıtım yakıt tüketimini, fosil yakıtların kullanımından kaynaklanan istenmeyen emisyonları azaltır ve binalardan kaybedilen ısı kayıplarını minimize ederek ısıl konforu arttırır. Bu çalışmada Isparta Unikent Sitesi'nde bulunan ve farklı dış duvar sistemlerine sahip olan dört konutun ısıl performansı incelenmiştir. Konutların 3'ünde kullanıcılar duvar sistemine yalıtım eklemişlerdir. Konutlardan biri yalıtımsız, biri içten yalıtımlı, ikisi de dıştan yalıtımlıdır. Dıştan yalıtımlı olan konutlardan bir tanesinin balkonu kullanıcı tarafından cam malzeme ile kapatılmıştır. Her konutun 2. katında bulunan aynı pencere büyüklüğüne sahip, aynı yöne bakmakta olan ve yatak odası olarak kullanılmakta olan bir odasına bu mekanların sıcaklık ve nem değerlerini almak amacıyla veri kaydediciler konulmuştur. Yalıtımlı olan yapılar, yalıtımsız yapıdan daha iyi performans göstermiştir. Bu çalışmada, ısıtmanın gerçekleşmediği dönemde içten yalıtımlı yapı, yalıtımsız yapı gibi davranmıştır. Buna rağmen ısıtmanın gerçekleştiği dönemde içten yalıtımlı yapının duvar iç yüzeyinde kullanılan malzemelerin ısıyı tutarak konutun dış hava koşullarından daha az etkilenmesini sağladığı görülmüştür. Araştırmaya göre balkonu kapatılmış olan dıştan yalıtımlı yapı, duvar U değeri daha düşük olan diğer dıştan yalıtımlı yapıya göre daha iyi performans göstermektedir. Cam malzeme kullanılarak kapatılmış olan balkon ısı kazancını arttırmış, kendisi ile ilişkili olan odanın iç mekan sıcaklığının dengede kalmasını sağlamıştır.
Anahtar kelimeler: İçten yalıtım, Dıştan yalıtım, Kış bahçeleri, Isıl performans.

NOMENCLATURE

k thermal conductivity ($Wm^{-1}K^{-1}$)
R thermal resistance (m^2KW^{-1})
U overall heat transfer coefficient ($Wm^{-2}K^{-1}$)
x insulation thickness (m)

Subscripts

i inside
ins insulation
o outside
w wall material

INTRODUCTION

The external walls of the buildings are directly exposed to atmospheric conditions. Physical modifications in the structural elements, such as expansion and contraction, negatively affect the safety and life span of the buildings; this is especially true in Turkey, which undergoes all four seasons (Altınışık, 2006). In innovated building standards, the trend for energy savings is reflected by requirements such as an increase of thermal resistance of building envelope systems, a decrease of thermal transmittance of fenestration products, and more efficient use of ventilation systems (Toman et al., 2009).

Additional or retrofitted thermal insulation systems of existing buildings appeared as the most straightforward way to achieve almost immediate improvements in heating energy consumption. Therefore, they quickly became an important segment of building industry (Toman et al., 2009). Enabling energy savings, protection of the environment, provision of thermal comfort and noise control, prevention of condensation in the structural elements and their surfaces, and protection of the structural elements against external effects could be possible as a result of the application of insulation in walls. While enabling the comfort conditions bears significance for human health, the protection of the building against external effects is significantly important with regards to the durability and longer life span of the structures. Thermal insulation would reduce the amount of gases diffusing into the atmosphere, such as carbon dioxide, sulfur dioxide, and other harmful gases because heating of the buildings would require less fuel, having a beneficial impact on the greenhouse effect and climate change (Sezer, 2005). The most widely used categories of insulating materials are inorganic fibrous (glass-wool and stone wool) and organic foamy ones (expanded and extruded polystyrene and, to a smaller extent, polyurethane), while all other materials cover the remaining 10% of the market (mainly wood-wool) (Papadopoulous and Giama, 2007).

