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The Effect of Cross-Laminated Timber (CLT) Material on Building Heating-Cooling Loads in a Temperate Humid Climate Zone

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Abstract

Cross Laminated Timber (CLT) is a structural wood material that is renewable, nature-friendly, and with a great number of advantages. The aim of the study is to examine the energy performance of a building that has been constructed by means of CLT materials and compare it to that of another one with traditional construction materials. In the study, the energy loads of a model building, the exterior walls of which had been made from CLT, and different thermal insulation materials were analyzed through the DesignBuilder simulation program. Also, the thermal conductivity coefficients of 22 different CLT walls made from various exterior coating materials and insulation materials were experimentally measured. According to the results of the experimental measurements, the lowest thermal conductivity coefficient was obtained for CLT walls with EPS thermal insulation. While a decrease by 8-16% was observed in the CLT model building in comparison to the reference building in terms of annual total heating loads, an increase by 13-23% was observed in the CLT model building in terms of annual total cooling loads.

1. INTRODUCTION

Energy policies have been actively discussed all over the world because of climate change, global warming, and environmental effects. The use of environmentally friendly and sustainable building materials is becoming increasingly common in order to reduce energy consumption in buildings. Building houses with wooden materials, which has many advantages, will help to improve the ecological situation of the environment as a whole and provide comfortable living conditions for the users [1]. In many countries around the world, studies have continued to develop systems and technologies that use wood, an environmentally friendly and reliable material. Few building materials have the environmental benefits of wood [2,3]. Cross-laminated timber (CLT) wall layers, which can be given as examples of such renewable materials, are produced in large solid panels and used in various building systems such as residences, office buildings, schools, bridge applications, exhibition venues, gymnasiums, theater, commercial buildings, and wind turbine towers [4,5].

As defined by American National Standards Institute (APA), Cross Laminated Timber (CLT) also known as “X-lam” or “Solid Timber” is a prefabricated solid wood panel made from at least 3 layers of timber, each of which is oriented, glued, and pressed perpendicular to adjacent layers [6]. Exponentially increasing production demand and also uses of CLT being preferred in building high-rise structures have made a great contribution to the further development of wooden construction as a sustainable alternative to steel and concrete [4,7,8]. The CLT industry is considered an opportunity to penetrate into a new market and grow by enterprisers/investors because of its strong and steady position in the European construction market. In the wooden construction sector in other parts of the world including the US, Australia, New Zealand, Japan, and North America, the potential of CLT is quite remarkable and drawing more and more interest [7].

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Besides the growth in the world, the CLT sector has a wide range of applications increasing and varying fast in our country as well.

Tree species predominantly preferred for the manufacturing of CLT are particularly picea, pine (pinus cembra also known as Swiss pine and pinus nigra namely black pine), and abies commonly known as fir (abies concolor, pseudotsuga menziesii) [9,10]. CLT panels usually consist of 3, 5, 7, or more layers and are placed at 90° angles with the fiber directions crossing each other. They are resisting and rigid components with dimensional stability which are bonded with glue on the wide faces and in some cases on the narrow faces under at least a compressive force of 0,6 N/mm2 in the manufacturing process [11,12,13]. It can be used in building elements such as walls, roofs, and floors and can carry in/out-of-plane loads [12] (Fig. 1).

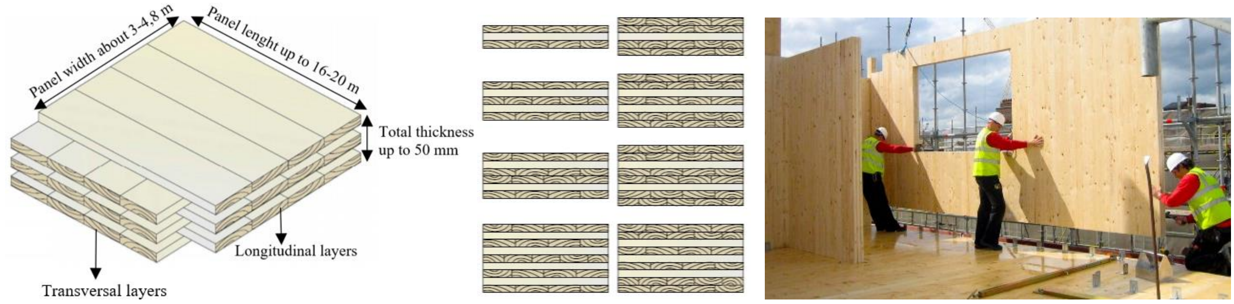


Figure 1. CLT panel section [13] and application in buildings [14]

In addition to the numerous advantages (modern opportunities to use, structural characteristics, earthquake resistance, quick manufacturing and installation, being applicable in high-rise buildings, being recyclable, CO_2 storage, energy performance, high air impermeability, being natural), CLT solid wood panels have high thermal performance characteristics [15, 16]. Thermal conductivity of CLT is 0.12 W/mK according to EN ISO 10456 [17]. Since CLT is a solid wood panel and acts as a thermal mass. The values of U (heat transfer coefficient) and R (heat resistance coefficient) which affect the thermal performance of CLT are directly related to the panel thickness. Thicker panels have lower U values and better insulators [18].

