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Evaluating the Effect of Building Envelope on Thermal Performance in Cold and Warm Climate Regions of Turkey

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ABSTRACT

Buildings consume significant amount of energy to keep interior environment at comfort conditions. Most heat losses occur in building envelope, causing the interior comfort conditions to be affected negatively. This leads buildings to consume more energy for keeping interior temperature at comfort level. This paper aims to propose building envelope details that limits the energy consumption and meets the required thermal comfort conditions for Erzurum city, locating at the coldest region in Turkey, and Mardin city, locating at the warmest region in Turkey. There is limited information about energy conservation of buildings in Erzurum city, and comparing of modern and traditional materials' performances for both warm and cold regions in Turkey. Traditional buildings in Erzurum and Mardin cities have been constructed mostly as masonry which is traditional construction technic, whereas modern buildings are mostly built as reinforced concrete structural system. In this paper, the effect of building envelope on thermal performance has been analyzed for Erzurum and Mardin cities. 25 different building envelope detail alternatives, made up of modern and traditional materials with different insulation and covering materials, have been designed. Reinforced concrete, autoclaved aerated concrete and perforated brick have been chosen as a core material for modern building envelope details, whereas masonry stone, adobe brick and wooden frame have been chosen for traditional building envelope details. In the second part of study, different building envelope alternatives have been modelled in Design Builder software with Energy Plus simulation engine. Heating, cooling and total energy loads of these alternatives have been calculated for Erzurum and Mardin cities. The results of simulation are provided along with the evaluation and comparison. It was showed that adobe brick alternative has the lowest total energy consumption among all building envelope alternatives for both cities.

1. Introduction

Energy consuming is one of the most critical issues in the world because fossil fuels which are main sources for creating energy are limited. That's why, the energy conservation is getting more important especially for construction industry which has a big part in the market. If there is a weak part in building component which cause comfort conditions to get deteriorated, buildings consume large amount of energy to meet the interior comfort conditions.

Thermal losses cause interior comfort environment to be affected negatively and most of them occur in the building envelope [1]. That's why, to prevent heat loses and use the energy

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efficiently, some precautions should be taken in building envelope detail. After recent innovations, materials that has low heat transmittance quality have been widely chosen for building envelope designs. The purpose is to reduce the rate of heat traveling through the wall by conduction. This is known as thermal transmittance (U-value) of the wall [2]. However, another method that building envelope acts as thermal barrier is thermal capacity. Thermal capacity is described as a necessary amount of heat to raise a unit volume of the wall with a unit temperature. Exterior walls with high thermal capacity require more amount of heat to increase its temperature than walls with low thermal capacity. That’s why, exterior walls with higher mass have greater heat storage capacity. The duration of the heat loss is directly proportional to the amount of heat stored by the wall. Therefore, walls with high heat storage capacity react late to temperature changes. This causes the building envelope to be able to meet the interior temperature comfort conditions [3]. The time delay on transmission of temperature drop from outside to inside of the building envelope is referred as time lag. The longer this delay is, the better thermal performance of building envelope. This thermal inertia of building envelope’s transmission of temperature changes from outside to inside is called as damping [4].

There is limited information about the effect of building envelope’s physical qualities on thermal performance in cold regions and comparing of modern and traditional materials’ performances for both warm and cold regions in Turkey. Erzurum is located at the coldest climate region in Turkey, whereas Mardin is at warmest climate region. Erzurum is under the influence of Siberian anticyclone and Basra cyclone and in the winter season the effect of Siberian anticyclone is seen in Erzurum [5]. Because of harsh climate, roads are closed to transportation and education is suspended for several days in winter season [6]. This also causes buildings to consume significant amount of energy to keep interior environment at thermal comfort conditions. In Mardin, summers are very dry and hot, and winters are rainy and mild. It is under the influence of the Desert Climate (Basra Low Pressure) [7]. Because of extreme hot summer days, buildings consume significant amount of energy for cooling.