Various thermal insulating systems, which take advantage of different types of insulation materials including both organic and inorganic ones, are being designed and tested, and new methods for analyzing the properties of both insulation materials and insulation systems are being devised (Pavlik and Cerny, 2009). Today, the wall insulation is implemented with three different systems according to the location of the thermal insulation material (BRER, 1994):

- Thermal insulation implementations applied to the external surface of the walls: The insulation material in this system is applied to the external surface of the wall by adhering or using a dowelled joint; a very thin synthetic plastering is then applied over it (Yılmaz, 2006). Exterior thermal insulation systems are capable of forming compact insulation layers, with which the possible thermal bridges that can lead in specific cases to significant increase of thermal losses are easily eliminated (Papadopoulous and Giama, 2007).

- Thermal insulation implementations applied to the internal surface of the walls: The most obvious problem of interior insulation systems is the presence of thermal bridges that cannot be fully eliminated. Another problem is the temperature differences in envelope walls that are not protected against the external environment; as a result, the masonry can deteriorate faster. Probably the most serious problem typical for interior thermal insulation systems is the risk of water vapor condensation in the thermal insulation layer (Papadopoulous and Giama, 2007). Internally applied insulation is used in particular for the thermal insulation of existing buildings and for cases in which externally applied insulation is not preferred. Nonetheless, in these thermal insulation implementations, precautions need to be taken to eliminate the thermal bridges encountered in the joints where floorings, columns, beams, and shear walls are pinned to the external wall. The simpler implementation technique and the decrease in the cost of internally insulated walls in comparison with externally insulated walls are regarded among their positive features (Altınışık, 2006).

- Thermal insulation implementations between two walls: Two layered walls, also termed as cavity walls, can be applied both with and without spacing. Condensation can occur within the construction in this type of insulation. This condensation can cause damage if it forms on the inner surface of unventilated impervious cladding or if water vapor is restricted from passing through the construction by a vapor resistant layer on the cold side of the insulation (BRER, 1994).

RESEARCH METHOD

Four residences, with the same structural systems but different insulation systems, from the Isparta Unikent Residential Complex were chosen as the samples for this study. The users of three residences applied additional insulation layers to the wall system. One of these buildings had no insulation system, one had internally applied insulation, and the remaining two residences had externally applied insulation systems. One of the residences with an externally applied insulation system had an enclosed balcony. 20 cm aerated concrete blocks were used as the infill wall material in the buildings that were built with reinforced concrete systems. Detailed information about the wall systems of the residences can be found in the Table 1.

The overall heat transfer coefficient, U_{un} for a typical wall without an insulation is given by

$$U_{\mathrm{un}} = \frac{1}{R_{\mathrm{i}} + R_{\mathrm{w}} + R_{\mathrm{o}}}$$

where R_i and R_o are the inside and outside air film thermal resistances, respectively, R_w is thermal resistance of the composite wall materials without the insulation.

The overall heat transfer coefficient U_{ins} for a typical wall with the insulation is given by

$$U_{ins} = \frac{1}{R_i + R_w + R_{ins} + R_o}$$

and R_{ins} is the thermal resistance of the insulation layer, which is

$$R_{ins} = \frac{x}{k},$$

where x and k are the thickness and thermal conductivity of the insulation material, respectively (Bolatturk, 2008).

A central heating system exists in these buildings, which are heated using coal. The boiler that exists in the basement floor of each building is switched on by the users. Dataloggers were placed in the bedrooms, which have the same sized windows and look towards the same direction and are located on the second floor of each building, to obtain the temperature and humidity values of these spaces (Figure 1). Hobo U10 dataloggers which record temperature and relative humidity were used for the study. The device, whose accuracy is ± 0.4°C @ 25°C, records from -20 to 70 ^{o}C (Pocasset).

Table 1. Wall systems of the residences.

