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Research Article

Thermal Bridge in the Building, Energy Loss and Environmental Effects

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ABSTRACT

In the presence of a thermal bridge in the building, some of the required energy becomes inactive in order to provide thermal comfort in the building. This situation negatively affects the energy efficiency of the building. The energy sources used throughout the world for air conditioning are fossil fuels with limited reserves. In terms of sustainability, transferring fossil fuels to future generations is an important issue. Moreover, as a result of the combustion process that occurs when energy is obtained from fossil fuels, carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide and various particulate matter are produced, causing air pollution.

Carbon dioxide gas, which is a monitoring parameter regarding climate change, is a parameter that is controlled during the fight against global warming. Various studies are carried out and policies are developed to reduce carbon dioxide emissions around the world. In the construction sector, which is among the areas where energy is used in large amounts throughout the world, a large part of the energy is consumed for air conditioning. At this stage, thermal bridges and insulation application in the building is a very important issue. In this review study, the importance of the thermal bridge is emphasized and its importance in terms of energy efficiency and thermal comfort in the building is determined. In addition, the areas where thermal bridges are commonly encountered in the building are summarized and the precautions to be taken in the building and the harms of thermal bridges to the ecosystem are evaluated together.

Keywords: Heat loss, energy efficiency, sustainability, air pollution, climate change

1. INTRODUCTION

Nearly 40% of the energy used in Germany, France, Italy and the United Kingdom is consumed in the building sector. In the European Union countries, 40% of the total energy is consumed in buildings and 63% of this value is used for air-conditioning in residences.[1,2] While 17% of the total energy use in Canada is used in the building sector, 63% of this value is consumed for heating purposes.[3] In Turkey, 35% of the total energy use is used in buildings and 65% of this value is used for thermal comfort.[4]

Fossil fuels are the most common type of fuel used in energy supply worldwide. In the case of using fossil fuels as fuel, various gaseous emissions, primarily carbon dioxide, arise from the combustion process.[5,6] As a result of the accumulation of carbon dioxide gas in the atmosphere, the problem of global warming or climate change occurs. As a result of this environmental problem, which results in the warming of the earth day by day, the melting of the glaciers, the cooling of the oceans and the climatic deterioration cause adaptation problems in the living populations.[7,8] In order to control these environmental problems and reduce them at their source, every factor that consumes energy must fulfill its responsibilities.

The construction sector consumes a large part of the energy produced in the world, increasing carbon emissions to the same extent as it consumes. The increase in the population day by day requires new housing needs and therefore more energy needs. In this regard, the amount of carbon dioxide that will be released into the atmosphere will increase day by day. It is thought that the average temperature increase in the

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world will be 1.1 to 6.4°C in 2100, and it is reported that a temperature increase of 2°C will cause significant ecosystem damage.[9,10] In this regard, the more efficient use of energy used for air conditioning in houses will be a more sustainable approach in terms of reducing carbon dioxide emissions. Currently, carbon dioxide quota applications are carried out in order to control carbon dioxide emissions in the fight against climate change problem and to reduce the amount of carbon dioxide released into the atmosphere nationally. At this stage, the most appropriate method in the building sector is to prevent thermal bridges in the building and to attach importance to thermal insulation.[11,12]

The environmental effect of thermal bridges does not always occur indirectly, as in environmental problems such as air pollution and climate change. If thermal bridges and insulation continuity are not provided at the source, that is, the structure, the living being is directly affected and damaged materially and morally. While there are mold problems on the wall surfaces of the building elements in the presence of thermal bridges, various deformations occur on the surface or inside of the building elements as a result of the condensation of water.[3,13] As a result of these undesirable deformations, there will be a need for maintenance and repair, and more raw material consumption will occur. This will increase resource use by causing additional consumption due to the lack of protection of the structure. Reducing excessive consumption, which is among today's important environmental problems, in all areas of life is a very important issue in terms of leaving a more livable world to future generations. In addition, while the costs paid for air conditioning will increase, indoor heat comfort will not be provided at the same time.[13,14] While this situation will negatively affect the energy efficiency of the building, it will also cause more energy consumption. In our country, legal regulations in order to use energy efficiency in buildings and prevent waste were made more clearer with the Energy Performance Regulation in Buildings in 2008 and have been developed until today with the necessary updates. In this study, the concept of thermal bridge in the building and the importance of insulation in the building are summarized. Energy efficiency in the building is discussed over the electrical energy consumed for air conditioning. In addition, the environmental effects of heat leaks caused by the thermal bridge on the earth were evaluated.

