Research Article GU J Sci 36(4): 1414-1432 (2023) DOI: 10.35378/gujs.997496

Gazi University

Journal of Science

http://dergipark.gov.tr/gujs

Recommendations for Improvement of the Thermal Performance of an Office Building Based on Retrofitting the Glazed Curtain Wall

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Highlights

- This paper focuses on the thermal performance of highly glazed building envelopes.
- Energy efficient refurbishment strategies were proposed.
- Calculations are based on energy simulation software.

Article Info

Received: 19 Sep 2021
Accepted: 08 Dec 2022

Keywords

Curtain wall
Thermal comfort
Thermal performance
Glass

Abstract

Glazed curtain wall systems have become indispensable particularly in office buildings due to their light weight, aesthetic appearance, easy installation, and resistance to climate conditions. Curtain walls, however, also have problems in terms of thermal efficiency because of their wide, glazed windows and metal frames that have high thermal conductivity. The aim of this study is to offer proposals for improving the thermal performance of an office building with a glass curtain wall system built in a hot-humid climate zone. An office building constructed in Antalya, Turkey was modelled with the help of DesignBuilder energy simulation software, and various modifications were made to the model in order to improve the thermal performance of the building. With the improvements proposed in the study, it is possible to decrease the annual thermal loads of the whole building by 6.6%, and the annual thermal loads of the space with the curtain wall by 33.2%. The study revealed that applying an additional skin is more effective than lowering the U-value of the glass of the curtain wall in terms of thermal performance improvement.

1. INTRODUCTION

Humans are not resistant to environmental and climatic conditions that cause changes in their body temperature. The most important factor that affects the physical and mental productivity of humans is the ambient thermal comfort conditions. The satisfaction level of users in a built environment from the ambient temperature, i.e., their thermal comfort, is the result of thermal exchange occurring between the body and the environment [1]. Comfort is a complex relationship between parameters including metabolic rates, clothes, air temperature, relative humidity, mean radiant temperature. and local air velocity [2]. Thermal comfort is provided by keeping the heat gains and losses in the environment in balance [3]. According to the International Energy Agency (IEA), approximately 40% of the total energy consumption is consumed by buildings [4]. The energy consumption of a building depends on many factors such as the design of the building, the intended use of the building, the climate conditions of the location, the heat permeability of the building materials, the duration of use of these materials, the type and efficiency of the heating and cooling systems, the behaviours of the users, and the quality of workmanship [5]. The elements that constitute the envelope of the building, namely walls, ceiling, flooring, doors, and windows, have a great effect on energy performance. İnan & Başaran (2013) [6] state that 40% of the energy losses in the buildings occur from the exterior walls, 30% from the windows, 17% from the doors, 7% from the ceilings, and 6% from the floors. According to Beggs (2009) [7], the ratio of transparent surfaces to opaque surfaces affects heat gains and losses significantly.

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Highly glazed curtain wall systems have become indispensable particularly in office buildings due to their light weight, aesthetic appearance, easy installation, and resistance to climate conditions [8]. However, these systems also enhance energy load due to excessive solar heat gains during summer daytime and heat loss during cold seasons [9]. Glass is a material with a higher conductivity coefficient than other building envelope elements [10]; thus, it is disadvantageous from the point view of energy conservation. Thoughtless usage of glass as building envelopes may lead to energy problems and user discomfort [11]. Shaik et al. (2022) mention that glazing is a weak building envelope that admits too much solar heat, resulting in increased air conditioning costs, especially in hot climates [12] Thus, glazed curtain wall (GCW) systems should be designed to provide optimum thermal comfort conditions with minimum energy consumption [13]. From this point of view, building scientists and architects must have an adequate understanding of the physics of heat transmission through glazed areas and should be able to carry out necessary calculations of energy gain indoors [14].

The optical and thermophysical properties of glasses that affect the heat transfer are the thermal conductivity coefficient (U-value), time delay and amplitude reduction factor, solar heat gain coefficient (SHGC), and the transparency ratio [15]. The units for U are W/m^2 K (watts per square metre, per degree of temperature difference). As the U-value increases, the amount of heat that will flow through a material under a constant temperature differential will increase [16]. The lower the U-value of a building envelope element, the less the energy loss that occurs in that element [17]. In recent years, the thermal performance of glass has been improved remarkably with the use of a Low-E (low-emissivity) coating, multiple sections, and various gases [4]. Thermal conductivity coefficients are improved by reflecting the energy of long-wave radiation without changing the optical characteristics of the glass. Low-E glass prevents the cold zone in front of the window and provides a more even distribution of room temperature, greatly reducing the heat loss in the glass [18]. It is possible to reduce heating and cooling loads by preventing energy losses using types of glass that are selected and designed correctly [19].

Buildings are rendered out of proper function as they age or with the ever-changing requirements of users. In some cases, problems may be encountered in the use of buildings due to design decisions or application errors. Improvements shall be made in buildings in such cases. Improvement is defined as the restoration or renewal of the components, and materials that have been rendered out of the standards in an existing building [20].

Upgrading the energy efficiency of existing buildings is a well-known issue all over the world [21]. Building improvements provide significant improvements in the users' quality of life, energy costs, and environmental protection. These works unquestionably increase the value of buildings [22]. Dascalaki & Santamouris (2002) [23] describe the building renewal work as operations covering building materials and elements and heating, cooling, ventilation, and lighting systems and where these materials and elements shall be considered in the integrity of active and passive systems. Improvement of façade systems directly interacting with external conditions may be inevitable [20]. The aim of these works is to improve the thermal performance of buildings by optimizing the energy loads [23]. Improvements in façades are performed in the form of adding, removing, modifying, and renovating the building's layers, envelopes, and elements. The improvement method is directly related to the design, function, materials, and energy consumption of the building and user comfort and cost [24].

According to Chidiac et al. (2011) [25], energy retrofit measures allowed 19-32% natural gas saving in low-rise office buildings in the cities of Edmonton, Ottawa, and Vancouver in Canada. Various retrofit studies [26-31] have indicated that glazing is a critical part of the building envelope and need to be focused on. Van den Brom et al. (2019b) [32] state that, among the commonly implemented building energy retrofit options, upgrading window type and improving facade insulation is significant. According to Serghides et al. (2017b) [33] writing about conditions in Cyprus, replacing single-glazed windows with double-glazed windows can result in energy savings that can lead to a payback of investment within 4-5 years. Somasundaram et al. (2020) [34] studied the energy saving potential of Low-E coating-based retrofit double glazing for tropical climate and concluded that double glazing can provide significant energy savings (from 4 to 10%). Retrofit through glazing improvement in hot arid climate was investigated by Edeisy & Cecere (2017) [35]. The authors found that replacing a single clear glass with a double grey Low-E glazing reduced cooling load by 14%, and by the use of triple Low-E glazing, cooling loads could be reduced by up to 31%. Charles et al. (2019) [36] investigated the retrofit of an existing office building in Vancouver. Simulations performed on different types of windows showed that the type allowing the highest reduction in the total energy consumption was the high-performance Low-E windows double tinted and filled with argon. The total energy consumption decreased by 2% with this type of window.