	Insulation system	Wall system	Wall U value (Overall heat transfer coefficient)
RESIDENCE 1	No insulation	2 cm int. plaster+20 cm aerated concrete block+3 cm. ex. plaster	0.827 W/m^{2}K
RESIDENCE 2	Internally insulated	1 cm. plaster board +2,5 cm. XPS +2 cm int. plaster+20 cm aerated concrete block+3 cm. ext. plaster	0.483 W/m^{2}K
RESIDENCE 3	Externally insulated	2 cm int. plaster+20 cm aerated concrete block+3 cm. ext. plaster+ 5 cm. EPS	0.407 W/m^{2}K
RESIDENCE 4	Externally insulated enclosed balcony	2 cm int. plaster+20 cm aerated concrete block+3 cm. ext. plaster+ 4 cm. XPS+ 0,5 cm. plaster	0.423 W/m^{2}K

a) Residence 1

b) Residence 2

c) Residence 3

d) Residence 4

Figure 1. Residences.

In the first phase of the study, the first set of data was obtained from 21-24 September 2008 when the heating and cooling systems are not used in the residences and the natural ventilation is at the minimum level. The data belonging to the external temperature and humidity were also recorded via a datalogger placed outdoors. In the second part of the study, the dataloggers were placed in the same locations in the same rooms of the residences from 3-13 February 2009; the users were asked to record their switching time of the central heating system, the amount of coal they used, the temperature of the thermostat in the room, and the temperature of the boiler water. The external temperature and humidity values for these dates were recorded.

RESULTS AND DISCUSSION

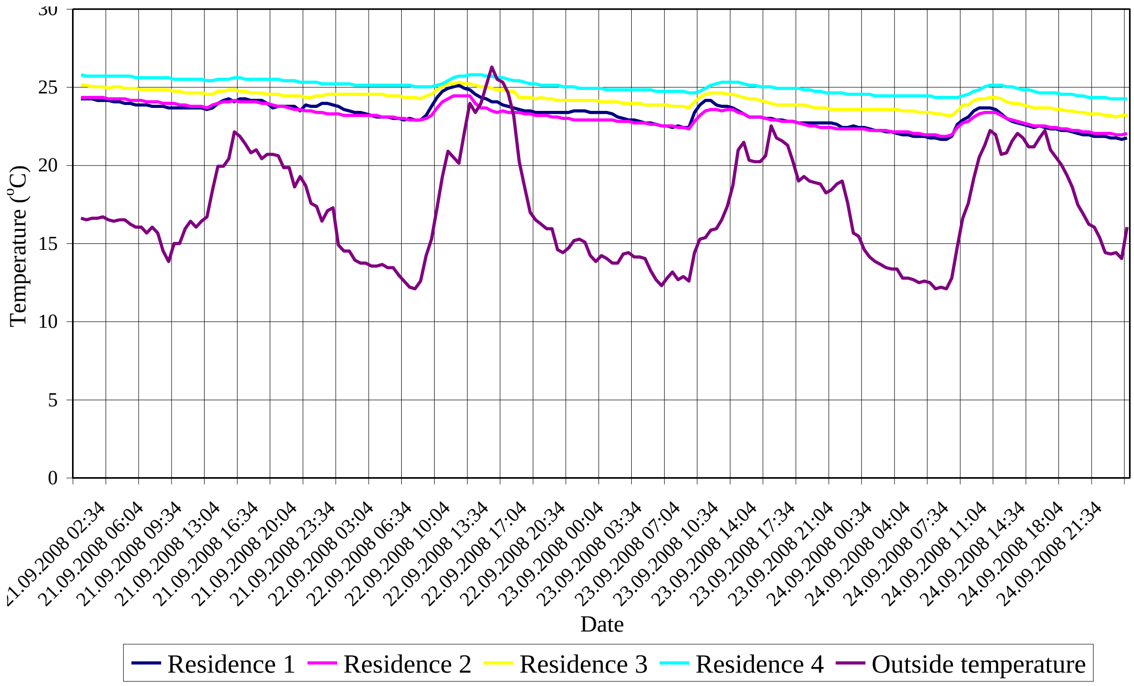

Figure 2. Graphics displaying the temperature values for the month of September.