1.1. Thermal Bridge in the Building

The heat in an environment tends to move from a warm environment to a cold environment.[15] If the heat in question passes through a material, the chemical and physical properties of the relevant material become effective factors in the transmission of heat.[16,17] Heat losses in a building are commonly transmitted through structural elements such as columns, beams, walls and roofs.[14,18] The regions where the heat loss in a building section is higher than the other parts of the building are called thermal bridges.[19] In other words, the transmission regions where there are unwanted heat losses in the structure are called thermal bridges.

There are three different types of thermal bridges in the building. The first of these is the thermal bridges formed in the areas where geometric changes occur in the structure. As a result of the insulation deficiencies in the room corners and the roof, the relevant thermal bridge is formed. The second is the thermal bridges, which are caused by structural material changes as a result of the use of different materials. This type of thermal bridges can occur around carrier elements. The last one is thermal bridges, including geometric shape changes and structural changes. Console balcony plates or mechanical pipe transitions can be shown as examples of this type of thermal bridges. Example representations of thermal bridge types are given in Figure 1.[20-22]

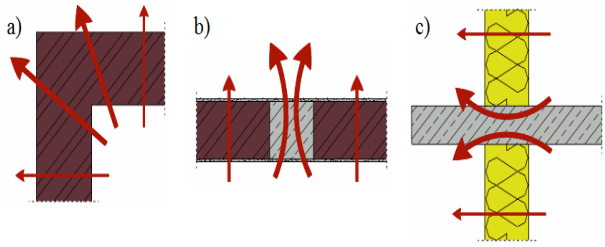

Figure 1. Types of thermal bridges (a): geometric, (b): structural, (c): combined[21]

The important factor in the formation of heat loss in buildings is the use of materials with different thermal conductivity in building elements.[23] In this regard, it is very important to create a thermal insulation plan at the planning stage of building projects. Currently, during the construction of thermal insulation applications, attention should be paid to the continuity of the insulation.[24]

Thermal cameras are used to detect thermal bridges in the building. Thermal cameras can be used practically in detecting the heat flow occurring on surfaces by means of infrared imaging technique.[25,26] Figure 2 shows the before and after thermal imaging images of a building that was imaged with a thermal camera.[27]

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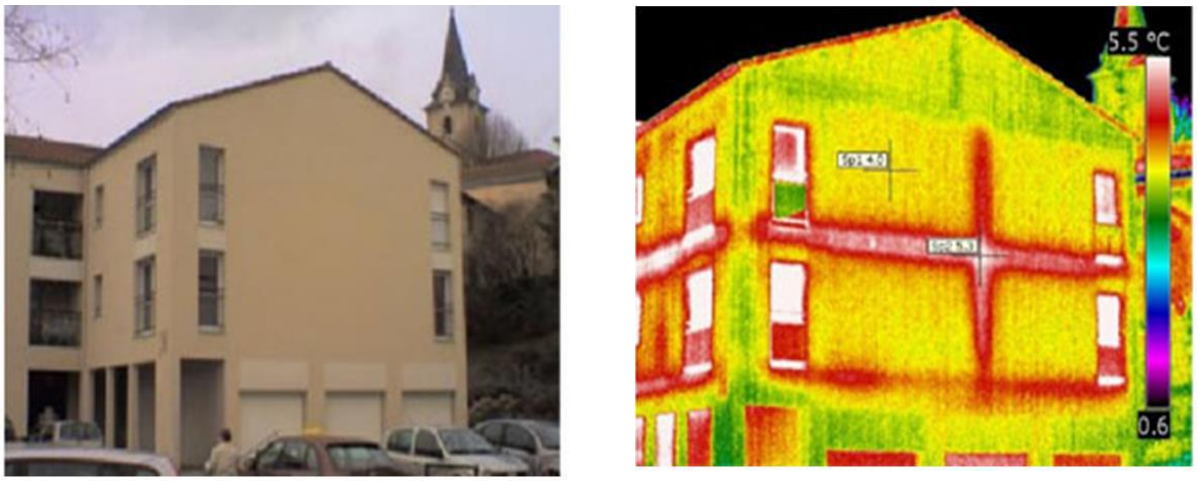