Flores Larsen et al. (2015) [37] state that, in the last few years, double skin glazed façades have been suggested as a suitable technology that could reduce the cooling load of buildings in the Mediterranean and hot arid climates. Gratia & de Herde (2007) [38] mention that the addition of a glazed skin leads to a decrease in energy consumption of a building from 46% to 57% if the building is moderately insulated. Pomponi et al. (2016) [39] investigated a large number of studies based on double skin glazed façade systems in temperate climates. According to the literature survey, this system allowed a reduction in energy consumption of 7.47% to 90% for heating and cooling.

The aim of this study is to propose methods to improve of the thermal behaviour of an office building with a GCW system built in Antalya, which is located in a hot-humid climate zone. Proper solutions for improvement of the thermal performance of the building were examined with models prepared using the DesignBuilder energy simulation software.

2. MATERIAL AND METHOD

Per the TS 825 Thermal Insulation Standard in Buildings, Turkey is divided into five degree-day zones. The Antalya province where the building in consideration is located is in the 1st degree-day zone among these zones [40]. In Antalya, the longest sunshine period is in July, and the shortest sunshine period is in December with a total annual sunshine duration of 3011 hours [41]. While the average temperature is 10.0°C in January (the coldest month), the average temperature is 28.5 °C in July (the hottest month), and the annual average temperature is 18.8°C. The average annual precipitation in Antalya is 1.060 mm, and most of this precipitation occurs in winter. The share of precipitation in summer within the total annual precipitation amount is 5.7%. Thus, summer drought prevails in the region [42].

The building selected for the study is the Antalya Chamber of Mechanical Engineers building, built in 2009 in the Şirinyalı neighbourhood of Antalya. The building consists of a basement and five floors. The sloped GCW system applied to the north-east-south façades of the building constitutes 27% of the total façade area. The GCW of the building is connected to an open plan office (Figure 1). This space is called “space with the GCW” in this paper. Table 1 shows the areas of the whole building, façade, GCW and the space with the GCW.

Figure 1. *Plan of the building*

Table 1. *Areas of the façade, GCW, and the whole building*

	DF
Whole building	6.950 m2
Façade	3.268 m2
GCW	777 m2
Space with the GCW	475 m2

Aluminium joinery and 6-12-6 mm tempered glass with argon gas between the glass panels were used in the curtain wall system of the building, and a composite coating was used on the other walls. A photograph of the building may be seen in Figure 2. The U-values of building envelope components may be seen in Table 2.

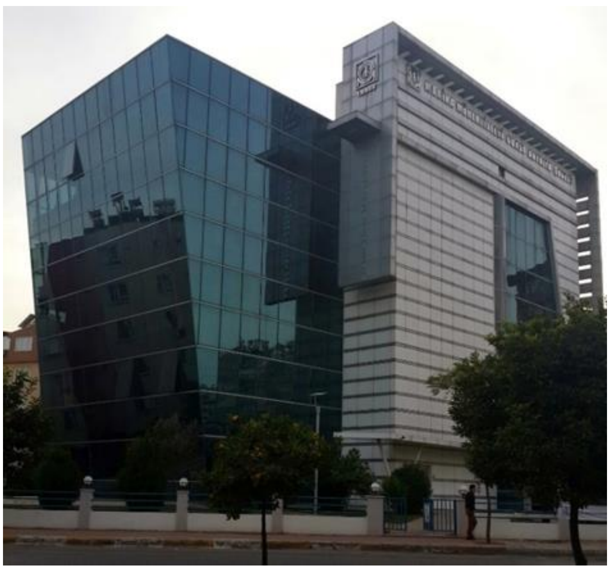


Figure 2. *Antalya Chamber of Mechanical Engineers Building*

Table 1. *U-Values of the Building Envelope Components*

Building Component	U-Value (W/m^2K)
Wall	0.481
Floor	0.233
Roof	0.250
Glazing	2.4

2.1. User Survey

This study consists of two phases. In the first phase, the building manager was interviewed, and information about the heating, cooling, and ventilation systems of the building was gathered. Additionally, a survey was conducted with the users of the building. Questions were asked about the thermal conditions of interior spaces in summer and winter, the effects of the GCW system on the thermal and visual and acoustic comfort, and how they control solar gain in summer months. The survey was conducted with 27 persons between 26 and 38 years old.

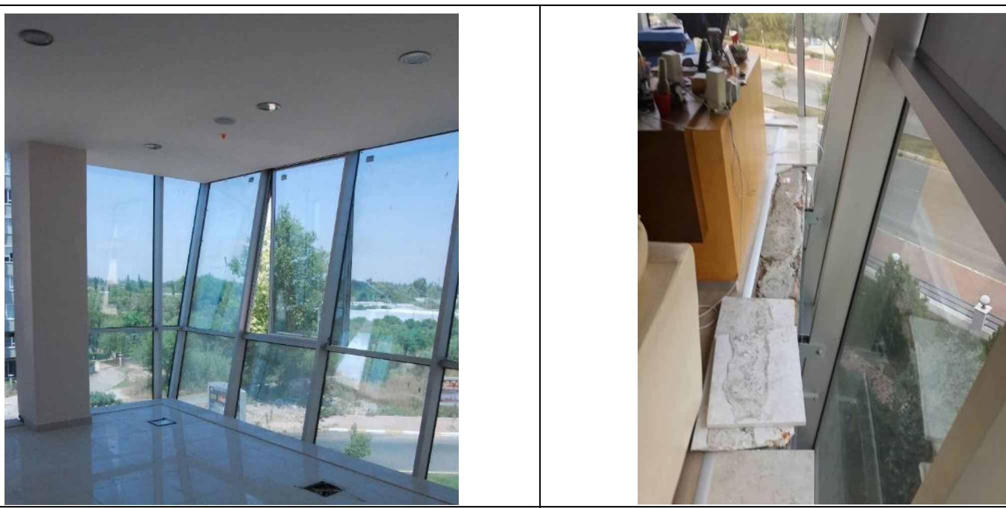
2.2. Energy Simulations

In the second phase, the Chamber of Mechanical Engineers building was modelled using the DesignBuilder simulation software. Heating and cooling loads of the current state of the building were calculated. Then, different versions of the model, including modifications with regards to the GCW, were prepared, and the thermal loads of each model were calculated. Thermal loads of the models were compared, and the effects of the recommended improvements were analysed.