In the literature, there are studies that are intended to examine the effects of insulating materials applied together with CLT materials on building energy performance. One of these studies which was conducted by Dong et al. [19] evaluates the heating and cooling energy consumption of office buildings (CLT) for 5 different climatic zones in China. According to the simulation results, the CLT buildings seem to save about 11.9 to 23.30% of heating energy when compared to the reference building. Cho et al. [20] in a study analyzed the mid-rise apartments with CLT in South Korea in terms of energy consumption by using 4 different insulation types. The study indicated that the energy consumption for the CLT building in which hybrid insulation was applied decreased by 14.14% while the saving rate for the CLT building with the rock wool insulation type was 12.81%. Chang et al. [21] in their study analyzed the thermal characteristics and heat transfer performance of CLT. The thermal conductivity coefficients of CLT in radial, tangential, and longitudinal directions were respectively rated as 0.104 W/(m K), 0.111 W/(m K), and 0.122 W/(m K). In the study, the CLT walls with external insulation had lower heat bridges than the wood-frame construction walls was pointed out. As part of the study conducted by Guo et al. [22], the energy consumption of the buildings with reinforced concrete, CLT, and hay bale in the different climatic zones of China was simulated by means of the IES-VE program. The results demonstrated that the buildings with CLT and hay bale were more efficient in terms of energy consumption than the reinforced concrete buildings.

Dodoo et al. [23] paid regard to the energy performances of 3 different wood systems (CLT, Glulam-LVL, and Prefabricated Modular System) and their insulating materials at the lifecycle processes for a multistory building. In general, the CLT building system insulated with rock wool provided a decrease of 6 – 16% when compared to the other systems. Guo et al. [24] in a study compared reinforced concrete constructions and CLT constructions in terms of energy consumption and carbon emissions for 31 different climatic zones of China by means of the IES TM program. In the study, the CLT constructions decreased by 24.6% in energy consumption compared to the reinforced concrete constructions [24]. Lakot Alemdağ et al. [25] in their study compared CLT constructions and brick & gas concrete constructions which were insulated with rock wool and EPS for the city of İstanbul by means of the DesignBuilder simulation program. According to the results of the study, the CLT building, in which rock wool is used, has saved 7%-5% in heating energy consumption compared to brick and gas concrete buildings. Studies on the energy performance of CLT buildings in the climatic conditions of our country are very limited. In this context, the aim of the study is to examine the annual energy performance of a building built with CLT material in Trabzon, which is located in the temperate-humid climate region of our country, and to compare it with traditional building materials.

2. MATERIAL AND METHOD

2.1. Study Area

The Black Sea region is an area with unique wooden buildings, where wood masonry and timber framing systems are used extensively. The city of Trabzon, chosen as the study area, is located in the Eastern Black Sea Region of Türkiye between 38° 30' - 40° 30' east meridians and 40° 30' - 41° 30' north parallels [14] (Fig. 2). According to Köppen-Geiger, Trabzon has a humid subtropical climate namely Cfa, and has a high rainfall every season. According to TS 825, Trabzon is located in the II. Climatic zone. The mean yearly temperature is 14.4 °C. In the city of Trabzon, the annual rainfall namely precipitation is 800-850 kg/m^2, and yearly humidity is up to 99% [14, 26]. Table 1 presents the 90-year climatic data of the city.

Figure 2. *Study area, Trabzon-Türkiye [27]*

Table 1. *Climate Data of Trabzon According to The Measurement Period Between 1927-2020 [28]*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Avg. Temp. (°C)	7.3	7.3	8.4	11.7	16.0	20.3	23.1	23.5	20.3	16.6	12.8	9.5	14.7
Avg. Max. Temp. (°C)	10.7	10.8	11.9	15.5	19.1	23.1	25.9	26.5	23.7	20.0	16.5	12.9	18.1
Avg. Min. Temp. (°C)	4.6	4.3	5.4	8.7	12.9	17.0	19.9	20.4	17.3	13.6	10.0	6.7	11.7
Avg. Sunrise Time (hours)	2.7	3.3	3.4	4.4	5.5	7.1	5.9	5.6	4.9	4.5	3.7	2.7	4.4
Avg. Num of Rainy Days	12.5	12.4	13.3	12.9	12.8	10.8	8.0	8.8	11.2	12.6	12.1	12.7	11.6

2.2. Method

This study, in which an energy performance analysis is carried out for a house built with CLT material, consists of two parts including experimental measurements and simulation analyses. In the first part, experimental measurements were carried out in order to determine the heat conductivity coefficients of CLT wall layers composed of various insulating and coating materials. For the measurements, LaserComp

