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Original Article

# Calculation of energy consumption and emissions of buildings in capitals of european with the degree-day method

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## ABSTRACT

In this study, firstly, for the building envelope properties of a reference building from TS 825 insulation standard, for 20 capitals selected from Europe, the minimum insulation thicknesses are calculated with different heat transmission coefficients depending on the requirements and/or recommendations thermal transmittance values in the building envelope such as building walls, roofs, floors. Then, $CO_2$ and $SO_2$ emissions, which will be produced by the consumption of coal, natural gas, and fuel-oil fuels, depending on the heating degree-day values and the thermal transmittance values of the building envelope, are investigated for the 20 selected capitals. In the cooling period, depending on the cooling degree-days and the thermal transmittance values of the building envelope, the electricity consumption and the $CO_2$ and $SO_2$ emissions to be released for the coal, natural gas, and fuel oil used in the production of electricity in the power plants are determined. The place of Ankara, the capital of our country, among the selected capitals in European countries has been examined. It has been calculated that Sarajevo, the capital of Bosnia-Herzegovina, has the highest fuel consumption and the highest $CO_2$ and $SO_2$ emissions for three building components and three fuel types for heating. In the study, the highest thermal transmittance value recommended for floor was found to be Athens with 1.90 $W/m^2.K$. Accordingly, it has been determined that the highest electricity consumption for cooling and the highest associated $CO_2$ and $SO_2$ emission values occur in Athens, the capital of Greece.

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## 1. INTRODUCTION

Global energy demand has been growing exponentially. It is of international importance to try to reduce the $CO_2$ emissions that will occur due to energy consumption and to reduce climate change. In this context, Europe is responsible for around 40% of the world's total energy consumption. More than 25% of this energy consumption in Europe comes from residences alone and represents the largest energy consumption sector [1, 2]. Within the scope of energy efficiency, the European Union (EU) has set a target of approximately 30% reduction in energy use in buildings and 40% reduction in greenhouse gas (GHG) emissions by 2030 [3].

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The primary purpose of policies and regulations regarding sustainable energy for buildings is to improve the performance of buildings to minimize their energy consumption and reduce their carbon footprint without compromising standard usage requirements such as the thermal comfort of building occupants [4].

The degree days method (DD) is a versatile climate indicator that is widely used in the analysis of building energy performance. With the degree-day method, energy evaluation of existing and new buildings can be made, regional energy consumption can be analyzed, energy consumption estimation analyzes can be developed. The importance of the degree days method is that it can make quick analyzes in various fields and for different purposes [1].