DesignBuilder is an EnergyPlus-based software tool developed to measure and control the performance of buildings in terms of energy, carbon footprint, lighting, and comfort. ASHRAE indicates that most occupants are comfortable at space temperatures between 68-74° F (20-23.3 °C) in the winter and 73-79° F (22,7-26.1ºC) in the summer [43]. According to ASHRAE (2021) [44], for office buildings, a temperature setback between 55°F and 90°F is appropriate during off hours. The thermal comfort range of the building, which is used between 08:00 and 17:00 on five days of the week, was set between 22 and 24°C. The model was also set to activate the heating system when the interior temperature falls below 12°C and to activate the cooling system when the interior temperature exceeds 28°C for the days and hours that the building is not used.

3. MATERIAL AND METHOD

According to the data obtained in the survey, usually an air conditioner is used for heating and cooling the building, and a mechanical ventilation system is used for the ventilation of the building. Natural ventilation may also be used in the building; however, difficulties are experienced in the use of the windows due to the very large size of the sashes in the GCW system, their weight, and the fact that they may open downward only on the sloped façade. Thus, significant amount of electric power is used for heating and cooling purposes. The temperature in the interior spaces of the building is targeted at 22°C in winter and 24°C in summer. The air conditioning system is operated for six to seven hours per day for the heating and cooling of the interior spaces. All the users who were interviewed stated that the building receives a large amount of sunlight and that blinds are used in the windows where no GCW is applied for the control of sunlight. Since the GCW is sloped, solar control is not possible in this part of the building. All users consider the sloped GCW positive in terms of visual appearance; however, they think that the windows are difficult and dangerous to use. 74% of the users stated that there is an excessive amount of heat exchange between the floors of the building due to the problems with detailing and workmanship. 85% of the users stated that, in particular, the space with the GCW is warmer in summer and cooler in winter than other spaces. Users do not prefer to sit close to the GCW because of the excessive amount of heat in the summer months in the space with the GCW. It can be said that there are thermal comfort problems in the space with the GCW. Figure 3a shows a view of the GCW from the interior, and Figure 3b shows the detailing of the GCW that leads to heat exchange between the floors.



a)	*b)*

Figure 3. *Photographs of GCW system from interior figure; a) View of the GCW from the interior ample b) Detailing of the GCW which leads to heat exchange between the floors*

4. RESEARCH FINDINGS WITH REGARDS TO THE SIMULATIONS

The office building was modelled using the DesignBuilder simulation software, and thermal loads were calculated. In the current conditions, the annual heating load of the building is calculated as 184.501 kWh, and the cooling load is calculated as 214.999 kWh. The total of heating and cooling loads are 399.493 kWh. According to the data obtained, the annual cooling load of the whole building is higher than the heating load; however, these values are close to each other. Since most of the users complain about the thermal comfort conditions of the space with the GCW, not only the whole building but also the space with the GCW was considered in terms of thermal loads in this study. The annual heating load of the space with the GCW was calculated as 20.179 kWh and the cooling load as 62.801 kWh. The total of the heating and cooling loads is 82.980 kWh. In the space with the GCW, the annual cooling load is about three times the heating load. This shows that the GCW has a negative effect on the thermal comfort conditions, particularly in summer.

4.1. Replacing the Current Glass in the Curtain Wall with Glass with Lower U-Values (RGCW) (Improvement Step 1)

During the construction period of the Antalya Chamber of Mechanical Engineers Building, the maximum U-value recommended for the window systems per the TS 825 Thermal Insulation Standard in Buildings was 2.4 W/m^{2}K. With the revision issued in 2013, a maximum U-value of 1.8 W/m^{2}K was allowed for window systems.

In order to increase the thermal performance of this building, models were prepared in which Low-E glasses with U-values of 1.8 W/m^{2}K, 1.6 W/m^{2}K, 1.3 W/m^{2}K, and 1.1 W/m^{2}K were applied instead of the existing glass. Low-E glasses that were manufactured by a Turkish glass production company and that provide benefits in terms of energy efficiency were examined, and U-values were determined per the products of this company. The minimum annual heating load obtained for the building was 172.805 kWh when the Low-E glass with a U-value of 1.1 W/m^{2}K was used. This model allowed a decrease of 6.34% as compared to the current condition. The minimum annual cooling load obtained for the building was 209.924 kWh when the Low-E glass with a U-value of 1.8 W/m^{2}K was used. This model allowed a decrease of 2.36% compared to the current condition. A maximum decrease in total energy use was obtained with the model where the Low-E glass with a U-value of 1.1 W/m^{2}K was used, and the rate of decrease in this case, was 2.8% (Table 3). Figure 4a shows the comparison of the heating and cooling loads obtained in the whole building per the different U-values with the current conditions.

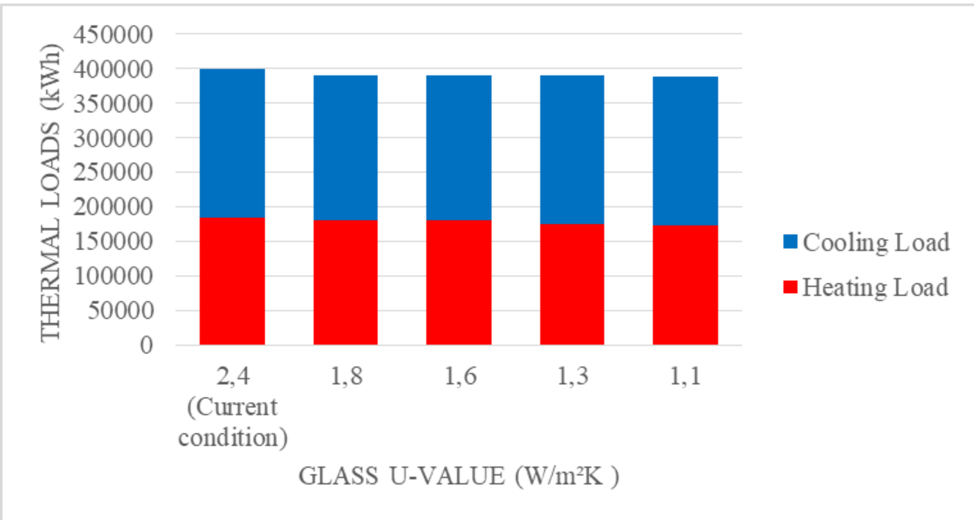
Table 3. *Thermal loads and changes in percentage obtained for whole building With Low-E glass applied*

Glass U-value (W/m^2K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
1.8	181.129	-1.83	209.924	-2.36	391.053	-2.11
1.6	179.622	-2.64	210.935	-1.89	390.557	-2.24
1.3	174.976	-5.16	215.090	+0.05	390.066	-2.36
1.1	172.805	-6.34	215.488	+0.23	388.293	-2.80

When we consider the heating and cooling loads for the space with the GCW, the highest decrease in the heating load was obtained when the Low-E glass with a U-value of 1.1 W/m^2K was used. In this model, the heating load was decreased by 20.15% to 16.113 kWh with respect to the current condition. The highest decrease in the cooling load was obtained when the Low-E glass with a U-value of 1.8 W/m^2K was used, and it was reduced to 59.322 kWh with a rate of decrease of 5.54%. The lowest total thermal load was achieved when the Low-E glass with a U-value of 1.1 W/m^2K was used. With this model, the total heating and cooling loads were decreased by 5.38% to 78.517 kWh (Table 4). Figure 4b shows the comparison of the heating and cooling loads obtained in the space with the GCW.