The traditional buildings of Erzurum were mostly constructed as masonry, and its plans and envelopes were designed as adapting to the outside harsh environment. Because of extremely cold climate conditions, traditional buildings have been constructed with materials that can be easily found and suitable for outside environment [8]. Likewise, traditional buildings in Mardin have been formed to respond outside hot climate and protect interior environment from overheating especially during summer days. Mostly, stone, adobe and wood materials were used for traditional buildings in both Erzurum and Mardin, and the thickness of load-bearing wall is between 70-115 cm [9]. After recent innovations, reinforced concrete structural system have been used for construction. Besides, different insulation and covering materials are used to meet the thermal comfort conditions. Because of new structural system and insulation materials, the thickness of exterior wall has been decreased to 20-30 cm [10]. However, these precautions in building envelope is not enough for energy conservation. Most of modern buildings in Erzurum and Mardin hardly meet thermal comfort conditions under the influence of harsh winter and hot summer seasons [11, 12]. Based on this information, to limit energy consumption effectively, the effect of traditional and modern building envelopes’ thermophysical properties on energy conservation should be analyzed. Therefore, the aim of this paper is to evaluate the heating, cooling and total energy loads of traditional and modern building envelopes, which consist of different materials, for Erzurum and Mardin cities, and determine how these building envelopes affect the energy loads along with the reasons. Unlike the previous researches, this study determines the physical properties of the materials, which are coming together in different building envelope alternatives, their effects on the energy loads for the hot and cold climatic zones, and defines the causes of these effects as well as evaluating them comparatively.

2. Methodology

This paper consists of two main parts. First part introduces information about model, details of building envelope alternatives and simulation process. In this part, 25 different building envelope alternatives, made up of traditional and modern materials, are provided along with its details and thermophysical properties. Second part presents simulation results of modelled building envelope alternatives' yearly heating, cooling and total energy loads for Erzurum and Mardin cities together with evaluation and comparison.

A. Information About the Model

In this study, all building envelope alternatives were modelled as 5 meters long, 5 meters width and 3 meters height. The windows were accepted as wood joinery in all facades and transparency rate was taken as 30%. The orientation is shown in Fig. 1.

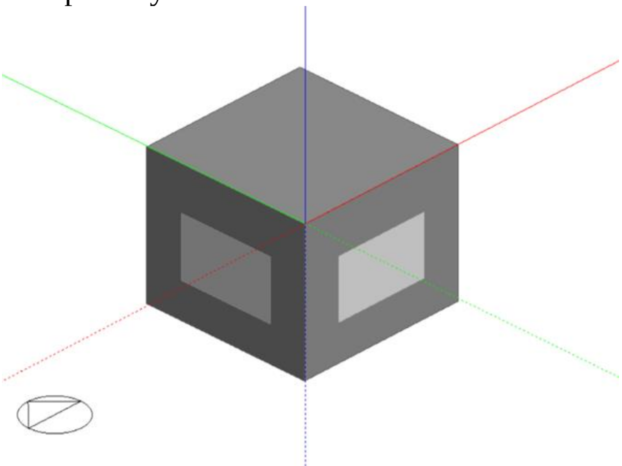

Fig. 1. Model which is used for simulation

B. Information About Building Envelopes

In this research, reinforced concrete, perforated brick and autoclaved aerated concrete have been chosen as a core material for modern building envelope details. Heat insulation which is integrated to exterior surface of core have been selected as Extruded Polystyrene (XPS) and glass wool. Gypsum plaster was used as the inner surface coating material, whereas cement-based plaster, stone covering, wood covering were used for facades. The thickness of building envelope's materials has been determined as keeping total heat transfer coefficients of building envelopes alternatives under or equal to 0,4 $W/m^2.K$ according to TS 825 rules, thermal insulation requirements for buildings [13].

Stone, adobe brick and wood materials have been chosen for traditional building envelope detail alternatives. Building envelopes with stone and adobe brick have been designed as masonry wall system, that is defined as load-bearing wall. Lime mixed plaster and adobe mixed plaster were used for inner and outer surface of masonry stone and adobe brick load-bearing walls. The building envelope, which has wooden bearing system, are formed with wooden frame structural system and 5x20 cm wooden load-bearing elements are used. This traditional construction technic is called hımış (bağdadi) that is inserting wood laths in each two or three centimeters among timber frames of wall and filling it with adobe mixed plaster. It has been decided that three alternatives would be formed for wooden frame system which are stone filled, adobe filled and air gapped building envelope alternatives. Both inner and outer surfaces of building envelope were covered with wood. Since the thermal mass effect of the building envelope alternatives was also taken into consideration, the desired value of total heat transfer coefficients, 0.4 W / m2.K, provided by TS 825 for building envelopes were not required. In Table 1, modern building envelope alternatives, and in Table 2, traditional building envelope alternatives as well as d (thickness, cm), λ (thermal conductivity coefficient, W / m.K), c

(specific heat, J / kg.K), density (kg/m^3), U (total heat transfer coefficient, W / m2.K) values have been given along with section details of alternatives.
Total heat transfer coefficients (U-value) of modern and traditional building envelope alternatives are given in Fig. 2.