Ozkan D. B. and Onan C. [5], investigated the effects of different insulation thicknesses and the consumption of natural gas and fuel oil fuels on the emissions of pollutants such as $CO_2$ and $SO_2$. deLlano-Paz F., Calvo-Silvosa A., Iglesias Antelo S., Soares I. [6] applied portfolio theory to both economically and environmentally efficient electricity production. With their model, they include all production costs for different technologies and a series of measures related to the risk arising from them and the emission of polluting gases such as carbon dioxide, sulfur dioxide, nitrogen oxides and particulate matter. Çay Y. ̧ Gürel A. E. [7] analyzed the effect of insulation thickness on the emission of $CO_2$ and $SO_2$ emissions. D'Agostino D., Cuniberti B., Bertoldi P. [8] presented the overall results of data collected by the Green Building Program (GBP), launched in 2006 to promote and improve energy efficiency in new and existing European non-residential buildings. Rodríguez-Soria B., Domínguez-Hernández J., M. Pérez-Bella J., Coz-Díaz J. J. [9] showed that countries set different permeability values defined on the basis of different degree-day variation intervals for each climate zone. They propose a new methodology that can be used to regulate the thermal insulation of buildings in all countries to ultimately harmonize the energy losses of the building envelope. Christenson M., Manz H., Gyalistras D. [10], in their study, the effect of climate change on Swiss building energy demand was investigated by degree-day method. A procedure was developed, tested and applied to four different Swiss locations to estimate heating degree days (HDD) and cooling degree days (CDD) from monthly temperature data. Rosa M. D., Bianco V., Scarpa F., Tagliafico L. [1] a compared the simplified methods based on reduced climatic data set with reference to the mean daily degree-hour method (MDDH). Rosa M. D., Bianco V., Scarpa F., Tagliafico L. A. [11] proposed a simple dynamic model to simulate heating/cooling energy consumption in buildings. The study analyzed the cooling energy demand on low-cooling days (CDDs) and explained that other factors such as solar radiation play an important role in this case. Ramírez-Villegas R., Eriksson O., Olofsson T. [3] investigate the effect of different building renovation strategies on the energy rating of a selected Building Environmental Assessment Tool and analyze the results in terms of GHG emissions for the local and district heating system. Annunziata E., Frey M., Rizzi F. [12] conducted a survey among 27 European Union Member States on energy efficiency in buildings, energy policy and strategy in Europe. Meng Q., Mourshed M. [13] examined four-year (2012–2016) half-hourly measured gas consumption from 119 non-residential buildings, and their relationship to baseline temperatures and their internal structure parameters using a three-parameter change-point regression model. Al-Hadhrami L.M., [14] in their study, annual and seasonal cooling (CDD) and heating (HDD) degree-day values for Saudi Arabia were presented using long-term average daily temperatures from 38 meteorological stations. Akıner İ., Akıner M. E., Tijhuis W. [15] selected cities from different regions of the country to examine the effects of local climate on energy use in energy-efficient buildings. In the study, Heating Degree Days (HDD) and Cooling Degree Days (CDD) values are used to estimate the energy demand for heating and cooling buildings. Pusat S., Ekmekci I. [16] compared a different climate belt approach proposed by the International Energy Agency (IEA) with respect to both heating and cooling degree-day data obtained from Typical Meteorological Year (TMY) data. Meng Q., Mourshed M., Wei S. [4] in their study, a change point regression technique was proposed to better define the baseline temperature and then applied in buildings with different operational energy use patterns. Spinoni J., Vogt J. V., Barbosa P., Dosio A., McCormick N., Bigano A., Füssel H.-M [17] took into account heating degree-days (HDD) and cooling degree-days (CDD) in relation to energy consumption for heating and cooling of buildings. An N., Turp M. T., Akbaş A., Öztürk Ö., Kurnaz M. L. [18] investigated how the heating and cooling days will change in the future with climate change in Turkey according to the RCP8.5 scenario for intense greenhouse gas emissions. Altun M., Akçamete A., Akgül Ç. M. [19] examined the effect of the outside temperature data on the building heating energy requirement and the validity of the DGBs (Degree day region) created from the TS 825 standard according to the outdoor temperature data. In this context, the validity of DGBs and the effectiveness of the updates made in the standard were examined by evaluating them separately for 81 provinces. Çomaklı, K. and Yüksel, B. [20] examined the effect of air pollution as a result of the burning of fossil fuels used to heat buildings in cold cities such as Erzurum. They found that with low quality fuel consumption, it causes very high air pollution and poor air quality for space heating. In the study, they investigated the environmental effects of thermal insulation used to reduce heat losses in buildings. Bolattürk A. [21] determined the optimum insulation thickness on the exterior walls of buildings. The study used the degree-hour method of estimating the annual energy consumption of the building. Goggins J., Moran P., Armstrong A., and Hajdukiewicz M. [22] to assess the contribution of changes in building codes to both the construction and operation of buildings' life cycles, they presented the case study for environmental and economic life cycle assessment of buildings in Ireland.

The aim of the study is to investigate the $CO_2$ and $SO_2$ emissions that will occur by using coal, natural gas, fuel-oil consumptions of the buildings heating period and the coal, natural gas and fuel oil used in power plants cooling period, depending on the heating and cooling degree-day values and the building envelope thermal transmittance values for 20 selected European capitals. The different climate and building envelopes with different thermal transmittance values accepted in Europe were selected. Among these 20 capitals, Ankara, the capital of our country, in terms of energy consumption and emission consumption has been examined. In the study, the minimum insulation thicknesses were calculated for the 20 capital cities selected from Europe, for the insulation materials, which are considered different heat transmission coefficients depending on the thermal transmittance values recommended in the building envelope, such as building walls, roofs, floors. It has been examined what can be done to reduce $CO_2$ and $SO_2$ emissions, depending on the thermal transmittance value of the building envelope of Ankara, by comparing it with other selected European countries.