Table 4. *Thermal loads and changes in percentage obtained for GCW space with Low-E glass applied*

Glass U-value (W/m^2K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
1.8	19.195	-4.89	59.322	-5.54	78.517	-5.38
1.6	18.270	-9.46	60.223	-4.11	78.493	-5.41
1.3	16.773	-16.89	63.925	+1.79	80.698	-2.75
1.1	16.113	-20.15	64.302	+2.39	80.415	-3.09



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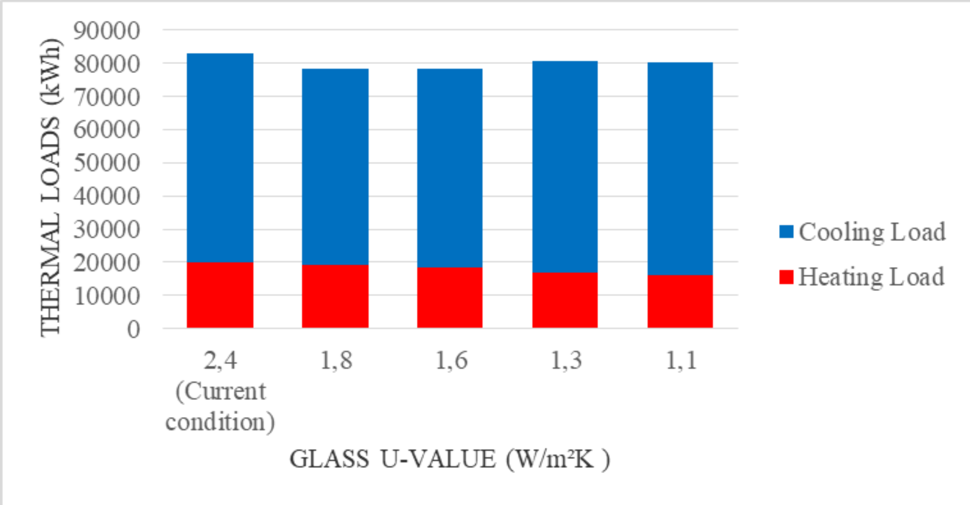
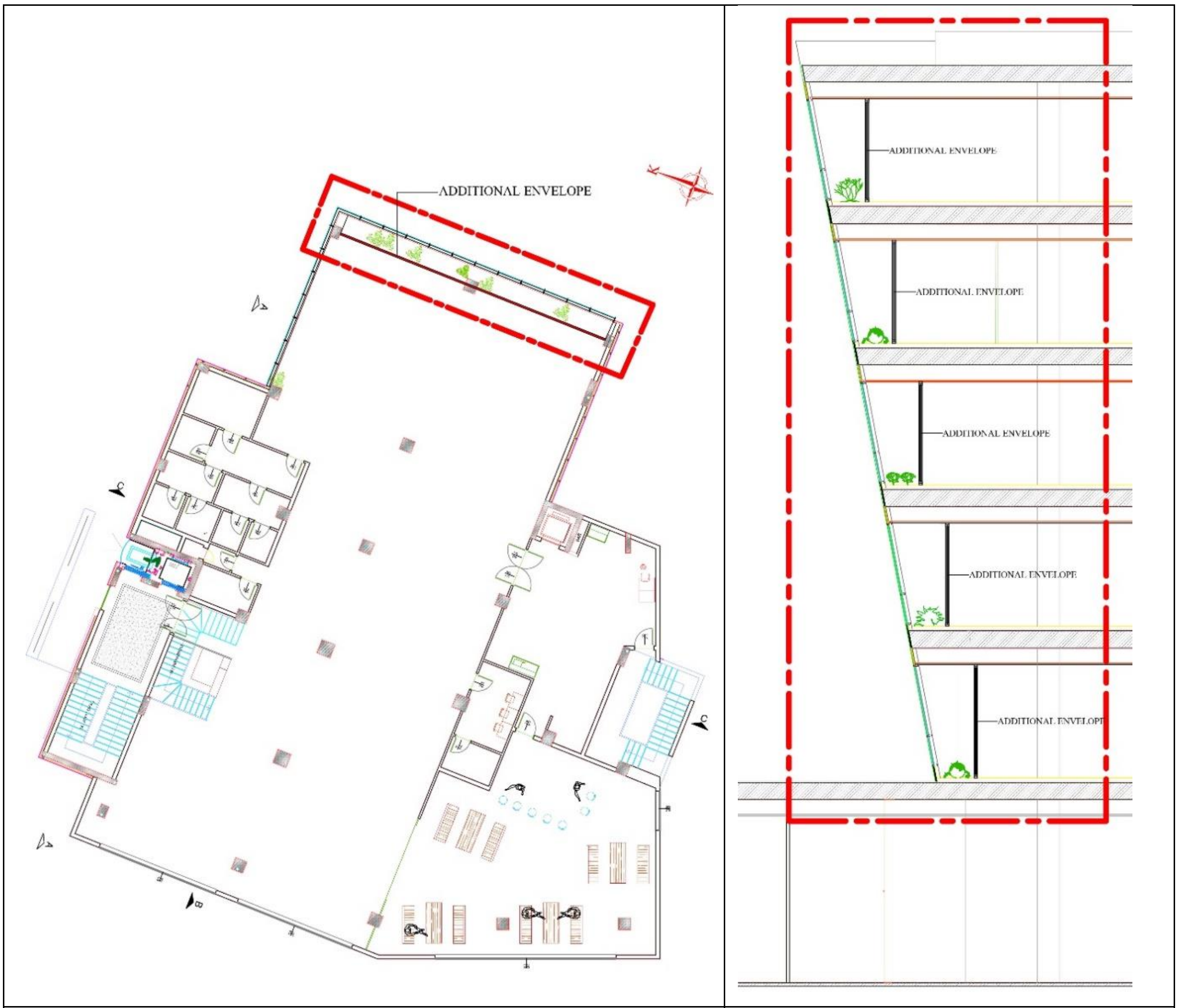


b)