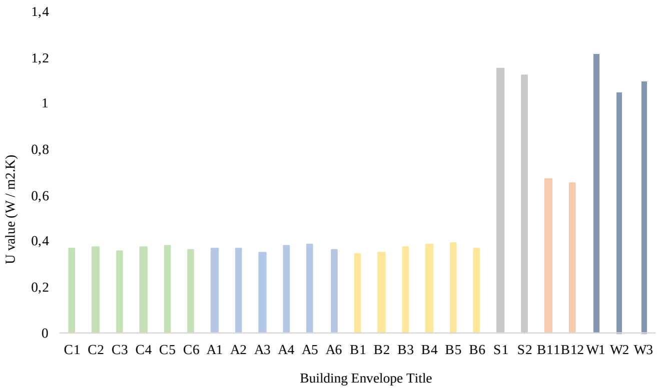

Fig. 2. Total heat transfer coefficients (U-value) of modern and traditional building envelope alternatives.

C. Information About Simulation

In this research, Design Builder software with EnergPlus simulation engine was used for calculations. TS 825 rules, thermal insulation requirements for buildings, were used as data for calculating total heat transfer coefficients of building envelope alternatives in Erzurum and Mardin cities. According to TS 825 rules, for Erzurum, which has been one of the coldest cities in Turkey, the total heat transfer coefficient of building envelope should be 0,4 W/m^2.K, whereas in Mardin, it should be 0,6 W/m^2.K [13].
The model was designed as studio apartment and it was assumed that one person is living in the apartment. Floor and roof surfaces were determined as “adiabatic” which means no heat loss occurs in these surfaces. Erzurum and Mardin meteorological data were downloaded in simulation engine and all energy loads were calculated for a year.
All models were assumed that it is heated by natural gas. It is known that air conditioning systems are rarely used in traditional buildings. However, in this paper, it is assumed that all models have been cooled by electrically. The indoor comfort temperature was accepted as 21 ^{o}C for heating and 25 ^{o}C for cooling. It was assumed that the heating systems
would be activated when the indoor temperature drops below 12 ° C and cooling systems would be activated when the temperature exceeds 28 ° C.

3. Results of Heating, Cooling and Total Energy Loads of Building Envelope Alternatives for Erzurum and Mardin Cities

A. Simulation Results in Erzurum City

According to simulation results, B11 and B12 (adobe brick core) alternatives were detected as the lowest heating loads under Erzurum climate conditions. This is followed by C1 to C6 (reinforced concrete core) alternatives. B1 to B6 (perforated brick core), A1 to A6 (autoclaved aerated concrete core) and S1 and S2 (masonry stone core) alternatives’ heating loads are close to each other. W1, W2, W3 alternatives (wooden frame system) have the highest heating loads, however; W2 (filled with adobe brick) alternative was detected as having the lowest heating loads among wooden frame alternatives (Fig. 3).

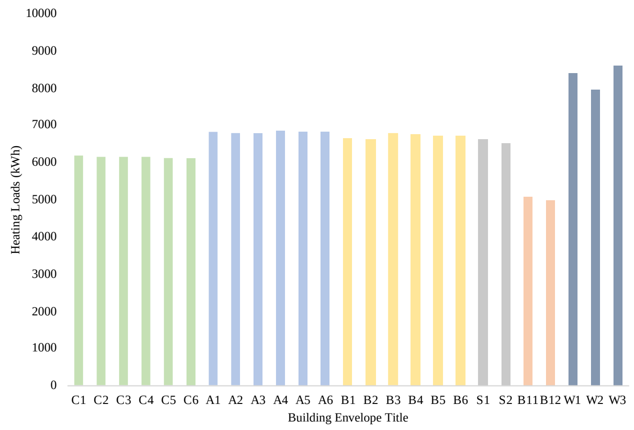

Fig. 3. Heating loads in Erzurum City

Traditional building envelope alternatives consume less energy for cooling than modern building envelope alternatives. S1 and S2 (masonry stone core) alternatives come the first as having the lowest cooling loads. This continues with B11, B12 (adobe brick core) and W1, W2, W3 (wooden frame system) alternatives. However, W3, which has air gap between wooden structures, demonstrates higher cooling load among traditional building envelope alternatives. This order is followed by C1 to C6 (reinforced concrete cores), A1 to A6 (autoclaved aerated concrete core) and B1 to B6 (perforated brick cores) respectively (Fig. 4).