## 2. MATERIAL AND METHOD

### 2.1 Building Envelope Insulation Thickness and Heating and cooling Energy Consumption Equations

Insulation thicknesses for building envelope;

$$d_{ins}=\lambda_{ins}\cdot\left(\frac{1}{U}-R_{si}-R-R_{se}\right) \quad (1)$$

Where U is thermal transmittance value, $R_{si}$ and $R_{se}$ are the internal and external surface thermal resistance, R is other thermal resistance of the structural component and $\lambda_{ins}$ is the thermal conductivity coefficient of the insulation material [20–23].

The amount of fuel consumed per year during the heating period,

$$M_{F_H}=\frac{86400.U.HDD}{H_u.\eta} \quad (2)$$

In the cooling period, the amount of electricity consumed per year,

$$M_{F_C}=\frac{86400.U.CDD}{COP} \quad (3)$$

Here, HDD is degree-day, CDD is cooling degree-day, COP (taken as 2.5) is cooling system coefficient of performance, $H_u$ is lower heating value (LHV) of fuel and η is heating system efficiency [5, 7, 20, 21]. For heating degree-days and cooling degree-days the last three year period were taken into account. Heating degree-days (HDD) cover the days of the months in which the heating is made, these are generally the sum of the days of January, February, March, April, November, and December. Cooling degree-days, on the other hand, cover the days of the months in which the cooling is done; these are generally the sum of the days of June, July, August, and September. May and October are defined as the transition months when heating and cooling are not done.

### 2.2 Combustion Equations

Combustion equation of fuel;

$$C_aH_bO_zS_pN_q + \alpha.\ A.\ (O_2+3.76\ N_2)\ aCO_2 + (b/2)\ H_2O + pSO_2 + B\ O_2 + D\ N_2 \quad (4)$$

Here, A, B and D are;

$$A=(a+b/4+p-z/2) \quad (5)$$

$$B=(\alpha-1)\ (a+b/4+p-z/2) \quad (6)$$

$$D=3.76\ \alpha\ (a+b/4+p-z/2)+q/2 \quad (7)$$

$C_aH_bO_zS_pN_q$ is overall chemical formula of fuel. $CO_2$ and $SO_2$ emissions produced by the combustion of 1 kg of fuel;

$$M_{CO_2}=\frac{a.CO_2}{M} \quad (kg\ CO_2/\ kg\ fuel) \quad (8)$$

$$M_{SO_2}=\frac{p.SO_2}{M} \quad (kg\ SO_2/\ kg\ fuel) \quad (9)$$

If the right side of the above equations is derived by writing the total amount of fuel burned in $M_P$, the total emissions of $CO_2$ and $SO_2$ are found as follows.

$$M_{CO_2}=\frac{44.CO_2}{M}.M_F \quad (kg\ CO_2/m^2year) \quad (10)$$

$$M_{SO_2}=\frac{64.SO_2}{M}.M_F \quad (kg\ SO_2/m^2year) \quad (11)$$

M is the molar weight of the fuel and is found as follows. Where a, b, z, p, q are the combinations of the elements in the chemical formula of the fuels, α is air excess coefficient, which is one of the effective parameters in the combustion of fuel and A indicates the minimum amount of oxygen required for the combustion process [5, 7, 20, 21].

$$M=12.a+b+16.z+32.p+14.q\ (kg/kmol) \quad (12)$$

### 2.3 The values used in the calculations

In the study, the characteristics of the fuels used in European capitals during the heating period are shown in Table 1. In Table 1, LHV is the lower heating value and η is the theoretical efficiency of the combustion system. The lowest recommended thermal transmittance value for the wall is