Figure 4. *Comparison to current conditions of thermal loads obtained with Low-E glass with application of different U-values; a) Whole building b) Space with the GCW*

4.2. Application of an Additional Envelope to the Interior (AE) (Improvement Step 2)

At this phase of the study, it was decided to add a second skin on the façade of the building so that a double skin façade could be achieved. Since the GCW was sloped, it was not possible to add a skin to the exterior. Because of that, an additional envelope consisting of glass and aluminium joinery was applied after leaving a 1 m. gap on the interior side of the GCW system. There would be no change in the appearance of the building since the application was performed from the interior surface of the façade. It was possible to provide a better visual appearance to the gap between the two layers by planning this space. On each floor, doors that provide access to the gap were provided. The additional skin would reduce the energy loads of the building as well as the heat and noise transfer between the floors. The disadvantage of this skin was that it reduced the perception of the façade slope from the interior. The plan and cross-section in Figure 5 show the skin added to the interior. The models where an additional skin was applied were analysed in three different ways. First, models where only an additional skin was applied to the interior without making any additional changes to the exterior façade have been prepared. At this stage, three models with additional skin alternatives with U-values of 2.4 W/m²K, 1.8 W/m²K, and 1.1 W/m²K were prepared, and energy analyses of these models were performed. Then, additional skin alternatives with U-values of 2.4 W/m²K, 1.8 W/m²K, and 1.1 W/m²K were applied to the model with an external façade having a U-value of 1.8 W/m²K. Next, additional skin alternatives with U-values of 2.4 W/m²K, 1.8 W/m²K, and 1.1 W/m²K were applied to the model with an external façade having a U-value of 1.1 W/m²K. Energy analyses of these models were performed.



a) *b)*

Figure 5. *Envelope added to interior on plan and cross-section; a) Plan b) Cross-section*

At this stage, no changes were made to the GCW system. Additional skin alternatives with U-values of 2.4 W/m²K, 1.8 W/m²K, and 1.1 W/m²K were applied to the interior side of the GCW system, and energy analyses of these three models were performed. The application of an additional envelope reduced the heating and cooling loads. The lowest heating load for the whole building was achieved when the additional skin with a U-value of 1.8 W/m²K was used. With this application, the annual heating load of the building was decreased by 0.47% to 183.643 kWh. A maximum decrease in cooling load was achieved when the additional envelope with a U-value of 1.1 W/m^{2}K was used. With this application, the cooling load of the building was decreased by 1.54% to 211.687 kWh. The minimum value for total thermal loads was achieved when the additional envelope with a U-value of 1.8 W/m^{2}K was used. Total thermal loads of the building were decreased by 1.5% to 395.351 kWh (Table 5). Figure 6a shows the heating and cooling loads of the whole building.

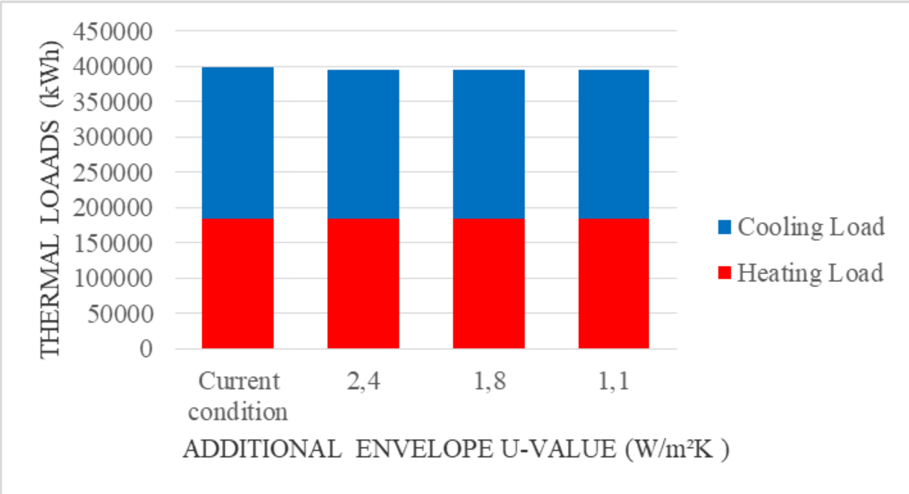
Table 5. *Thermal loads and changes in percentage obtained for whole building when additional skin applied to interior*

AE U-value (W/m^{2}K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
2.4	184.047	-0.25	211.731	-1.52	395.778	-0.93
1.8	183.643	-0.47	211.708	-1.53	395.351	-1.04
1.1	184.104	-0.22	211.687	-1.54	395.791	-0.93

The lowest heating and cooling loads in the space with the GCW were achieved when the additional envelope with a U-value of 1.1 W/m²K was used. In this additional skin application, the heating load was decreased by 22.6% to 15.619 kWh, and the cooling load was decreased by 29.95% to 43.992 kWh (Table 6). Total thermal loads in the space were decreased 28.16% to 59.611 kWh in this model. Figure 6b shows the heating and cooling loads of the space with the GCW. It was seen that the improvements were more effective in the space with the GCW than in the whole building because the space with the GCW is a zone in the building.

Table 6. *Thermal loads and changes in percentage obtained for GCW space with additional skin applied to interior*

AE U-value (W/m^2K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
2.4	15.868	-21.36	44.364	-29.36	60.232	-27.41
1.8	15.800	-21.70	44.175	-29.66	59.975	-27.72
1.1	15.619	-22.60	43.992	-29.95	59.611	-28.16



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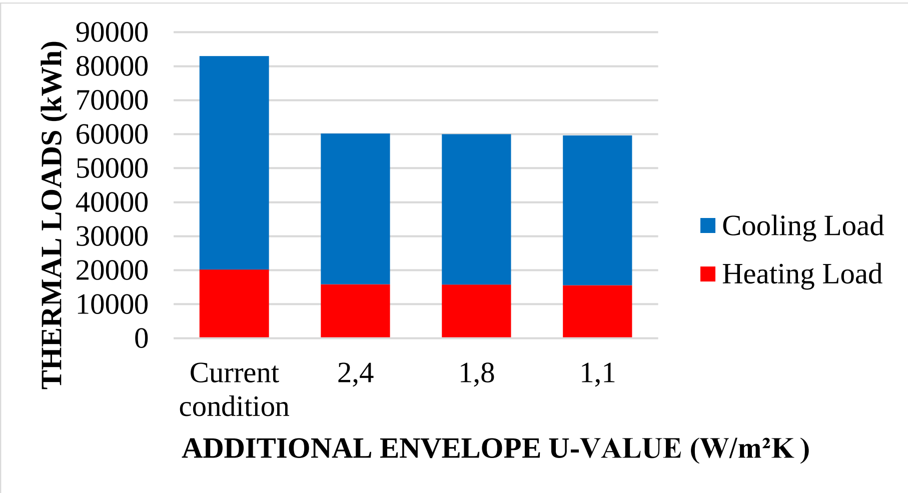


b)