Figure 2. Imaging a structure with a thermal camera (left): before imaging, (right): after imaging[27]

When Figure 2 is examined, it is understood that no thermal insulation application has been carried out in the relevant building. In addition, the existence of thermal bridge formation is observed from all structural elements of the building. Şahin and Çarkacı[14] examined thermal insulation applications in public buildings in Gümüşhane province. The researchers[14] studied the differences between the uninsulated form of a public building and after the insulation was applied, and they determined that there are still thermal bridges in the building after the insulation application. The thermal camera images before and after the insulation application of the related study are given in Figure 3.[14]

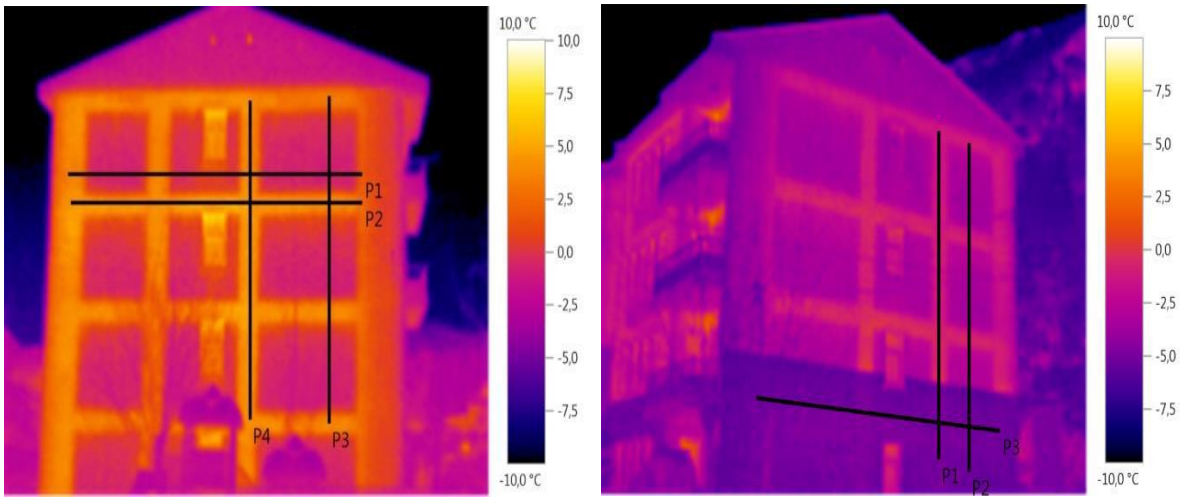

Figure 3. Pre-insulation (left) and post-insulation (right) thermal camera images of the study[13]

When the images are examined together with the heat loss scale in Figure 3, it is seen that the thermal bridges before the thermal insulation application decreased after the insulation application, but the heat leaks in the columns and beams of the building continued. In the presence of thermal bridges in buildings, the thermal comfort of the building is affected and various destructions occur in the building elements.[28] Living things under the cold wall effect are faced with diseases such as colds and rheumatism.[13] The heat passing through the building element causes condensation in the building material or on its surface when the environment cools. In this case, mold formation (Figure 4) occurs on the building surface, while at the same time destroying the paint and plaster on the wall surfaces. In addition, as a result of the condensation of water in the structure, it can corrode the reinforcement in reinforced concrete structures, as well as cause deterioration in the concrete structure, negatively affecting the mechanical durability of the structure.[20,29,30]

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Figure 4. Mold formation in the presence of thermal bridges[29]