**Table 1.** The chemical formulas of fuels [7]

| Fuel | Chemical Formula | LHV (Hu) | Efficiency (η) |
|---|---|---|---|
| Coal | $C_{7.074} H_{5.149} O_{0.521} S_{0.01} N_{0.086}$ | 29.295×10$^6$ J/kg | 0.65 |
| Natural gas | $C_{1.269} H_{4.516} O_{0.024} N_{0.012}$ | 34.526×10$^6$ J/m$^3$ | 0.93 |
| Fuel-oil | $C_{7.3125} H_{10.407} O_{0.04} S_{0.026} N_{0.02}$ | 40.594×10$^6$ J/kg | 0.80 |

**Table 2.** Requirements and/or recommendations for cities in Europe thermal transmittance values for walls, roofs and floors (U-value W/m²K) [24]

| City | Country | Wall | Roof | Floor |
|---|---|---|---|---|
| Tirana | Albania | 0.53 | 0.38 | 0.59 |
| Bruxelles | Belgium | 0.60 | 0.40 | 1.20 |
| Sarajevo | Bosnia-Herzegovina | 0.80 | 0.55 | 0.65 |
| Sofia | Bulgaria | 0.50 | 0.30 | 0.50 |
| Prag | Czech Republic | 0.30 | 0.24 | 0.45 |
| Berlin | Germany | 0.30 | 0.20 | 0.40 |
| Madrid | Spain | 0.66 | 0.38 | 0.66 |
| Tallinn | Estonia | 0.25 | 0.16 | 0.25 |
| Helsinki | Finland | 0.25 | 0.16 | 0.25 |
| Paris | France | 0.36 | 0.20 | 0.27 |
| Athens | Greece | 0.70 | 0.50 | 1.90 |
| Budapest | Hungary | 0.45 | 0.25 | 0.50 |
| Roma | Italy | 0.50 | 0.46 | 0.46 |
| Skopje | Macedonia | 0.90 | 0.60 | 0.75 |
| Amsterdam | The Netherlands | 0.37 | 0.37 | 0.37 |
| Oslo | Norway | 0.18 | 0.13 | 0.18 |
| Warschau | Poland | 0.30 | 0.30 | 0.60 |
| Stockholm | Sweden | 0.18 | 0.13 | 0.15 |
| Beograd | Serbia | 0.90 | 0.65 | 0.75 |
| Ankara | Turkey | 0.48 | 0.28 | 0.43 |

**Table 3.** Heating and cooling degree-days for cities in Europe [25]

| City | Country | Heating degree-day 19.5°C | Cooling degree-day 22°C |
|---|---|---|---|
| Tirana | Albania | 1981 | 406 |
| Bruxelles | Belgium | 3247 | 55 |
| Sarajevo | Bosnia-Herzegovina | 3579 | 173 |
| Sofia | Bulgaria | 3232 | 242 |
| Prag | Czech Republic | 3292 | 151 |
| Berlin | Germany | 3407 | 103 |
| Madrid | Spain | 2270 | 583 |
| Tallinn | Estonia | 4678 | 20 |
| Helsinki | Finland | 4833 | 27 |
| Paris | France | 2926 | 115 |
| Athens | Greece | 1413 | 734 |
| Budapest | Hungary | 3293 | 226 |
| Roma | Italy | 1811 | 370 |
| Skopje | Macedonia | 2974 | 369 |
| Amsterdam | The Netherlands | 3194 | 32 |
| Oslo | Norway | 5021 | 13 |
| Warschau | Poland | 3789 | 110 |
| Stockholm | Sweden | 4344 | 22 |
| Beograd | Serbia | 2841 | 310 |
| Ankara | Turkey | 3430 | 264 |

Oslo and Stockholm with 0.18 W/m$^2$.K, and the highest value is Skopje and Beograd with 0.90 W/m$^2$.K. The lowest recommended value for the roof is Oslo and Stockholm with 0.13 and the highest value is Beograd with 0.65 W/m$^2$.K. The lowest recommended value for flooring is Stockholm with 0.15 W/m$^2$.K and the highest value is Athens with 1.90 W/m$^2$.K. These are given in Table 2.