Figure 6. *Heating and cooling loads of models with additional envelope applied compared to current conditions; a) Whole building b) Space with the GCW*

4.3. Replacing the Glass in the Curtain Wall with Glass with a U-value of 1.8 W/m²K and Applying an Additional Envelope to the Interior (RGCW1.8-AE) (Improvement Step 3)

The model where the glass of the curtain wall system was replaced with glass with a U-value of 1.8 W/m²K was modified at this phase of the study. Three alternative models were prepared. Envelopes with U-values of 2.4 W/m²K, 1.8 W/m²K, and 1.1 W/m²K were applied to the interior side of the GCW in this model. The Thermal loads of the three alternatives were calculated in order to see the effect of the glass change on the GCW and additional interior envelope together. The lowest heating load for the whole building with respect to the current conditions was achieved when the additional envelope with a U-value of 2.4 W/m²K was used. The heating load of the building was decreased by 1.93% to 180.934 kWh. The lowest cooling load was achieved when the additional envelope with a U-value of 1.1 W/m²K was used. The cooling load of the building was decreased by 3.61% to 207.225 kWh. The lowest total thermal loads were achieved when the additional envelope with a U-value of 2.4 W/m²K was used. Total thermal loads were decreased by 2.8% to 388.195 kWh in this model (Table 7). Figure 7a shows the heating and cooling loads of the whole building.

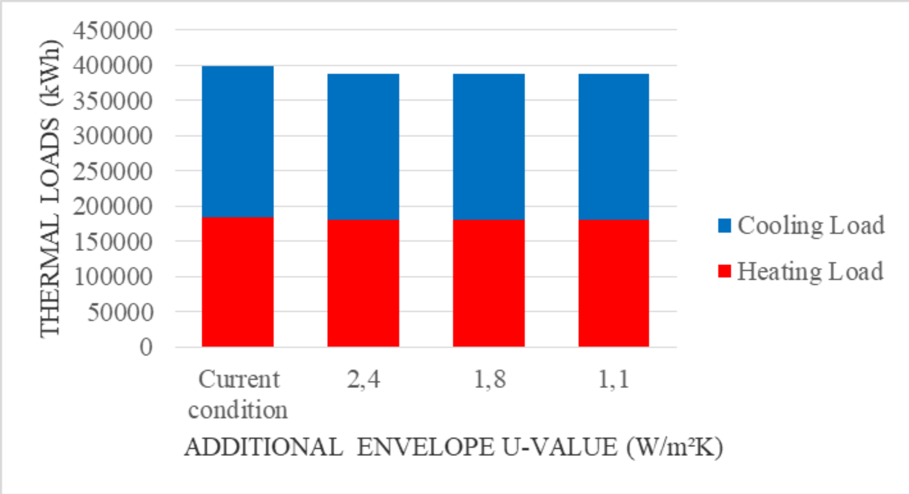
Table 7. *Thermal loads and changes in percentage obtained for whole building when glass with U-value of 1.8 W/m²K applied to curtain wall and additional skin applied to interior*

AE U-value (W/m²K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
2.4	180.934	-1.93	207.261	-3.59	388.195	-2.83
1.8	181.588	-1.58	207.244	-3.60	388.832	-2.67
1.1	181.616	-1.56	207.225	-3.61	388.841	-2.66

When we consider the space with the GCW, the lowest heating and cooling loads were achieved when an additional envelope with a U-value of 1.1 W/m²K was used. In this model, the heating load was decreased by 24.98% to 15.138 kWh, and the cooling load was decreased by 32.45% to 42.423 kWh. Total heating and cooling loads were reduced by 30.63% to 57.561 kWh with the addition of an additional envelope with a U-value of 1.1 W/m²K (Table 8). Figure 7b shows the heating and cooling loads of the space with the GCW.

Table 8. *Thermal loads and changes in percentage obtained for GCW when glass with U-Value of 1.8 W/m²K applied to curtain wall and additional skin applied to interior*

AE U-value (W/m²K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
2.4	15.356	-23.90	42.734	-31.95	58.090	-30
1.8	15.271	-24.32	42.603	-32.16	57.874	-30.26
1.1	15.138	-22.98	42.423	-32.45	57.561	-30.63



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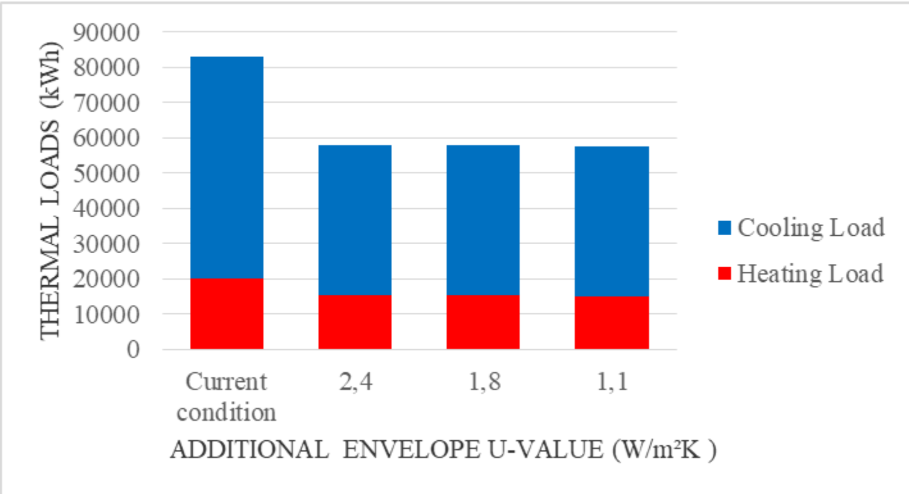


b)

Figure 7. *Effect of additional envelope added to interior of GCW system with glass with U-value of 1.8 W/m^{2}K; a) Whole building b) Space with the GCW*

4.4. Replacing the Glass on the Curtain Wall with Glass with a U-Value of 1.1 W/m^{2}K and Applying an Additional Envelope (RGCW1.1-AE) (Improvement Step 4)

The model where the glass of the curtain wall system was replaced with glass with a U-value of 1.1 W/m²K was modified at this stage. Three alternatives of this model were prepared. Envelopes with U-values of 2.4 W/m²K, 1.8 W/m²K, and 1.1 W/m²K were applied to the interior side of the GCW on this model, and energy analyses of the models were performed. The lowest heating load for the whole building was achieved when the additional envelope with a U-value of 1.8 W/m²K was used. The heating load was decreased by 6.61% to 172.311 kWh in this model. The lowest cooling load was achieved when the additional envelope with a U-value of 1.1 W/m²K was used with a reduction of 1.08% to 212.699 kWh. The minimum value for total thermal loads was achieved when the additional envelope with a U-value of 1.8 W/m²K was used. Total thermal loads were decreased by 3.62% to 385.040 kWh in this model (Table 9). Figure 78a shows the heating and cooling loads of the whole building.