1.2. Thermal Bridge and Energy Loss

When constructing a building, the primary issue is its design in accordance with its intended use. Considering the air conditioning, that is, thermal comfort, in the buildings where the accommodation will be realized is very important in terms of human health and air conditioning costs.[31,32] In this regard, it is necessary to eliminate the thermal bridge formation that may occur while the thermal insulation is expected to be appropriate and continuous in the building.[24] 10-25% of heat losses in a building are caused by windows, 25% by ceiling, 15-25% of infill walls, 10% by floors and 20-50% of thermal bridges. Figure 5 shows the image of heat losses occurring in the building.[33]

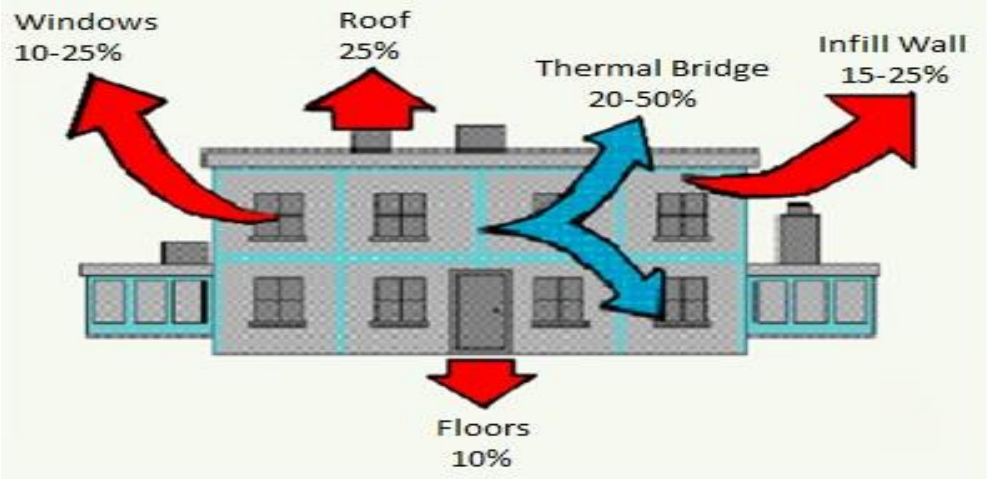

Figure 5. Heat losses in a structure[33]

When Figure 5 is examined, it is understood that up to 50% of the energy consumed in order to provide air-conditioning in the building cannot be used efficiently through the thermal bridge. In this regard, more energy is consumed in order to provide thermal comfort. Using Fluent software, Karabulut and Buyruk[34] studied the heat leakage that occurs through the beam when the mezzanine floors are uninsulated and if internal insulation is applied. Researchers[34] have determined that the heat leakage caused by the beam in a reinforced concrete structure can be reduced by 89% if insulation is applied.[34] Evola et al.[28] studied the effects of thermal bridge formation in the building by selecting two building types (terrace house and semi-detached house) in Italy, which is located in the Mediterranean climate. Researchers[28] working in two building types with reinforced concrete framed clay block walls reported that 25% heat leakage in the terraced building and 17.5% of the semi-detached building could be prevented as a result of the correction of the thermal bridge. In addition, the researchers[28] determined that as a result of the prevention of the thermal bridges, a 3.5% benefit in cooling performance and an average of 8.5% gain in total annual energy savings can be achieved.[28] Jedidi and Benjeddou[27] investigated the effect of thermal bridge on thermal comfort in a building. As a result of their calculations, the researchers[27] found a 16% reduction in heat loss by increasing the insulation thickness of 5 cm to 7.5 cm, and a 27%