The highest heating degree-day values occur in Oslo, Helsinki, and Tallinn, and the lowest in Athens, Rome, and Tirana. The highest cooling degree-day values occur in Athens, Madrid, and Tirana, and the lowest in Oslo, Tallinn, and Stockholm. These values and other European heating and cooling degree-day values are given in Table 3. Here, the heating degree-days (HDD) value during the year is the sum of the temperature values 19.5°C below the daily temperature. Cooling degree-days (CDD) is the sum of the temperature values above 22°C of the year. The daily average of the last three years is taken. The building envelope components used to find the minimum insulation thickness depending on the building envelope requirements and/or recommendations thermal transmittance values for European capitals and taken as an example according to TS 825 are shown in Table 4. In Table 5, the $CO_2$ and $SO_2$ emission factors released to the environment for electricity-generating power plants are given.

## 3. RESULTS AND DISCUSSION

### 3.1 Insulation Thicknesses for Different Thermal Transmittance Values

For the thermal conductivity coefficient values between 0.01 to 0.07 W/m.K, the minimum insulation thickness value for the external walls was calculated between 0.004 to 0.026 m in Skopje and Beograd, and the highest thickness between 0.048 to 0.337 m in Oslo and Stockholm. In Helsinki, it was calculated as 0.033–0.228 m. The average value of the minimum insulation thickness of these 20 selected capitals was calculated between 0.019 to 0.133 m. The insu-

**Table 4.** Reference building components for external wall, roof, and floor [23]

| Component | Thickness (m) | Heat conductivity coefficient (W/m.K) |
|---|---|---|
| External wall | | |
| Internal plaster | 0.020 | 1.000 |
| Horizontal brick | 0.190 | 0.360 |
| Insulation | --- | --- |
| External plaster | 0.008 | 0.350 |
| Roof | | |
| Internal plaster | 0.020 | 1.000 |
| Concerete | 0.120 | 2.500 |
| Insulation | --- | --- |
| Floor | | |
| PVC floor covering | 0.005 | 0.230 |
| Screed | 0.030 | 1.400 |
| Insulation | --- | --- |
| Leveling screed | 0.020 | 1.400 |
| Lightweight concrete | 0.100 | 1.100 |

**Table 5.** Gases harmful to the environment and human health (GHEH) emission amounts produced during electricity generation in power plants [6]

| GHEH | Coal | Natural gas | Oil |
|---|---|---|---|
| $CO_2$ (kg/kWh) | 0.7341 | 0.3561 | 0.5465 |
| $SO_2$ (gr/kWh) | 0.0735 | 0.0088 | 0.0547 |

lation thickness for Ankara is calculated between 0.013 to 0.094 m. This value is between the average values of the 20 selected European capitals. These values are given in Figure 1. The minimum value of the insulation thicknesses for the roof was calculated between 0.013 to 0.092 m in Beograd, and the highest thickness between 0.075 to 0.523 m in Oslo and Stockholm. In Helsinki, it is calculated as 0.060–0.422 m. The average value of the minimum insulation thickness of these 20 selected capitals was calculated between 0.035 to 0.248 m. The thickness of the insulation for Ankara is calculated between 0.034 to 0.234 m. This value is also between the average values of the 20 selected European capitals. These values are shown in Figure 2. The minimum value of the insulation thicknesses for the floor was calculated between 0.002 to 0.013 m in Athens, and the highest thickness between 0.063 to 0.443 m in Stockholm. In Oslo, it is 0.052–0.365 m, and in Helsinki, it is 0.037–0.257 m. The average value of the minimum insulation thickness of these 20 selected capitals was calculated between 0.022–0.153 m. The thickness of the insulation for Ankara is calculated between 0.020 to 0.139 m. This value is between the average values of the 20 selected European capitals. These are given in Figure 3. In Scandinavian countries such as Sweden, Norway and Finland, the thermal transmittance values of the building shell are much lower than in other countries in Europe and the insulation thicknesses are higher because they have a colder climate.