Fox 314 thermal conductivity measuring device was used. The device is designed to measure the thermal conductivity of materials, positioned between 2 temperature-controlled plates, with a 30*30cm size and max a 10-cm thickness (Fig. 3). With this device, the thermal conductivity constant (k) of the materials can be determined in W/mK. During the measurement, the surface of the material is contacted with the sensor of the device, and the thermal conductivity coefficient of the material is determined from the temperature interaction between the sensor and the sample. The device is used to measure the thermal conductivity of low-conductivity building materials [29]. The thermal conductivity measurement was conducted in accordance with ASTM C518 [30] and ISO 8301 [31] standards. The ASTM C518 standard states that tests should be performed on a sample of at least 300x300 mm and at an average temperature between 1.67ºC and 43.3ºC. ISO 8301 standard describes the use of the heat flow meter method to measure steady-state heat transfer through flat plate samples and calculate heat transfer properties. In the thermal conductivity tests carried out in the study, the upper plate (cold plate) temperature was set to 20°C and the lower plate (hot plate) temperature at 40ºC.

In the experimental measurements, 22 different CLT wall layers, approximately 10 cm thickness, were analyzed. Since there is a thickness limitation in the measuring device, the cross-sectional height of the wall layers created in this part of the study is approximately 10.5 cm in total. In the simulation part of the study, real-size building wall layers were created. In the wall layers used experimental measurements, 4 alternatives (plasterboard, wainscoting panel, OSB, and plywood) for exterior coating panels and 7 alternative materials (XPS, EPS, cellulose, sheep wool, hemp insulation, rock wool, and glass wool) for insulation materials are determined and the heat conductivity coefficient measurements were carried out. While selecting insulation materials, in addition to the materials most commonly used in exterior insulation, natural materials with high thermal insulation properties that can be compatible with CLT were especially preferred. In the experimental measurements, CLT materials with a 45-mm thickness, external coating plates with a 10-mm thickness, and insulating materials with a 40-mm thickness were used.

Figure 3. *Measurement Examples Made on The LaserComp Fox-314 Thermal Conductivity Device*

In the second part of the study, a single-story house project with CLT material and alternative insulation materials on its outer walls was designed. The DesignBuilder program was used to examine the energy performance of this designed model building in Trabzon city climatic conditions. For the analysis of heating and cooling loads, a dynamic building energy performance simulation was carried out, taking into account the information about the location and direction of the building, the characteristics of the building materials, the HVAC system, and climatic conditions.

2.3. Model Building Properties

The model building, for which energy simulation was made in the DesignBuilder program, is a single-story, detached building designed for a family with two children (4 people). The floor area covers 126 m^2 (12 m x10.5 m), the terrace covers 41.5m^2, and the story height is 3.00 m (Fig. 4). In the model building simulation, natural gas (radiator) is used in the heating system and air conditioner is used in the cooling, and natural ventilation is defined as the ventilation system. The model-building activity template is defined in the system as a single zone. Electrical equipment and hot water values are not included in the study.

Heating temperature was determined as 19 ºC, cooling temperature 25 ºC, heating set back 15 ºC, and cooling set back 28 ºC, the value of infiltration was accepted as 0.8 arc-1.

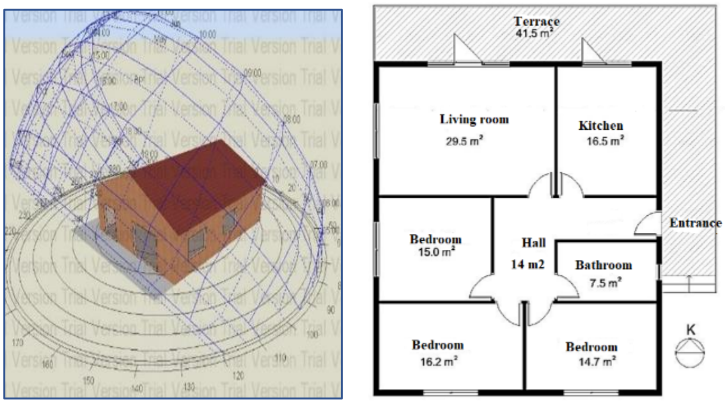


Figure 4. 3D View and Plan of CLT Model Building

It is accepted that the building is used between 8.00-18.00 five days a week and all day on weekends. The wall, roof, and foundation layers of the model building were determined as a result of interviews with Asmazlar Ahşap A.Ş, which produces and implements CLT in Türkiye. Layer details and thermophysical properties of the construction elements of the model building are presented in Table 2.