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decrease by increasing it to 10 cm[27]. Dikici and Kocagül[15] studied the effects of EPS, XPS and rock wool materials used as insulation materials in Elazig province on heat losses. The study was carried out in July and August. Researchers[15] constructed four identical buildings and did not apply thermal insulation in one of them (control). They[15] found that the indoor temperature of the uninsulated experimental structure changed between 26-29 ^{o}C as a result of the study, which they carried out using a cooling compressor inside the buildings. In addition, as a result of the stone wool, XPS and EPS thermal insulations they applied to the outside of the other three structures, they obtained indoor temperatures varying between 9-12^{o}C, 13-15^{o}C and 15-17^{o}C, respectively. Researchers[15] have stated that the cooling compressor in the uninsulated room consumes more energy to reduce the ambient temperature.[15] Şahin and Çarkacı[14] examined the thermal bridge that occurred in a public building located in Gümüşhane province, before and after thermal insulation application. Researchers[14] have determined that the insulation is not suitable as a result of the thermal insulation application. Researchers[14] observing the existence of existing thermal bridges have determined that the insulation application is not in accordance with the TS 825 thermal insulation rules standard in buildings. In addition, they[14] reported that as a result of the insulation process to be formed in accordance with the standards in the building, energy savings of up to 50% can be achieved[14]. Turkan et al.[13] investigated the effect of thermal insulation on the inner surface of the building by using the lowest temperature values measured in Turkey between the years 1927-2017. The researchers[14] investigated the effect of the insulated and non-insulated state on the thermal bridge with a 3D model they created with the Comsol Multiphysics program. As a result of the research, they reported[13] that with the prevention of thermal bridge in the building, 75.3% less energy consumption per year will be realized.[13] Paraschiv et al.,[35] on the other hand, investigated the effect of energy consumption in a structure with and without insulation. Researchers[35] have reported that as a result of external insulation, energy consumption will be between 13-16% compared to the uninsulated situation.[35] Summaries of the studies carried out on the thermal bridge are given in Table 1.

Table 1. Summaries of the studies carried out on the thermal bridge

Research	Subject of study	Work Output(s)
Karabulut and Buyruk[34]	They investigated the evolution of the heat escaping from the reinforced concrete beam according to the insulated and non-insulated conditions.	In the study, they reported that 89% reduction in heat loss could be achieved if insulation was applied.
Evola et al.[28]	The effects of thermal bridge formation were studied in two building types (terrace and detached house) with reinforced concrete framed clay walls.	Researchers have reported that 25% and 17.5% heat leakage can be prevented in terraced and detached buildings, respectively, with the thermal insulation application to be established. In addition, the researchers determined that as a result of the insulation arrangement, a 3.5% benefit in cooling performance and an average of 8.5% gain in total annual energy savings can be achieved.
Jedidi and Benjeddou[27]	Researchers investigated the effect of thermal bridge on the thermal comfort in the building.	Researchers have reported that 27% reduction in heat loss can be achieved by increasing the thickness from 5 cm to 10 cm in thermal insulation application.
Dikici and Kocagul[15]	They investigated the effect of EPS, XPS and rock wool materials on heat loss in the building.	As a result of the study, they reported that the temperature value in the building, which is insulated with glass wool, changes between 9-12^{o}C, while it changes between 26-29^{o}C in the uninsulated building. In addition, they determined that the refrigerant compressor used consumes more energy in the non-insulated structure.
Şahin and Çarkacı[14]	In this study, examined the insulation application in a public building in Gümüşhane.	Researchers reported that as a result of the thermal insulation application carried out in the public building, the application was not made in accordance with TS 825 and that up to 50% energy savings could be achieved with the appropriate insulation application.
Türkan et al.[13]	They investigated the effect of the thermal bridge on the temperature change in the interior surface of the building, using the lowest temperature value of Turkey for 90 years as data.	Researchers have reported that as a result of the insulation application, an annual gain of 75.3% can be achieved in the energy consumption cost.
Paraschiv et al.[35]	In the study, the effect of insulated and non-insulated conditions on energy consumption was investigated.	Researchers have reported that as a result of external insulation, energy consumption will be between 13-16% compared to the uninsulated situation.