Evaluation of the data for the period when the residences are not heated

When examining the data obtained from 21-24 September 2008 (when the heating and cooling systems are not in use and the natural ventilation level is at minimum), it is observed that the building that was most affected by the external climate conditions was Residence 1; both Residences 1 and 2 showed similar thermal performances (Figure 2). The floorings and beams are not insulated in Residence 2. The thermal bridges occurring in the floorings and beams do affect the thermal performance of the building and cause the building to show a performance similar to an uninsulated building.

One way variance analysis (ANOVA) using the temperature values was employed to understand whether a significant difference between the thermal performances of the uninsulated Residence 1 and internally insulated Residence 2 exists, based on the hypothesis presented below:

Ho: $\bar{X}1=\bar{X}2$ (α= 0.05) indicates that no significant difference exists between the performance of the groups.

Calculated F value of 1.914 is less than the critical F value of 3.865, as can be seen from Table 2. Therefore, the hypothesis was rejected with 95% reliability. In other words, no significant difference exists between the thermal performance of Residences 1 and 2. Binary combinations were formed for the four residences and variance analyses were performed for each group. Significant differences exist between the thermal performances of the residences belonging to the other binary combinations according to the results presented in Table 2.

When Figure 2 is examined, a smaller fluctuation is observed in Residence 4 when compared with Residence 3. This may be explained by the presence of an enclosed balcony for Residence 4, which also has a higher U - thermal conductivity- value than Residence 3. This balcony, enclosed with glass material, functions as a sunspace.

Table 2. ANOVA results comparing the thermal performance of the residences for the period when heating systems were not in use.

	F Value	Critical F Value	
Residence 1-2	1.914	3.865	There is no significant difference
Residence 1-3	204.505	3.865	There is a significant difference
Residence 1-4	789.313	3.865	There is a significant difference
Residence 2-3	294.748	3.865	There is a significant difference
Residence 2-4	1065.911	3.865	There is a significant difference
Residence 3-4	278.964	3.865	There is a significant difference

When the differences belonging to the maximum and minimum temperature values obtained from the internal living spaces of the four residences were compared, it was observed that the maximum differences were 1.164 °C, 1.445 °C, 2.115 °C and 2.986 °C for Residences 4, 3, 2, and 1, respectively. According to these results, it can be stated that Residence 4 displayed the best performance, followed by Residences 3, 2, and 1.

When the humidity values belonging to the four examined structures are evaluated, it is seen that the least fluctuation occurred in Residence 4 (Figure 3). This condition could be due to two reasons. As the first reason, water vapor diffusion cannot occur between the wall of the room, from which the data are obtained, and the external atmosphere because of the enclosed balcony. Secondly, the insulation material used in this building is extruded polystyrene foam (XPS) with a water vapor diffusion resistance factor (μ) of 80 [10]. This material decreases the water vapor diffusion from the structural coating in Residence 4. The fluctuation is observed to be more dominant in Residence 3 when compared with Residence 2, as shown in Figure 3. XPS was used as the insulation material on the walls of Residence 2 while the insulation material applied on the walls of Residence 3 was expanded polystyrene foam (EPS). EPS, having a water vapor diffusion resistance factor of 30 (TS 825), permits a higher amount of vapor diffusion compared with XPS. The fluctuations occurred most in Residence 1. Since there is no insulation material applied on the walls of Residence 1, the vapor diffusion from the external coating of the structure occurs more in this residence compared with the other buildings.