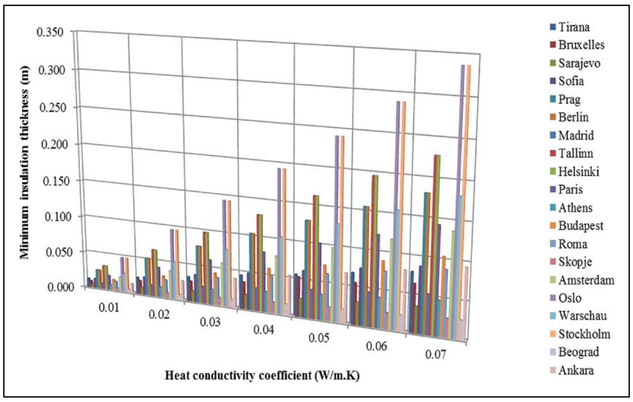


**Figure 1**. Minimum insulation thicknesses for external wall depending on different heat conductivity coefficients.

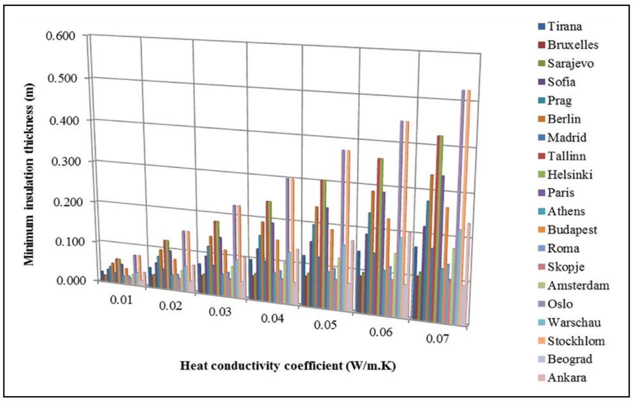


**Figure 2**. Minimum insulation thicknesses for roof depending on different heat conductivity coefficients.

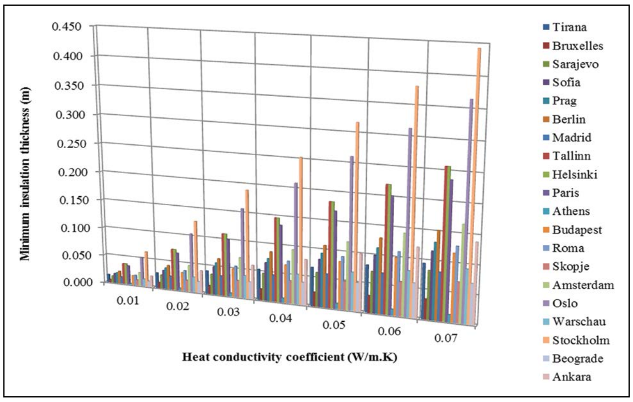


**Figure 3**. Minimum insulation thicknesses for floor depending on different heat conductivity coefficients.

### 3.2 $CO_2$ and $SO_2$ Emission Values

For the heating period, the highest natural gas consumption is 7.704 kg/$m_2$ in Sarajevo, depending on the wall structure. Based on natural gas consumption, $CO_2$