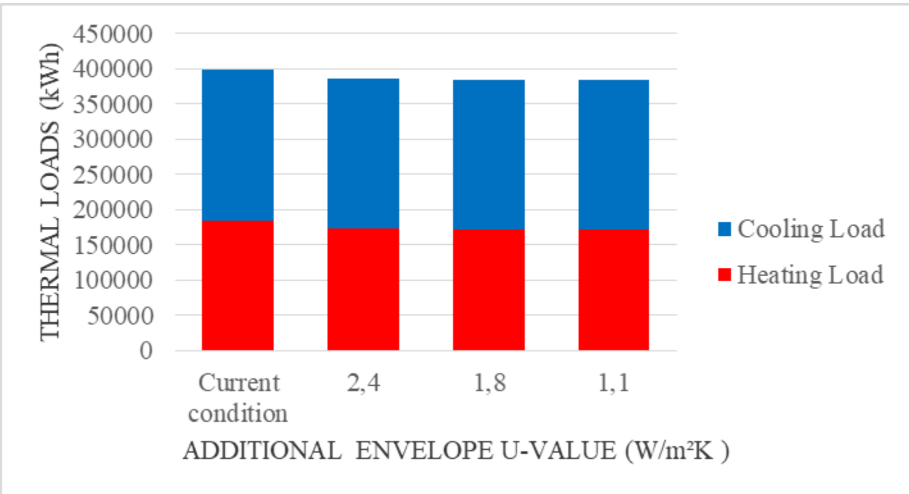
Table 9. *Thermal loads and changes in percentage obtained for whole building when glass with U-value of 1.1 W/m²K applied to curtain wall and additional skin applied to interior*

AE U-value (W/m^2K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
2.4	173.343	-6.05	212.740	1.05	386.083	3.36
1.8	172.311	-6.61	212.729	1.053	385.040	3.62
1.1	172.499	-6.51	212.669	1.08	385.168	3.59

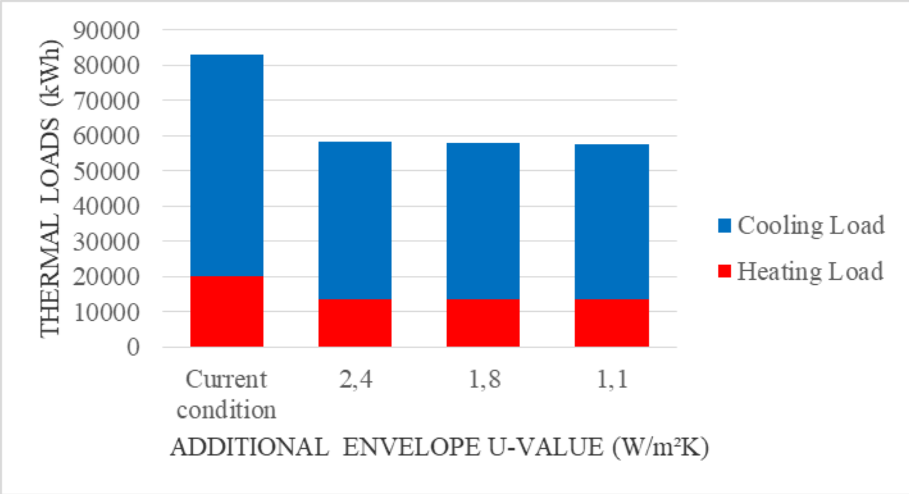
When we consider the space with the GCW, the lowest heating and cooling loads were achieved when an additional envelope with a U-value of 1.1 W/m²K was used. The heating load was decreased by 33.25% to 13.469 kWh, and the cooling load was decreased by 29.47% to 44.293 kWh. The lowest total thermal load was achieved when the additional envelope with a U-value of 1.1 W/m²K was used. Total thermal loads were decreased by 30.3% to 57.762 kWh in this model (Table 10). Figure 8b shows the heating and cooling loads of the space with the GCW.

Table 10. *Thermal loads and changes in percentage obtained for GCW space when glass with U-value of 1.1 W/m²K applied to curtain wall and additional skin applied to interior*

AE U-value (W/m^2K)	Heating loads (kWh)	Changes in percentage (%)	Cooling loads (kWh)	Changes in percentage (%)	Total thermal loads (kWh)	Changes in percentage (%)
2.4	173.343	-6.05	212.740	1.05	386.083	3.36
1.8	172.311	-6.61	212.729	1.053	385.040	3.62
1.1	172.499	-6.51	212.669	1.08	385.168	3.59



a)



b)

Figure 8. *Effect of additional envelope added to interior of the GCW system with glass with a U-value of 1.1 W/m^{2}K; a) Whole building b) Space with the GCW*

5. DISCUSSION

The research findings showed that there are thermal comfort problems in the space with GCW in the office building. As a result of the study, it was concluded that the cooling loads of the office building located in the Antalya province where a Mediterranean climate prevails were more than its heating loads. Particularly in the space with the GCW, the annual cooling load was three times more than the annual heating load. In this study, various proposals were recommended to improve the thermal performance of the space with the GCW and the whole office building. These proposals included replacing the glass of the curtain wall with glasses with lower U-values, applying an additional layer to the interior without changing the glass of the curtain wall, and replacing the glass on the curtain wall and applying an additional layer to the interior at the same time. Findings of the research findings showed that all of the proposals decreased the heating and cooling loads of the building but that the recommended modifications were more effective in the space with the GCW than in the whole building.

The calculations of the 13 models prepared for the study were examined, and the lowest heating, cooling, and total loads achieved at each step were recorded. Figure 9 shows a comparison of the heating, cooling and total loads calculated for the current conditions of the office building and the lowest loads achieved in the four improvement steps. It can be said that the four improvement methods decreased the thermal loads of the whole building; however, the calculated loads were close to each other. The big difference in the heating loads was seen in the fourth improvement step for the model where the U-value of the GCW was 1.1 W/m²K and the U-value of the additional interior layer was 1.8 W/m²K.; and this difference was 6.61%. Regarding the cooling loads, it was seen that the lowest cooling load was obtained in the third step for the model where the U-value of the GCW was 1.8 W/m²K and the U-value of the additional interior layer was 1.1 W/m²K. The percent of the difference was 3.61. When the total loads were examined, it was seen that the lowest total thermal loads were achieved in the fourth step for the model where the U-value of the GCW was 1.1 W/m²K and the U-value of the additional interior layer was 1.8 W/m²K; and this difference was 3.62%.