Table 2. *Thermophysical Properties of Building Materials [10, 32]*

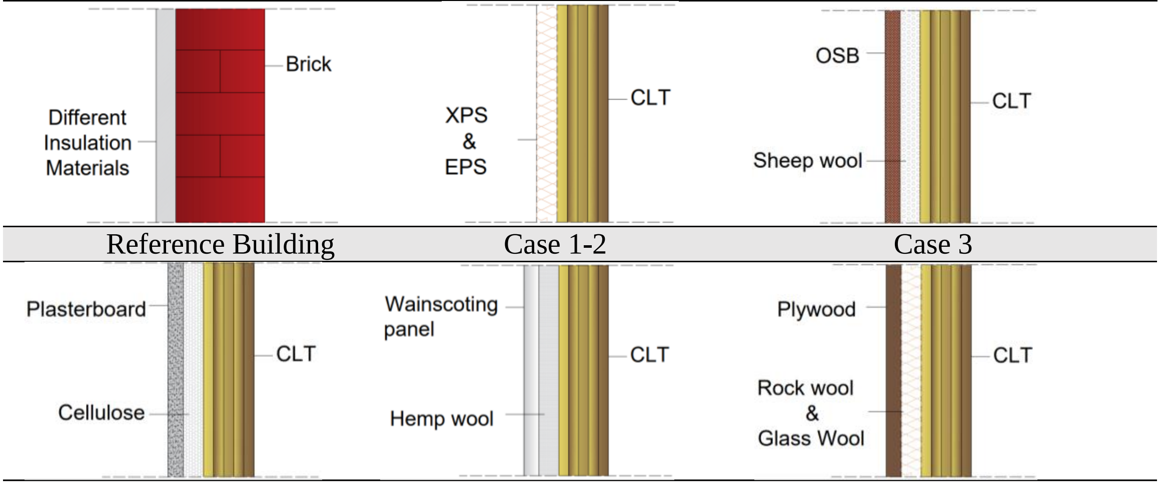
	No	Materials	Dim (mm)	Conductivity λ (W/m.K)	Density (kg/m3)	Heat Capacity (J/kg·K)	U- value (W/m^2K)
Roof	1	Roof tile	30	1.0	2000	800	0.295
	2	Vaporproofing membrane	1	2.3	130	2300	
	3	Air gap	15	-	-	-	
	4	Rock wool	40	0.035	150	840	
	5	Rock wool	40	0.035	110	840	
	6	Waterproofing membrane	1	0.23	1.3	1000	
	7	CLT	100	0.13	500	1300	
Clt Wall	1	Paneling	30	0.13	700	1200	0.423
	2	Air Gap	15	-	-	-	
	3	Vaporproofing membrane	1	2.3	130	2300	
	4	Rock Wool	40	0.038	40	840	
	5	Waterproofing membrane	1	0.19			
	6	CLT	100	0.13	500	1300	
Window	1	Standard float glass with wooden sash (glass-argon-glass)	4 16 4	-	-	-	2.8
Ground Floor	1	Wood flooring	3	0.14	650	1200	1.342
	2	Adhesive	-	-	-	-	
	4	Cement finish	50	1.40	1200	840	
	5	Double membrane	2	2.3	130	2300	
	6	Lean concrete	100	1.30	1800	1000	
	7	Crushed stone base	8	1.3	2400	920	
	8	Compacted soil subgrade	-	-	-	-	
Ref. Building Wall	1	Gypsum plaster	5	0.70	1400	1000	0.442
	2	Cement Mortar plaster	15	1.60	2000	1200	
	3	Rock wool*	40	0.038	40	840	
	4	Cement mortar plaster	5	1.60	2000	1200	
	5	Brick	190	0.33	600	840	
	6	Cement mortar plaster	1	1.60	2000	1200	

* Rock wool insulation and wainscoting panel were chosen as examples among the materials used in wall alternatives.

In the study, 7 different exterior wall scenarios were created and compared with the reference building data in order to examine the effects of CLT and various insulation materials on building heating and cooling loads. While creating the wall scenarios, the exterior cladding and insulation materials were changed without changing the CLT material (Table 3). While creating these wall scenarios, similar wall alternatives in the experimental measurements were used (Table 4).

***Table 3**. Exterior Wall Alternatives for Simulation*

Wall Alternatives	Wall materials and thickness
Reference Building	Exterior sheathing with different insulation materials (4 cm) (EPS, XPS, Sheep wool, Rockwool, Glass wool, Cellulose, Hemp wool insulation) + Brick (19 cm)
Case 1	Exterior sheathing with XPS (4-6-8 cm)+CLT(10 cm)
Case 2	Exterior sheathing with EPS (4-6-8 cm)+CLT (10 cm)
Case 3	OSB (3 cm) + Sheep wool (4-6-8 cm)+CLT (10 cm)
Case 4	Plasterboard (3 cm)+ Cellulose (4-6-8 cm)+CLT (10 cm)
Case 5	Wainscoting panel (3 cm)+ Hemp wool insulation (4-6-8 cm)+CLT (10 cm)
Case 6	Plywood (3 cm)+ Rockwool (4-6-8 cm)+CLT (10 cm)
Case 7	Plywood (3 cm)+ Glass wool (4-6-8 cm)+CLT (10 cm)