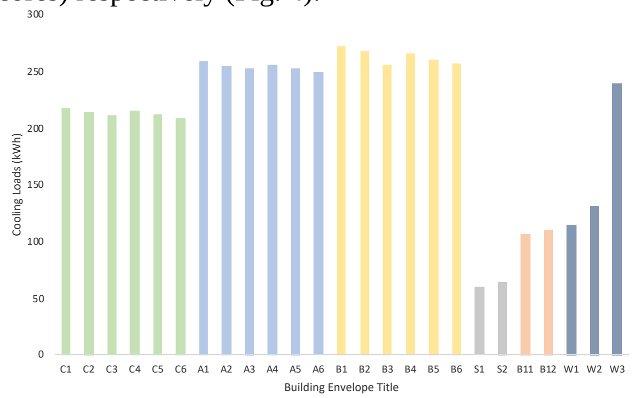

Fig. 4. Cooling loads in Erzurum City

According to total energy loads, B11 and B12 (adobe brick core) shows the best performance by having the lowest energy loads among all the building envelope alternatives (Fig. 5). The second alternative having less energy loads is S1 and S2 (masonry stone core), and it is followed by C1 to C6 (reinforced concrete core) alternatives. However, there is small difference of total energy loads between these two alternatives. Building envelope alternatives with the highest total energy loads are B1 to B2 (perforated brick core) and A1 to A6 (autoclaved aerated concrete core) which having the close amounts between each other.

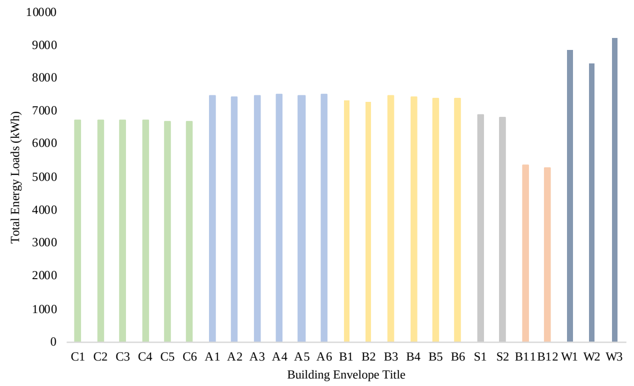

Fig. 5. Total energy loads in Erzurum City

B. Simulation Results in Mardin City

According to simulation results, A1 and A2 (adobe brick core) alternatives showed that they consume the least amount of energy for heating in Mardin city. It is followed by C1 to C6 (reinforced concrete core), B1 to B6 (perforated brick core), A1 to A6 (autoclaved aerated concrete core) and S1, S2 (masonry stone core) alternatives respectively (Fig. 6). The highest heating load is in W1, W2, and W3 (wooden frame system) alternatives, however; W2, wooden frame system filled with adobe brick, alternative has the lowest heating load among wooden frame alternatives.

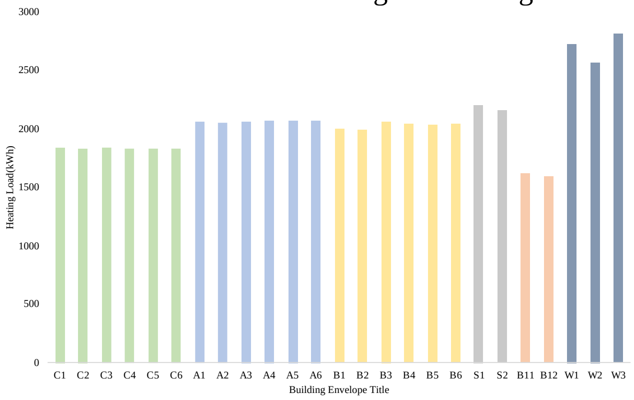

Fig. 6. Heating loads in Mardin City

In Mardin climate conditions, traditional building envelope alternatives require less energy for cooling. B11 and B12 (adobe brick core) have the lowest energy load. It is followed by S1, S2 (masonry stone core) and W1, W2, W3 (wooden frame system) alternatives respectively. B1 to B6 (reinforced concrete core) alternatives come in fourth place, whereas A1 to A6 (autoclaved aerated concrete core) and B1 to B6 (perforated brick core) alternatives have the highest cooling load and the amount of energy they consume is close to each other (Fig. 7).