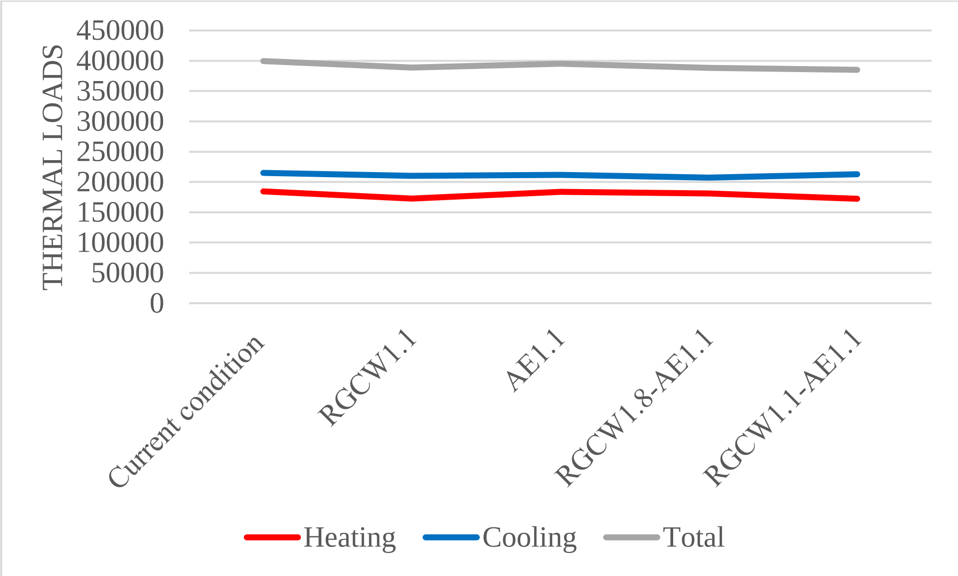


Figure 9. *Comparison of thermal loads of current conditions and lowest loads achieved in four improvement steps (Whole building)*

Figure 10 shows the comparison of heating, cooling, and total loads calculated for the current condition of the space with the GCW and the lowest loads achieved in the four improvement steps. Findings of the research revealed that all improvement steps decrease the thermal loads of the space with the GCW. It can be said that the second step was much more effective than the first step with regards to the cooling and total thermal loads. In other words, adding an additional layer decreased the cooling and total thermal loads more than lowering the U-value of the glass of the curtain wall. The big difference in heating loads was seen in the fourth improvement step for the model where both U-values of the GCW and the additional interior layer were 1.1 W/m²K.; and this difference was 33.25%. Regarding the cooling loads, it was seen that the lowest cooling load was obtained in the third step where the U-value of the GCW was 1.8 W/m²K and the U-value of the additional layer was 1.1 W/m²K. The percent of the difference was 32.45. When the total loads were examined, it was seen that the lowest thermal loads were also achieved in the third step where the U-value of the GCW was 1.8 W/m²K, and the U-value of the additional interior layer was 1.1 W/m²K.; and the difference was 30.63%.

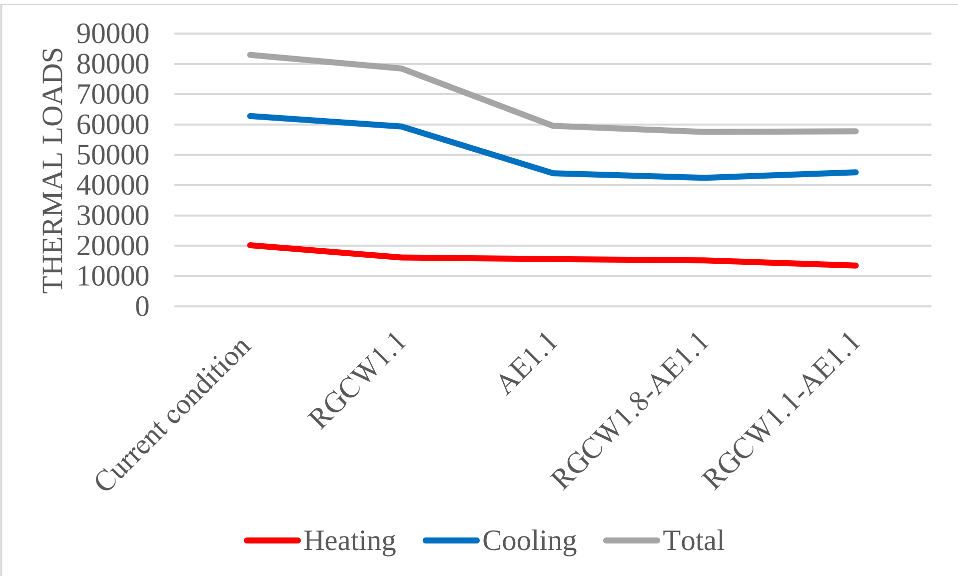


Figure 10. *Comparison of thermal loads of current conditions and lowest loads achieved in four improvement steps (Space with GCW)*

6. CONCLUSIONS

Since electric power is used for both the heating and cooling purposes of the building and cooling loads are higher than heating loads, the model where the lowest cooling load was achieved can be proposed for this building. The most advantageous model in terms of cooling loads is the model where the U-value of the GCW was 1.8 W/m²K and the U-value of the additional layer was 1.1 W/m²K, the one prepared in the third step of the study. This model reduced the annual cooling loads of the whole building by 7.774 kWh and the annual cooling loads of the space with the GCW by 20.378 kWh. The research showed that improvement step 2, which was the application of an additional skin to the interior also had an important effect on decreasing the cooling loads. Adding a skin with a U-value of 1.1 W/m²K without replacing the glass on the curtain wall reduced the annual cooling loads of the entire building by 3.312 kWh and the annual cooling loads of the space with the GCW by 18.879 kWh.

It is not possible to apply a curtain on the glass surface that is sloped under present conditions. It would be possible to reduce the heat gain and thus reduce the cooling loads in the summer months further by applying a curtain and thus controlling solar radiation if an additional envelope was added to the interior. An additional interior envelope would also reduce the heat transfer between the floors.

The aim of this study was to offer proposals for improving the thermal performance of an office building with a glass curtain wall system built in a hot-humid climate zone. It is possible to reduce the thermal loads of the building with the proposed interventions. It can be said that findings that this research achieved for the whole building were not consistent with the literature, but the results related to the space with the GCW were [25-39]. This is because the interventions applied to the building were more effective in the space with the GCW, a zone in the building. The present study was conducted for an office building in a hot-humid climate. The research can be extended to different building typologies and different climate types.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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