Reference Building | Case 1-2 | Case 3

Case 4 | Case 5 | Case 6 -7

CLT interior surfaces were not covered with any material for aesthetics and naturalness inside the building. In the reference building, brick was used instead of CLT on the exterior walls (U wall: 0.442 W/m^{2}K). In exterior insulation, XPS, EPS, and rock wool materials are applied with the sheathing technique, while other natural insulation materials are placed on the exterior with metal carriers and covered with plasterboard (Table 2).

3. RESULTS

3.1. Experimental Measurement Results

The thermal conductivity coefficient values of 22 different CLT wall layers formed with various exterior coating materials and thermal insulation materials are given in Table 4.

***Table 4.** Thermal Conductivity Coefficients of CLT Walls*

Wall Material	Thermal Insulation Materials (40 mm)	Thermal Conductivity Coefficient (Wm/K)		
		Min.	Max.	Avg.
CLT (45 mm) +	**XPS**	**0.067**	0.067	0.067
External Plaster (10 mm)	**EPS**	**0.064**	0.066	0.062

CLT (45 mm) + Plasterboard (10 mm)	Cellulose	0.080	0.088	0.084
	Sheep wool	0.078	0.088	0.083
	Hemp wool	0.078	0.092	0.085
	Rock wool	0.087	0.091	0.089
	Glass wool	0.077	0.086	0.081
CLT (45 mm) + OSB (10 mm)	Cellulose	0.078	0.092	0.085
	Sheep wool	0.076	0.083	0.080
	Hemp wool	0.078	0.086	0.082
	Rock wool	0.084	0.088	0.086
	Glass wool	0.075	0.093	0.084
CLT (45 mm) + Wainscoting panel (10 mm)	Cellulose	0.077	0.091	0.084
	Sheep wool	0.076	0.086	0.081
	Hemp wool	0.078	0.088	0.083
	Rock wool	0.087	0.091	0.089
	Glass wool	0.076	0.087	0.081
CLT(45 mm) + **Plywood** (10 mm)	Cellulose	0.075	0.088	0.082
	Sheep wool	0.076	0.085	0.080
	Hemp wool	0.076	**0.094**	0.085
	Rock wool	0.082	0.085	0.083
	Glass wool	0.073	0.083	0.078

In the study, the thermal conductivity coefficient of the CLT material was measured alone and found to be 0.103 W m/K. According to the measurement results, the lowest thermal conductivity value (~0.06 W m/K) was obtained in the CLT wall where EPS thermal insulation material is used as exterior sheathing. The highest thermal conductivity value (0.094 W m/K) was measured in the CLT wall layer used with hemp wool insulation material and plywood (Table 4). It has been observed that the average thermal conductivity values of natural insulation materials except XPS and EPS were very close to each other.

3.2. Simulation Results

In the study, 7 different types of insulation materials selected from traditional and alternative insulation materials were used on the CLT model building and the reference building exterior wall, and the heating and cooling loads (monthly/annual) and Uwall values were analyzed in the DesignBuilder simulation program using local climatic data. Calculations were made for three different insulation thicknesses as 4 cm, 6 cm, and 8 cm.

Uwall values calculated for the CLT wall alternatives and the reference building are given in Table 5. In all scenarios, lower Uwall values than recommended Uwall value (0.60 W/m^{2}K) for the 2nd climate zone according to TS 825 standards, were obtained. The limit value was obtained for the wall with hemp wool insulation material only in the reference building. The lowest Uwall value has been seen in Case 6 for 4 cm insulation thickness and in Case 1 for 6 cm and 8 cm insulation thickness in the CLT building. It has been observed that the Uwall values approach each other for most scenarios due to the increase in the insulation thickness. In addition, the U values obtained in the simulation results are similar to the thermal conductivity values in the experimental measurements.

Table 5. *U-value of CLT Walls and Reference Building Walls*

U-value of CLT Walls (W/m^{2}K)				U-value of Reference Building Walls (W/m^{2}K)	
	4 cm	6 cm	8 cm	Insulation	4 cm
Case 1	0,427	**0,333**	**0,272**	**XPS**	**0,524**
Case 2	0,465	0,367	0,303	EPS	0,566
Case 3	0,438	0,367	0,304	Sheep wool	0,590

Case 4	0,435	0,358	0,303	Cellulose	0,566
Case 5	0,464	0,385	0,328	**Hemp wool**	**0,604**
Case 6	**0,423**	0,346	0,293	Rock wool	0,550
Case 7	0,433	0,356	0,302	Glass wool	0,566