When Table 1 is examined, valuable results have been obtained about the thermal bridges in a building and the necessity of thermal insulation. Researchers[13,34] have determined that 89% of heat loss can be prevented with a suitable thermal insulation application and that a financial gain can be achieved from 75.3% of annual energy. In addition, they[15,27,28,34,35] reported important studies on the effect of insulation thickness on thermal bridge and energy efficiency in

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buildings. Another study on thermal bridges in the building was carried out by Yılmazoğlu,[29] (Figure 6). The researcher[29] observed the heat loss from the building envelope behind the existing floor heater in the building with the image of the thermal camera.[29]

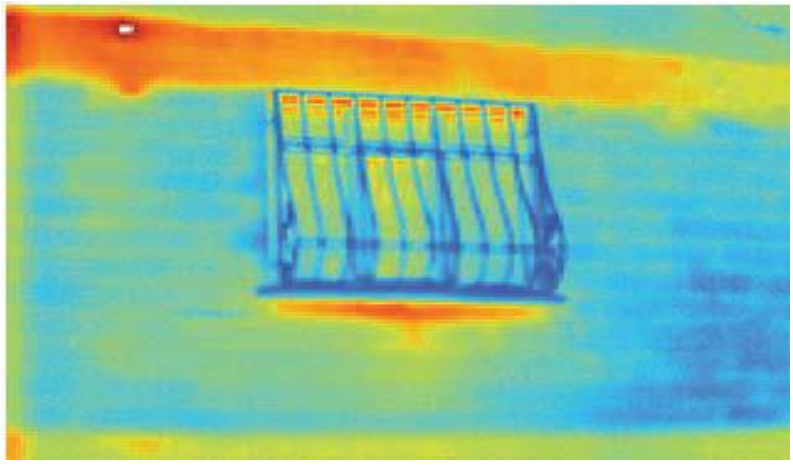

Figure 6. The thermal camera image of the area where the heating system used in the building is located[29]

In Figure 6, it is seen that the heat produced by using energy in an uninsulated building passes from the heater core under the window to the outside environment. In this case, some of the energy used for heating purposes in the building is not used in the source in accordance with its purpose. While energy is wasted, natural resources are used ineffectively.

Regarding heat loss in buildings, the Energy Performance Regulation in Buildings (EPRB), which came into force after being published in the Official Gazette in 2008, is in force in our country. Within the scope of the relevant regulation, legal regulations for energy efficiency and loss prevention in the building have been determined by the relevant institutions and organizations.[36] The legal regulations and the practices to be carried out during or after the construction of the building and the responsible parties are clearly stated. Within the scope of the same regulation, an Energy Identity Certificate is mandatory for existing building stock and new buildings. The document in question is in a very important position in terms of using energy effectively and functionally. That is, if a building is determined to be low-efficiency among the energy classes determined within the scope of EPRB, the energy level will need to be increased thermal insulation. In expansions to be made in old buildings, the energy class of the new unit must be determined. The Energy Identity Certificate issued for the existing structure is valid for 10 years, which means that it is monitored regularly. This means improving the current situation with updates to energy classes. However, thermal bridges are the most important factor that must be taken into consideration in all applications to be carried out in accordance with legal regulations. This can be achieved by complying with TS 825 Thermal Insulation Rules in Buildings and by supervising and managing all applications by competent personnel. As a result of their study, Şahin and Çarkacı stated that they will achieve 50% energy savings with thermal insulation in accordance with TS825.[14]

1.4. Thermal Bridge in the Building and Its Environmental Effects

Today, most of the energy consumed for building air conditioning is obtained from fossil fuels (coal, natural gas and petroleum derivatives).[37] The consumption of fossil fuels, which have limited reserves on the globe, is increasing day by day.[38] In 2021, 30.9% of electricity was obtained from coal in Turkey, and 33.2% of it was obtained from natural gas. In addition, electrical energy consumption in Turkey increased by 8.74% in 2021 compared to the previous year.[39]

While energy is obtained from fossil fuels, emissions such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and particulate matter (PM) occur. These emissions, which occur as a result of the combustion of fossil fuels, cause various health problems such as lung cancer, heart diseases, joint rheumatism and bronchitis on living things.[40] The gases formed as a result of the combustion process occur as a result of industrial activities as well as as a result of domestic uses. In this regard, it is recommended to switch from coal to natural gas fuels used for heating, especially in order to prevent the formation of sulfur dioxide (SO_2).[41] In winter, air pollution caused by fuels burned due to heating is felt more than in other months.[42] In addition, various residues such as fly ash and boiler slag occur as a result of the combustion of coal and its derivative fossil fuels. These combustion residues cause various health