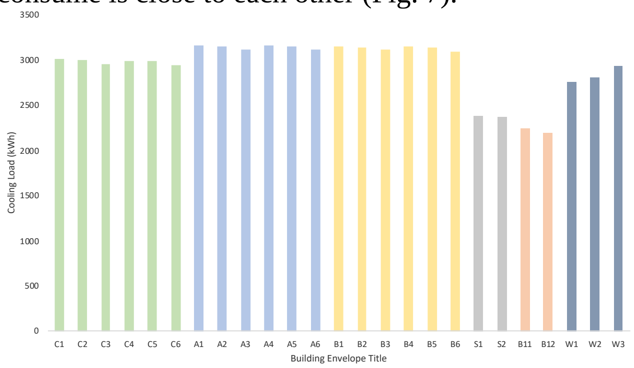

Fig. 7. Cooling loads in Mardin City

According to results, B11 and B12 (adobe brick core) alternatives have the lowest total energy load, whereas S1 and S2 (masonry stone core) alternatives have the second lowest total energy load. It is followed by C1 to C6 (reinforced concrete core), A1 to A6 (autoclaved aerated concrete core) and B1 to B6 (perforated brick core) respectively. The amount of total energy loads of A1 to A6 (autoclaved aerated concrete core) and B1 to B6 (perforated brick core) are close to each other. W1, W2, and W3 (wooden frame system) alternatives were detected as having the highest amount of total energy, however; W3 alternative, having air gap between wooden structures, consumes the highest amount of total energy in a year (Fig. 8).

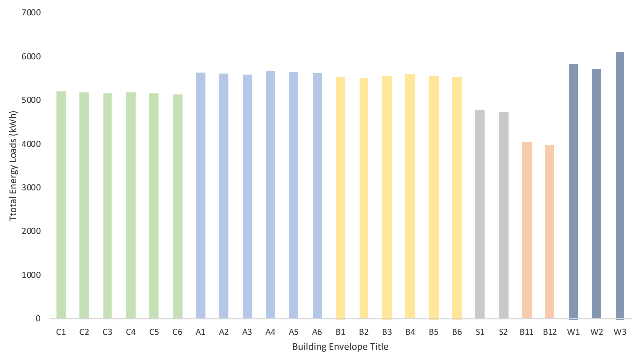

Fig. 8. Total energy loads in Mardin City

C. Comparison between Building Envelope Alternatives

In Erzurum, the majority of energy consuming is composed of heating loads. Building envelope alternatives with adobe brick core demonstrate the lowest heating and total energy loads, whereas building envelope alternatives with masonry stone core have the lowest cooling load.

The total amount of energy consumed by building envelope alternatives is sorted in order from minimum to maximum in Fig. 9.

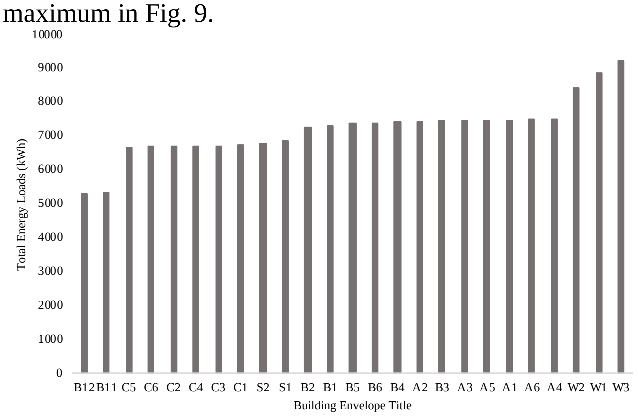

Fig. 9. Total energy loads in Erzurum from minimum to maximum

In Mardin, cooling load dominates in energy consuming. Building envelope alternatives with adobe brick core were detected as having the lowest heating, cooling and total energy loads among all alternatives. The total amount of energy consumed by building envelope alternatives is sorted in order from minimum to maximum in Fig. 10.