When monthly heating loads are analyzed according to insulation thickness for all scenarios, the highest heating load value was obtained in January in Case 2 (CLT+EPS). Accordingly, 778.3 kWh heating load for 4 cm thick EPS insulation, 722.4 kWh for 6 cm thick EPS insulation, and 685.2 kWh for 8 cm thick EPS insulation were calculated. In reference building, 848.2 kWh heating load was calculated in January for 4 cm EPS insulation. The lowest monthly heating loads were obtained in Case 6 (CLT+rock wool) in October. 16.3 kWh heating load for 4 cm thick rock wool insulation, 15.4 kWh for 6 cm, and 14.7 kWh for 8 cm were calculated. In the reference building, 19.4 kWh heating load was calculated for 4 cm rock wool insulation in October. Thus, when compared for the same type of insulation with the same thickness, a savings of 9.2% in January and 8.4% in October was achieved in the CLT building compared to the reference building (Fig. 5).

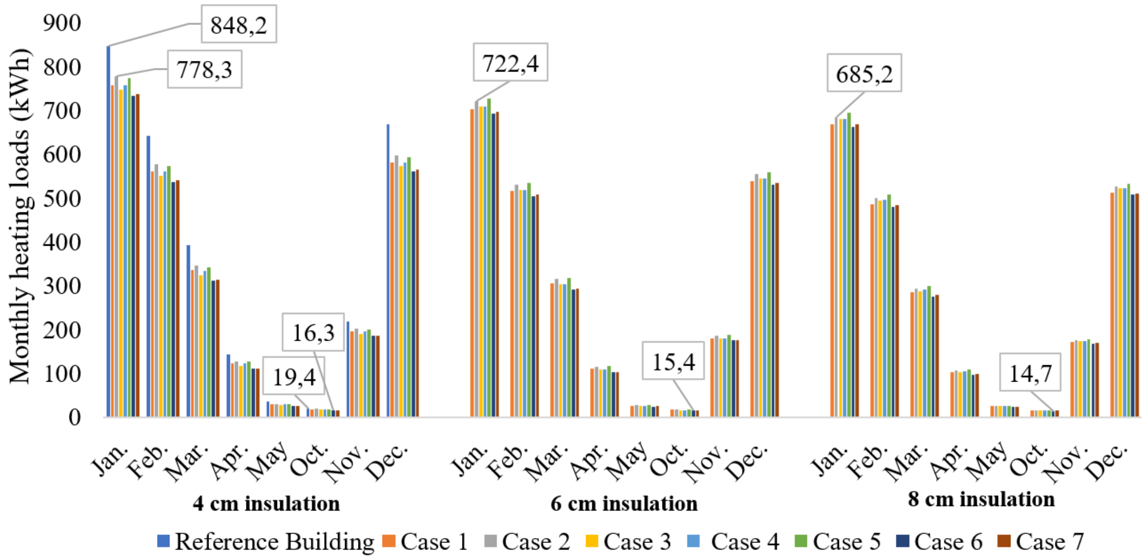


Figure 5. Monthly Heating Loads for Different Insulation Thicknesses of CLT Building Alternatives

When monthly cooling loads were analyzed according to insulation thicknesses for all scenarios, the highest cooling load value was obtained in August in Case 7 (CLT+glass wool). Accordingly, 115.8 kWh cooling load for 4 cm thick glass wool insulation, 111.9 kWh for 6 cm, and 109 kWh for 8 cm were calculated. In reference building, 102.4 kWh cooling load was calculated in August for 4 cm glass wool insulation.

The lowest monthly cooling loads were obtained in September in Case 4 (CLT+cellulose). 30.5 kWh cooling load for 4 cm thick cellulose insulation, 30.1 kWh for 6 cm thick cellulose insulation, and 29.1 kWh for 8 cm thick cellulose insulation were calculated. In the reference building, 25.5 kWh cooling load was calculated in September for 4 cm of cellulose insulation. Thus, when comparing the same type of insulation with the same thickness, the cooling load of the CLT building increased by 13.4% in August and 19.6% in September compared to the reference building (Fig. 6).