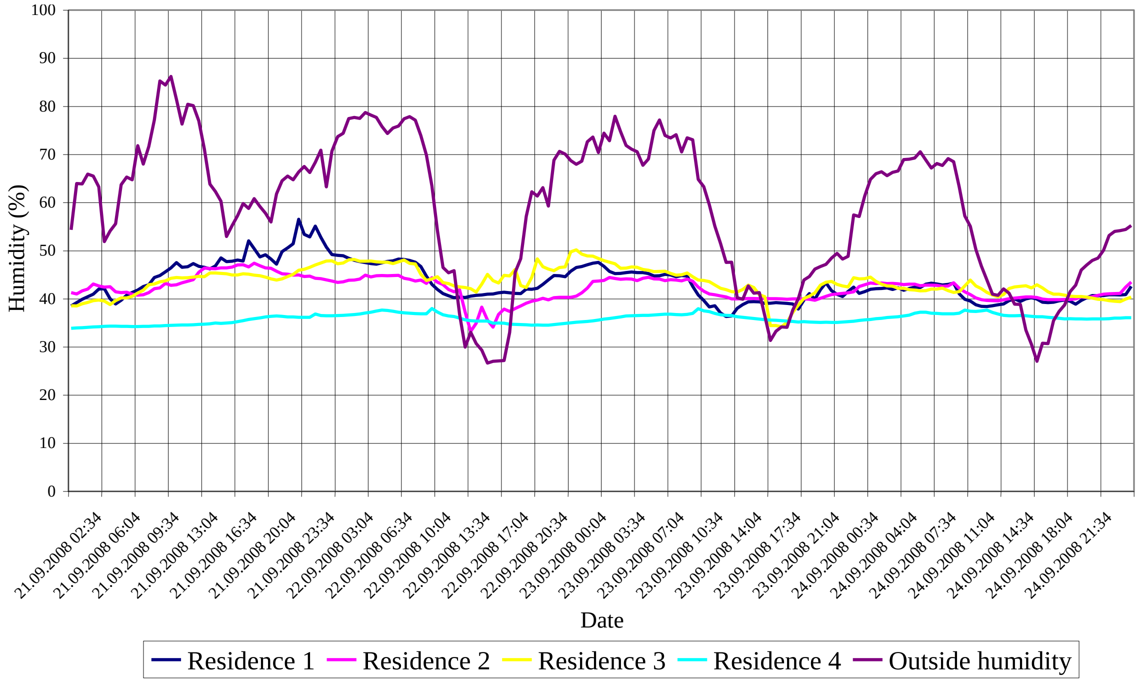

Figure 3. Graphics displaying the humidity values for the month of September.

Evaluation of the data for the period when the residences are heated

To find out which variables are most effective for determining the internal room temperatures during the period of 3-13 February 2009, when the heating systems are in use in the examined four buildings, a regression analysis was performed according to a null hypothesis with 95% level of confidence. The analysis included the internal temperature values, external temperature values, thermostat leveling, amount of coal used, U value for the wall, and boiler water temperature (Table 3).

Table 3. Data for the period when the residences are heated.