According to results, the building envelope alternatives with the same core and coating material but different thermal insulations have been compared. It was detected that glass wool thermal insulation demonstrates the most favorable results for building envelope with reinforced concrete core alternatives, whereas XPS shows the most favorable for building envelope with autoclaved aerated concrete core and perforated brick core alternatives in both Erzurum and Mardin cities. The thickness of glass wool is 8 cm, whereas the thickness of XPS is 2 cm in autoclaved aerated concrete core alternatives and 5 cm in perforated brick core alternatives.

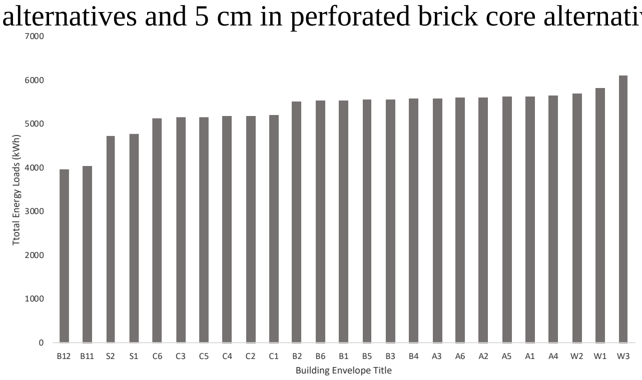

Fig. 10. Total energy loads in Mardin from minimum to maximum

In modern building envelope alternatives, according to comparison among the alternatives which have the same the core, interior coating and thermal insulation materials but different exterior coating materials like cement plaster, stone and wood, the most favorable performance was achieved by the stone coating in Erzurum climate and the wooden coating in Mardin climate.
According to traditional building envelope with adobe brick and masonry stone alternatives, alternatives with adobe plaster demonstrate more favorable than alternatives with lime plaster in both Erzurum and Mardin cities. In wooden frame system alternatives, the alternative filled with adobe brick between structures gives the most favorable result than alternatives with masonry stone and air gap.

4. Conclusion

In this paper, 25 different building envelope alternatives have been designed, and modelled in Design Builder software. These models' yearly heating, cooling and total energy loads have been calculated by EnergyPlus simulation engine under climates of Erzurum and Mardin, which are the coldest and the warmest regions in Turkey. Modern building envelope alternatives have been designed to provide the required thermal conductivity coefficient value for Erzurum and Mardin according to TS 825, thermal insulation requirements for buildings. It has been detected that traditional building envelopes could not provide the desired value due to materials' thermal conductivity coefficients.
According to results, building envelope alternatives with adobe brick core showed the lowest total energy load in both Erzurum and Mardin. However, it cannot provide the total thermal conductivity coefficient (U value) specified in the standard. The adobe brick is a material with high heat storage capacity because it has a high mass and density. The time delay that building envelope transmits temperature differentiation from outside to inside is high. Therefore, it requires less heating and cooling loads than other building envelope alternatives to provide internal comfort conditions under the challenging conditions of cold and hot climate zones. Therefore, not only the heat transfer coefficient (U value), but also the thermal mass has a significant effect in hot and cold climatic zones. When the results are examined, it is detected that traditional building envelope alternatives do not provide U value but give a more positive result. Therefore, it is concluded that thermal mass has more effect on heating, cooling and total energy loads.

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Table 1.
Modern building envelope alternatives and its coefficients