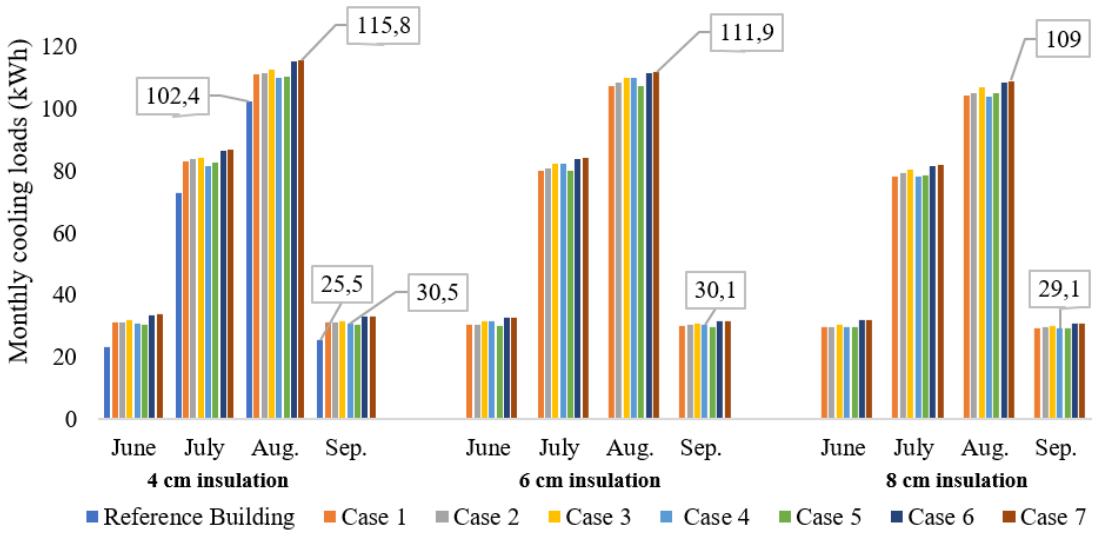


Figure 6. Monthly Cooling Loads for Different Insulation Thicknesses of CLT Building Alternatives

When annual heating loads were analyzed according to insulation thickness for all scenarios, the lowest heating load value was obtained in Case 6 (CLT+rock wool). In this scenario, 2482.1 kWh annual heating loads for 4 cm thick rock wool insulation, 2335.8 kWh for 6 cm, and 2230.5 kWh for 8 cm were calculated. In the reference building, 2934.4 kWh annual heating load was calculated for 4 cm rock wool insulation. Thus, when compared to the same type of insulation with the same thickness, 15% savings were achieved in the annual heating load in the CLT building compared to the reference building. It has been seen that the annual heating loads of Case 6 (CLT+rock wool) are close to Case 7 (CLT+glass wool) values as a result of the simulation. The reason is that thermal conductivity coefficient values of rock wool and glass wool are close to each other. In addition, there was a decrease in annual heating loads due to the increase in insulation thickness in the CLT building (Fig. 7).

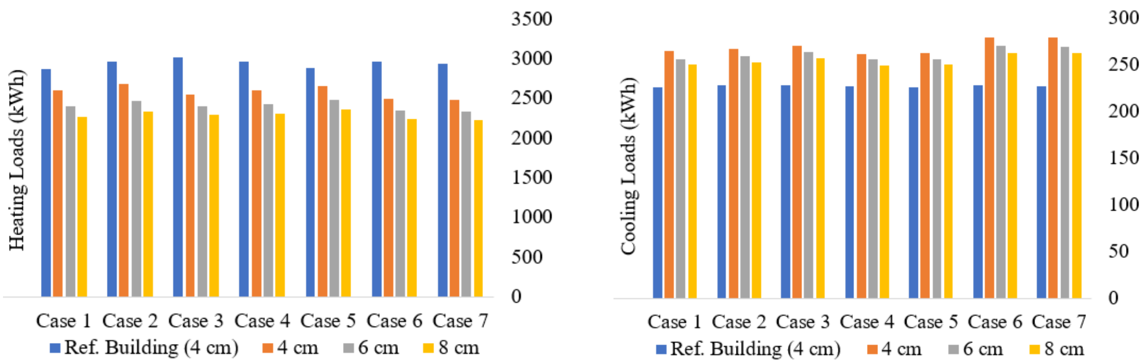


Figure 7. Annual Heating/cooling Loads for Different Insulation Thicknesses of CLT Building Alternatives

When the annual cooling loads were examined according to the insulation thicknesses for all scenarios, unlike the heating loads, the highest similar values in Cases 6 and 7 (~279Kwh for 4 cm, ~270Kwh for 6 cm, ~263 kWh for 8 cm) were obtained. In the reference building, ~228 kWh annual cooling load was calculated for 4 cm rock wool and glass wool insulation (Fig. 7). When comparing the same type of insulation with the same thickness, there was a ~23% increase in annual cooling load in the CLT building compared to the reference building. This is due to the fact that CLT is a high-density solid wood and its airtightness value is very low.

4. CONCLUSION

The use of technologically advanced, eco-friendly structural wood materials (CLT, Glulam, etc.) that can adapt to changing living conditions and needs have been quite common in the construction industry in recent years. Because of having high-performance characteristics, CLT is often used in buildings as the components of the wall, floor, etc., all over the world.