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problems such as cancer, reproductive problems, kidney disease, heart and lung problems.[43]

Another environmental problem that occurs during the burning of fossil fuels is acid rain. Sulfur dioxide and nitrogen oxides formed as a result of combustion react with the humidity of the air and cause the formation of sulfuric acid (H_2SO_4) and nitric acid (HNO_3). As a result of this negative situation, deterioration in the chemical and biological structure of the soil occurs and causes destruction of ecosystems.[40,44] In addition, it should not be forgotten that by 2100, it is estimated that petroleum-derived fuels and natural gas will be nearly exhausted and coal will be exhausted around 2150.[45] In this regard, it is very important for sustainability to reduce fossil fuel-related losses and to focus on alternative sources.

Carbon dioxide (CO_2) emission, which occurs as a result of the burning of fossil fuels due to the carbon element in its structure, tends to accumulate in the atmosphere together with other greenhouse gases. As a result of this accumulation, it causes an increase in temperature in regions close to the earth. With the increase in greenhouse gases accumulating in the atmosphere, the temperature of the earth increases day by day, causing an environmental problem known as global warming or climate change today.[8] As a result of the global climate change problem, there will be an increase in various environmental problems such as difficulties in accessing food, an increase in natural disasters such as drought and flood, melting of glaciers and rising oceans. In addition, there will be an increase in the spread of various infectious diseases around the world.[46]

The construction sector consumes one third of the final energy used, causing carbon dioxide emissions worldwide at the same rate. The current use value in energy consumption is expected to increase by 53% in the next ten years.[47] For this reason, it has a very important place in global warming and climate change policies, as reducing the energy used in the construction sector will directly lead to a reduction in carbon dioxide emissions.[48,49] At this stage, it is necessary to effectively use the energy consumed for air conditioning, to prevent the thermal bridge in the building and to maximize energy efficiency.[50]

2. CONCLUSION

The concept of thermal bridge must be well understood in terms of heat efficiency and reducing energy losses in the building. In this review study, the importance of the thermal bridge in the building is mentioned and basic information is given about the precautions to be taken and the legal legislation. In addition, the damage of the thermal bridge to the structure is mentioned and its damage to the living creatures living within it is discussed within the framework of the concept of sustainability. Karabulut and Buyruk[34] reported in their research that heat loss can be reduced by 89% by applying insulation in the building. Fossil fuels used to provide this lost energy are among the exhaustible raw materials with limited reserves on earth. Turkan et al. [13] In their study, they reported that 75.3% of annual energy use could be saved thanks to insulation application. These results mean that sustainable raw material management and energy efficiency can be maintained by protecting fossil fuels more and losing less energy. It is among the responsibilities of people living today to transfer the raw materials available in our world to future generations.

Combustion products such as carbon dioxide, carbon monoxide, sulfur oxides, nitrogen oxides and methane, which are formed as a result of energy production, cause lung diseases, heart diseases and respiratory problems as a result of inhalation by living things. In addition, combustion products cause pollution of the air we breathe and directly trigger the problems of global warming and climate change. Considering the construction sector as a whole, which has high energy requirements, it is necessary to protect the currently consumed energy and reduce heat loss. In addition, raising awareness in this area is also socially important.

Carbon dioxide reduction policies are implemented worldwide in global warming and climate change policies. However, the importance of thermal bridge and thermal insulation in combating climate change is not yet fully known. When a building is being constructed, both thermal comfort and sustainable energy management will be achieved by applying thermal insulation in accordance with legal legislation, especially TS825 Thermal Insulation Rules in Buildings. Şahin and Çarkacı[14] determined that construction was not carried out in accordance with the relevant regulatory in the existing insulated building in Gümüşhane province, and the researchers reported that energy savings of up to 50% could be achieved as a result of full compliance with the current regulation. Since our country is dependent on foreign sources for energy supply, every saving step will contribute to the country's economy and will also reduce the cost of electricity reaching the end user. In addition, the structure will be protected from the effects of moisture and can be used for a longer time.

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Conflict of interest

I declare that there is no a conflict of interest with any person, institute, company, etc.

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