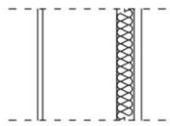
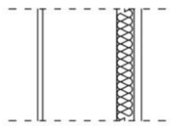
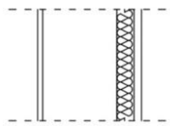
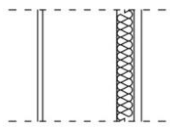
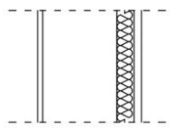
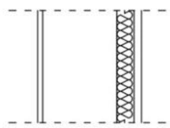
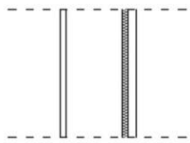
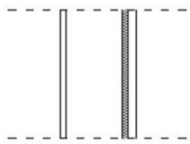
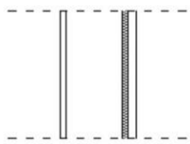
Building Envelope Title	**Layers**	**Thickness d (cm)**	**Thermal Conductivity λ (W / m.K)**	**Specific Heat c (J / kg.K)**	**Density p (kg/m^3)**	**Total Heat Transfer Coefficient U (W / m^2.K)**	**Section Detail**
C1	Gypsum Plaster	2	0,51	960	1120	0,371	
	Reinforced Concrete	30	0,51	1000	1400		
	XPS	7	0,03	1400	35		
	Cement Plaster	3	0,72	840	1760		
C2	Gypsum Plaster	2	0,51	960	1120	0,375	
	Reinforced Concrete	30	0,51	1000	1400		
	XPS	7	0,03	1400	35		
	Stone Covering	4	2,80	1000	2600		
C3	Gypsum Plaster	2	0,51	960	1120	0,356	
	Reinforced Concrete	30	0,51	1000	1400		
	XPS	7	0,03	1400	35		
	Wood Covering	3	0,19	2390	700		
C4	Gypsum Plaster	2	0,51	960	1120	0,378	
	Reinforced Concrete	30	0,51	1000	1400		
	Glass Wool	8	0,035	1000	25		
	Cement Plaster	3	0,72	840	1760		
C5	Gypsum Plaster	2	0,51	960	1120	0,382	
	Reinforced Concrete	30	0,51	1000	1400		
	Glass Wool	8	0,035	1000	25		
	Stone Covering	4	2,80	1000	2600		
C6	Gypsum Plaster	2	0,51	960	1120	0,362	
	Reinforced Concrete	30	0,51	1000	1400		
	Glass Wool	8	0,035	1000	25		
	Wood Covering	3	0,19	2390	700		
A1	Gypsum Plaster	2	0,51	960	1120	0,368	
	Autoclaved Aerated Concrete	20	0,11	896	2800		
	XPS	2	0,03	1400	35		
	Cement Plaster	3	0,72	840	1760		
A2	Gypsum Plaster	2	0,51	960	1120	0,372	
	Autoclaved Aerated Concrete	20	0,11	896	2800		
	XPS	2	0,03	1400	35		
	Stone Covering	4	2,80	1000	2600		
A3	Gypsum Plaster	2	0,51	960	1120	0,353	
	Autoclaved Aerated Concrete	20	0,11	896	2800		
	XPS	2	0,03	1400	35		
	Wood Covering	3	0,19	2390	700		