In this study, energy performance analyzes were made with the data defined on the single-story CLT model building and the reference building created in the city of Trabzon, the Eastern Black Sea region. In the heating and cooling loads obtained for the reference building, XPS insulation gave the lowest value, while sheep wool insulation gave the highest value. In the results obtained in U values, while XPS insulation gave the lowest value, hemp wool insulation gave the highest value. According to the simulation results, it was observed that the insulation materials, whose thermal conductivity coefficients are very close to each other, had similar effects on the U values, heating load, and cooling load of the walls in the reference building. In addition, it was observed that the type of insulation material did not have a serious effect on the cooling load in the reference building.

When the reference building simulation results were compared with the CLT model building results, a 10% decrease in heating loads in Case 1 and 8% in Case 2, 13% in Case 3, 11% in Case 4, 7% in Case 5, 13% in Case 6, and Case 7 was observed in January, when heating demand is maximum in the city of Trabzon. In the CLT model building, the annual total heating loads decreased by 10% in Case 1 and 13% in Case 2, 16% in Case 3, 14% in Case 4, 8% in Case 5, 15% in Case 6, and case 7 compared to the reference building. In addition, according to the CLT model building simulation data, the values of the heating load, 733.3 kWh, 692.5 kWh, and 663.4 kWh, were obtained, respectively, for rock wool insulation with 4 cm, 6 cm, and 8 cm thicknesses in January, when the heating demand is maximum. In the CLT model building, case 6 with rock wool insulation gave the lowest value in annual heating loads. Cho et al., [20b] also stated in their study that the CLT model building with rock wool insulation material has the lowest heating energy consumption. In a study, Rönnelid et al., [33] declared that the insulated CLT wall delivered a high energy performance and U values of the wall decreased.

When the reference building simulation results were compared with the CLT model building results, an 8% increase in cooling loads in Case 1 and 9% in Case 2, 9% in Case 3, 7% in Case 4, 8% in Case 5, 13% in Case 6, and Case 7 was observed in August, when cooling demand is maximum in the city of Trabzon. In the CLT model building, the annual total cooling loads increased by 13% in Case 1 and 17% in Case 2, 17% in Case 3, 15% in Case 4, 16% in Case 5, 23% in Case 6, and Case 7 compared to the reference building. In addition, according to the CLT model building simulation data, the values of the cooling load, 109.8 kWh, 109.9 kWh, and 103.8 kWh, were obtained, respectively, for cellulose insulation with 4 cm, 6 cm, and 8 cm thicknesses in August, when the cooling demand is maximum. In the CLT model building, case 4 with cellulose insulation gave the lowest value in annual cooling loads.

Since CLT is a high-density solid wood and has a very low airtightness, it creates a thermal mass effect. While this situation increases energy efficiency, it causes a negative effect on cooling loads. In light of the data obtained in the simulation, the cooling loads of the CLT model building confirm the mentioned issue when compared with the reference building. Glass et al., [12] and Khavari et al., [34] stated in their studies that the cooling loads of CLT buildings are higher, but the upper limit value is lower than the reference building. When the thickness of CLT panels increases, the U value of the wall decreases. In such cases, lower thicknesses of insulation material can be used.

According to the simulation results for all scenarios of the CLT model building, values below the U value given for the 2nd region in the TS 825 standard were obtained. The lowest U value was calculated as 0.42 W/m^2K in 4 cm thick rock wool insulation material, 0.33 W/m^2K, and 0.27 $W/m^2 K$ for the XPS insulating material with respectively 6 cm and 8 cm thickness. The highest U values were calculated as 0.465 W/m^2K for 4 cm thickness in EPS, 0.385 W/m^2K, and 0.328 W/m^2K for the hemp wool insulation material with respectively 6 cm and 8 cm thickness. The U values varied depending on the thickness selected in different insulation materials. When the U values of the reference building and the CLT model building walls were compared, it was seen that a 19% decrease in Case 1, 18% in Case 2, 26% in Case 3, 23% in Case 4, 23% in Case 5, 22% in Case 6, and 23% in Case 7. According to the results obtained, the insulated CLT wall showed higher energy performance than the insulated brick wall, and the use of natural insulation materials significantly reduced the U-value.

In the study, the CLT model building was also analyzed without insulation. According to the simulation results, the uninsulated CLT wall thickness should be applied as at least 16 cm in order to provide the recommended U value in Trabzon, which is in the 2nd climate zone. Since this situation will cause a significant increase in cost economically, it is more reasonable to create a CLT wall layer with appropriate insulations than to increase the thickness. In the energy performance evaluation of CLT buildings, the climate zone, the function of the building, its structural features, dimensions, HVAC systems, and ambient thermal load are the features to be considered.

As a result of the study, it is seen that CLT walls increase the energy performance of the building in the temperate climate region compared to the walls built by using traditional wall material (brick). This shows that buildings designed with CLT material, which has many advantages, can be a good alternative to today's reinforced concrete structures. In order to increase the use of this material, especially in the housing sector and any kind of architectural field in our country; the required standards need to be constituted, CLT production must be encouraged, and the number of academic studies in this field must be increased.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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