	Date	3 hours before the central heating was switched on		3 hours after the central heating was switched on		Thermostat leveling (°C)	Amount of fuel used (kg)	U value of the wall (W/m^2K)	Boiler water temperature (°C)
		Internal temperature (°C)	External temperature (°C)	Internal temperature (°C)	External temperature (°C)				
RES. 1	3 Feb.	21,282	10,455	22,429	6,775	22	25	0,827	50
	4 Feb.	21,664	10,846	22,812	9,176	22	25	0,827	50
	5 Feb.	20,519	8,779	21,569	7,782	22	25	0,827	50
	6 Feb.	21,76	9,077	22,717	8,481	22	15	0,827	50
	7 Feb.	21,664	10,357	22,525	9,571	22	15	0,827	50
	8 Feb.	21,664	10,846	22,621	10,259	22	25	0,827	50
	9 Feb.	20,805	8,879	22,525	7,28	22	25	0,827	50
	10 Feb.	20,138	3,472	21,569	3,893	22	25	0,827	50
	11 Feb.	20,71	10,553	21,664	7,782	22	25	0,827	50
	12 Feb.	20,329	10,063	21,76	7,782	22	25	0,827	50
	13 Feb.	20,329	10,357	21,473	7,682	22	25	0,827	50
RES. 2	3 Feb.	23,1	12,883	22,238	6,573	20	60	0,483	30
	4 Feb.	23,1	10,944	22,908	8,879	20	60	0,483	30
	5 Feb.	23,196	11,722	23,196	9,768	22	60	0,483	35
	6 Feb.	23,388	12,207	23,292	9,077	22	60	0,483	35
	7 Feb.	23,484	10,161	23,196	9,866	21	60	0,483	30
	8 Feb.	23,581	9,965	23,581	10,259	21	60	0,483	30
	9 Feb.	23,677	10,063	23,677	7,179	22	55	0,483	30
	10 Feb.	23,677	5,45	23,292	3,049	22	55	0,483	30
	11 Feb.	22,908	12,207	23,581	7,481	22	55	0,483	30
	12 Feb.	23,1	12,787	22,908	8,182	22	55	0,483	30
	13 Feb.	23,1	11,528	22,621	6,166	21	52	0,483	30
RES. 3	3 Feb.	21,569	12,883	22,717	6,573	24	25	0,407	60
	4 Feb.	22,429	10,553	22,525	8,779	24	25	0,407	60
	5 Feb.	22,717	11,722	22,429	9,669	24	25	0,407	60
	6 Feb.	23,677	14,134	23,484	9,176	24	25	0,407	60
	7 Feb.	23,196	14,23	23,581	9,669	24	25	0,407	60
	8 Feb.	23,1	12,013	24,545	10,259	24	25	0,407	60
	9 Feb.	24,351	8,082	23,388	6,471	24	25	0,407	60
	10 Feb.	23,773	7,882	24,158	3,683	24	25	0,407	60
	11 Feb.	23,292	11,431	23,581	7,481	24	25	0,407	60
	12 Feb.	22,429	13,173	23,292	8,481	24	25	0,407	60
	13 Feb.	23,1	11,819	23,581	6,674	24	25	0,407	60
RES. 4	3 Feb.	24,255	13,654	23,966	7,28	24	37,5	0,423	55
	4 Feb.	25,028	11,431	24,931	8,779	25	37,5	0,423	55
	5 Feb.	25,319	11,722	25,222	9,768	25	37,5	0,423	55
	6 Feb.	26	14,709	25,61	9,077	25	25	0,423	55
	7 Feb.	25,902	13,558	25,319	9,077	24	25	0,423	55
	8 Feb.	25,319	12,304	25,222	7,882	24	37,5	0,423	55
	9 Feb.	25,222	9,866	25,125	6,775	25	25	0,423	55
	10 Feb.	24,835	6,573	24,545	39,85	25	37,5	0,423	60
	11 Feb.	24,835	13,076	24,545	7,983	25	25	0,423	55
	12 Feb.	24,738	13,173	24,641	8,481	24	37,5	0,423	55
	13 Feb.	24,835	11,722	24,641	7,582	25	37,5	0,423	55

The results indicated that there is no significant correlation among these variables. Internal and external temperature values 3 hours before and after the central heating was switched on were determined in each of the residences for 11 days. In the regression analysis performed according to this finding, the variables were detected to be 92% effective on the results obtained. Since P values are less than 0.05, the inner room temperature value three hours before the central heating was switched on and the U value of the wall were determined to have significant effects on the inner room temperature value three hours after the central heating was switched on (Table 4).

When examining the data from the internal and external spaces of the residences during 3-13 February, the smallest fluctuation is observed for Residence 4 (Figure 4). On the other hand, Residence 3 had the lowest U value among the four buildings examined. Thus, although the best performance was expected from Residence 3, Residence 4 was the building that was least affected by the external temperature differences because of the existence of its enclosed balcony. This balcony, enclosed by using glass material, increased the heat gain and enabled the maintenance of the internal temperature of the related room.