Table 1 (continued).
Modern building envelope alternatives and its coefficients

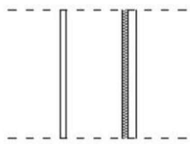
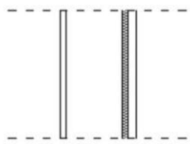
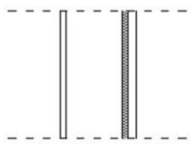
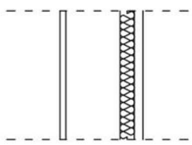
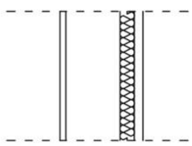
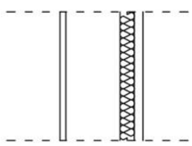
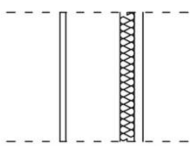
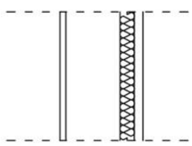
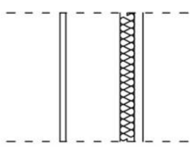
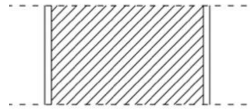
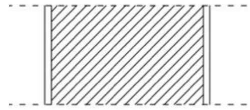
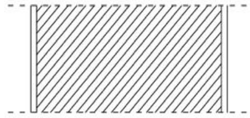
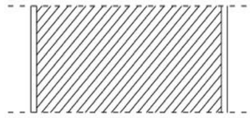
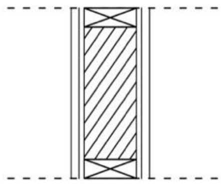
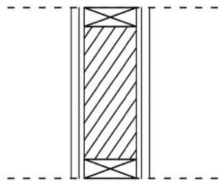
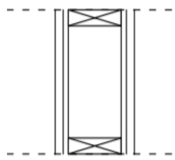
Building Envelope Title	**Layers**	**Thickness d (cm)**	**Thermal Conductivity λ (W / m.K)**	**Specific Heat c (J / kg.K)**	**Density p (kg/m^3)**	**Total Heat Transfer Coefficient U (W / m^2.K)**	**Section Detail**
A4	Gypsum Plaster	2	0,51	960	1120	0,382	
	Autoclaved Aerated Concrete	20	0,11	896	2800		
	Glass Wool	2	0,035	1000	25		
	Cement Plaster	3	0,72	840	1760		
A5	Gypsum Plaster	2	0,51	960	1120	0,386	
	Autoclaved Aerated Concrete	20	0,11	896	2800		
	Glass Wool	2	0,035	1000	25		
	Stone Covering	4	2,80	1000	2600		
A6	Gypsum Plaster	2	0,51	960	1120	0,365	
	Autoclaved Aerated Concrete	20	0,11	896	2800		
	Glass Wool	2	0,035	1000	25		
	Wood Covering	3	0,19	2390	700		
B1	Gypsum Plaster	2	0,51	960	1120	0,349	
	Perforated Brick	19	0,30	840	1000		
	XPS	5	0,03	1400	35		
	Cement Plaster	3	0,72	840	1760		
B2	Gypsum Plaster	2	0,51	960	1120	0,353	
	Perforated Brick	19	0,30	840	1000		
	XPS	5	0,03	1400	35		
	Stone Covering	4	2,80	1000	2600		
B3	Gypsum Plaster	2	0,51	960	1120	0,378	
	Perforated Brick	19	0,30	840	1000		
	XPS	5	0,03	1400	35		
	Wood Covering	3	0,19	2390	700		
B4	Gypsum Plaster	2	0,51	960	1120	0,388	
	Perforated Brick	19	0,30	840	1000		
	Glass Wool	6	0,035	1000	25		
	Cement Plaster	3	0,72	840	1760		
B5	Gypsum Plaster	2	0,51	960	1120	0,392	
	Perforated Brick	19	0,30	840	1000		
	Glass Wool	6	0,035	1000	25		
	Stone Covering	4	2,80	1000	2600		
B6	Gypsum Plaster	2	0,51	960	1120	0,371	
	Perforated Brick	19	0,30	840	1000		
	Glass Wool	6	0,035	1000	25		
	Wood Covering	3	0,19	2390	700		

Table 2.
Traditional building envelope alternatives and its coefficients

Building Envelope Title	Layers	Thickness d (cm)	Thermal Conductivity λ (W / m.K)	Specific Heat c (J / kg.K)	Density p (kg/m³)	Total Heat Transfer Coefficient U (W / m².K)	Section Detail
S1	Lime Plaster	3	0,80	1000	1600	1,153	
	Masonry Stone	70	1,40	840	2200		
	Lime Plaster	3	0,80	1000	1600		
S2	Adobe Plaster	3	0,52	180	2050	1,126	
	Masonry Stone	70	1,40	840	2200		
	Adobe Plaster	3	0,52	180	2050		
B11	Lime Plaster	3	0,80	1000	1600	0,671	
	Adobe Brick	95	0,75	880	1730		
	Lime Plaster	3	0,80	1000	1600		
B12	Adobe Plaster	3	0,52	180	2050	0,653	
	Adobe Brick	95	0,75	880	1730		
	Adobe Plaster	3	0,52	180	2050		
W1	Wood Covering	3	0,19	2390	700	1,218	
	MDF Board	2	0,15	2500	560		
	Stone Filling	20	1,40	840	2200		
	MDF Board	2	0,15	2500	560		
	Wood Covering	3	0,19	2390	700		
W2	Wood Covering	3	0,19	2390	700	1,050	
	MDF Board	2	0,15	2500	560		
	Adobe Filling	20	0,75	880	1730		
	MDF Board	2	0,15	2500	560		
	Wood Covering	3	0,19	2390	700		
W3	Wood Covering	3	0,19	2390	700	1,101	
	MDF Board	2	0,15	2500	560		
	Air Gap	20					
	MDF Board	2	0,15	2500	560		
	Wood Covering	3	0,19	2390	700		