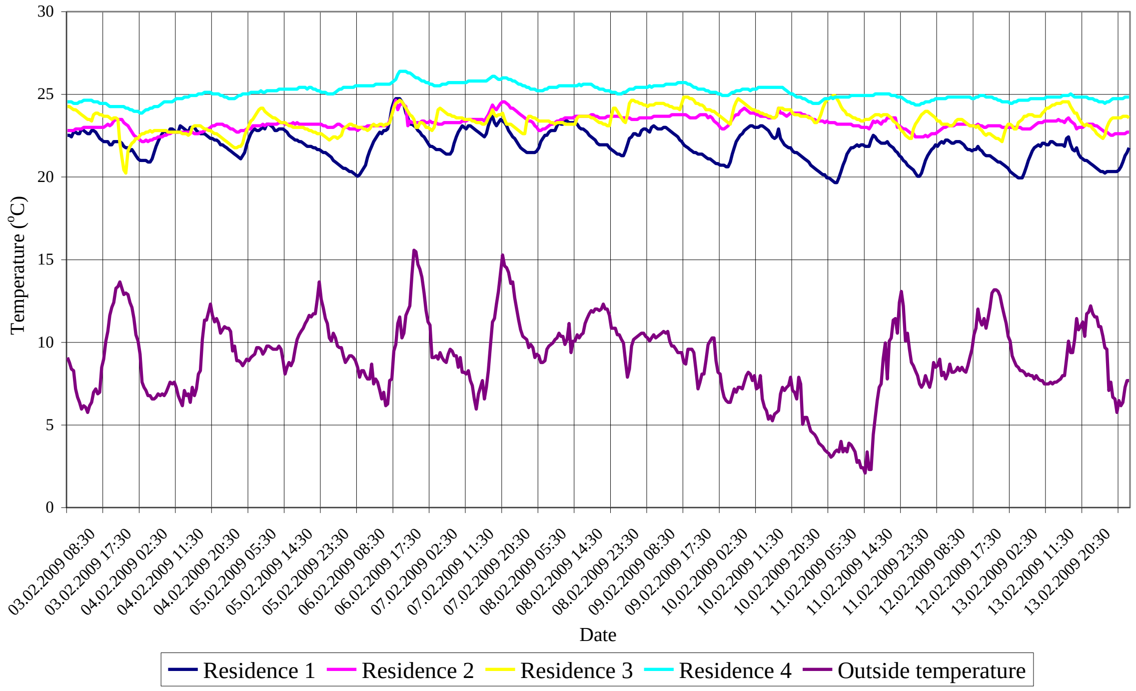

Figure 4. Graphics displaying the temperature values for the month of February.

Residence 2, with internal insulation application, is affected by the external temperature and displays a behavior similar to the uninsulated Residence 1 according to the September data, when the heating in the residences was not in use. On the other hand, when the February data are examined, the fluctuation of Residence 2 is observed to be significantly less. In other words, the building was less affected by the external climate conditions in the period when the heating system was in use. According to this result, the insulation used in the internal space of Residence 2 is found to fulfill its thermal mass duty. The fluctuation was observed to be highest for Residence 1 as can be seen from the graphic in Figure 4. Thus, this uninsulated residence is the building that is most affected by the external temperature changes. It is observed that Residence 2 and Residence 3 have similar fluctuations. Although Residence 3 has a lower U value than Residence 2, the insulation material applied in the internal space of Residence 2 stored the heat and contributed to the thermal performance of the building.

ANOVA was used to examine binary combinations for the four residences to understand whether a significant difference exists between the inner room temperature values obtained from the residences based on the hypothesis presented below:

H_o: $\bar{X}_1 = \bar{X}_2$ ($\alpha = 0.05$) indicates that no significant difference exists between the performance of the groups.

Table 4. The results of the regression analysis on the variables that affect the thermal performance of the residences.

Regression Statistics	
Multiple R	0,961283069
R Square	0,924065138
Adjusted R Square	0,909300026
Standard Error	0,4759295
Observations	44

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	99,23140255	14,17591465	62,58436361	3,0453E-18
Residual	36	8,154319993	0,226508889		
Total	43	107,3857225			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower %95*	*Upper %95*	*Lower95,0%*	*Upper 95,0%*
Intercept	0.438989247840	3,353245027	0,130914754	0,896571604	-6,361706828	7,239685324	-6,361706828	7,239685324
Ext. temp-3 h. before switching	-0,006498509	0,036156058	-0,179734989	0,858368499	-0,079826393	0,066829375	-0,079826393	0,066829375
Int. temp-3 h. before switching	1,058879186	0,124635414	8,495813105	3,99934E-10	0,806106851	1,31165152	0,806106851	1,31165152
Ext. temp-3 h. after switching	0,012129937	0,016294025	0,744440801	0,461441965	-0,020915876	0,04517575	-0,020915876	0,04517575
Thermostat leveling	0,040243658	0,162758825	0,247259455	0,806112175	-0,289846536	0,370333853	-0,289846536	0,370333853
Amount of fuel used	-0,004613921	0,01733055	-0,266230489	0,791580647	-0,039761904	0,030534063	-0,039761904	0,030534063
U value of the wall	-2,741309642	0,908492287	-3,017427534	0,004659329	-4,583817387	-0,898801897	-4,583817387	-0,898801897
Boiler water temperature	-0,029018478	0,025406097	-1,142185593	0,260916973	-0,080544429	0,022507474	-0,080544429	0,022507474

ANOVA results performed according to the inner room temperature values obtained three hours before and after switching on the central heating are the same as seen in Table 5 and 6. According to these results, only the thermal performances of Residences 2 and 3 displayed similarities. A total amount of 632 kg and 275 kg coal was used for Residences 2 and 3, respectively. In other words, the amount of coal used in the internally insulated Residence 2, with a U value of 0.483 W/m^2K, was 2.3 times the amount of coal used in Residence 3 with a U value of 0.407 W/m^2K; however, the thermal performances of these two buildings had similar values. It can be stated that both the higher U value and the thermal bridges on the structural coating of Residence 2 required more coal to be used compared to Residence 3. As the U value increases, it is known that the amount of heat lost from a structural element also increases. Thus, more coal was used in Residence 2 to reproduce the heat lost from the wall and thermal bridges.

Table 5. ANOVA results comparing the thermal performance of the residences 3 hours before the central heating was switched on.

	F Value	Critical F Value	
Residence 1-2	125.133	4.351	There is a significant difference
Residence 1-3	48.375	4.351	There is a significant difference
Residence 1-4	284.341	4.351	There is a significant difference
Residence 2-3	1.0034	4.351	There is no significant difference
Residence 2-4	108.265	4.351	There is a significant difference
Residence 3-4	55.612	4.351	There is a significant difference

Table 6. ANOVA results comparing the thermal performance of the residences 3 hours after the central heating was switched on.

	F Value	Critical F Value	
Residence 1-2	22.278	4.351	There is a significant difference
Residence 1-3	23.948	4.351	There is a significant difference
Residence 1-4	162.873	4.351	There is a significant difference
Residence 2-3	1.161	4.351	There is no significant difference
Residence 2-4	82.079	4.351	There is a significant difference
Residence 3-4	38.776	4.351	There is a significant difference

CONCLUSION

This study reveals the degree of positive effects obtained by using insulation on the thermal performance of the structures. The data obtained during the periods when the building was both heated and not heated from the four examined residences indicates that the uninsulated building is the residence that is most affected by the external climate conditions. The building with internally applied insulation behaves like an uninsulated building when the heating systems are not in use. The unprotected condition of the wall against the external atmospheric conditions and the thermal bridges occurring on the structural coating can explain the aforementioned result. Nonetheless, it was observed that the material used in the inner surface of the walls, belonging to the internally insulated building, stored the heat and enabled the residence to be less affected by the external climate conditions. Although this result is considered as a positive factor for the internally insulated buildings, precautions should be taken to prevent the occurrence of condensation and thermal bridges. The results of the study further indicate that the building with the enclosed balcony is least affected by the external temperature changes compared to the building with a lesser U value. The balcony, enclosed by using glass material, did increase the heat gain and enabled the maintenance of the inner temperature values of the related room. Although volumes enclosed by using glass materials help to prevent heat from escaping to the external environment during the winter months, it might cause the internal room temperature of the building to exceed comfortable conditions in the summer months. Thus, the need to implement solar control arises in this situation.

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Dr. Nese Dikmen is assistant professor of architecture, Suleyman Demirel University since 2006. Her principal areas of research lie particularly in the fields of reconstruction after disasters, traditional and contemporary construction techniques and thermal performance of buildings. She is a member of i-Rec (innovation and research for reconstruction) and Turkish Constructional Steelwork Association. She holds a master's of art from University of Hacettepe and PhD in building science in architecture from Middle East Technical University (METU).