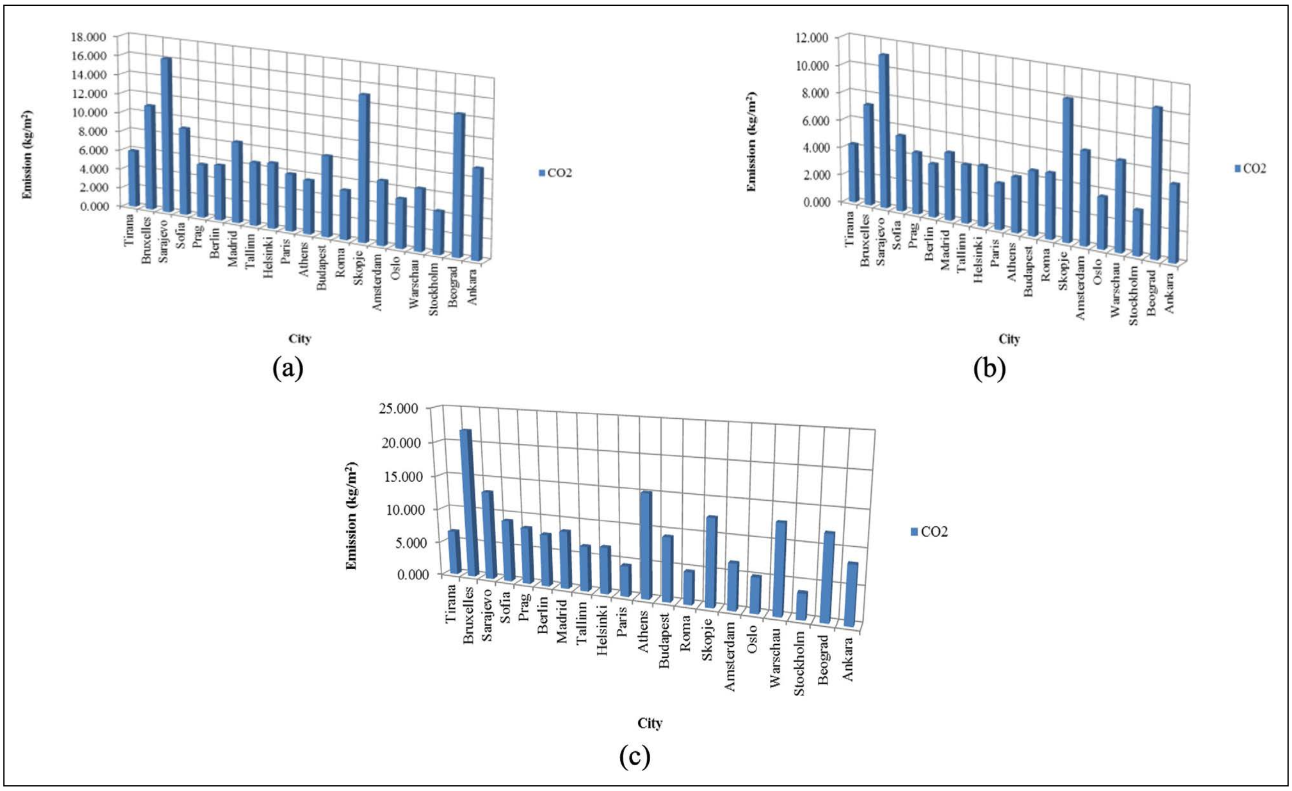


**Figure 4**. $CO_2$ emission to be generated by consuming natural gas for the heating period for **(a)** external wall area **(b)** roof area **(c)** floor area.

emissions are calculated as 16.109 kg/m$^2$ in Sarajevo. The lowest natural gas consumption was found in Stockholm as 2.104 kg/m$^2$. Based on natural gas consumption, $CO_2$ emissions are calculated as 4.399 kg/m$^2$ in Stockholm. The average natural gas consumption for these capitals is 3.858 kg/m$^2$, and $CO_2$ emission is 8.067 kg/m$^2$. Ankaras' natural gas consumption is 4.430 kg/m$^2$ and $CO_2$ emission is 9.263 kg/m$^2$. It is higher than the average of the 20 selected European capitals. Depending on the roof structure, the highest natural gas consumption is 5.297 kg/m$^2$ in Sarajevo. Depending on the natural gas consumption, the $CO^2$ emission in Sarajevo is calculated as 11.076 kg/m$^2$. The lowest natural gas consumption was 1.502 kg/m$^2$ in Stockholm. Based on natural gas consumption, $CO_2$ emissions are calculated as 3.178 kg/m$^2$ in Stockholm. The average natural gas consumption for these capitals is 2.680 kg/m$^2$ and $CO_2$ emissions are 5,604 kg/m$^2$. Ankaras' natural gas consumption was found as 2.584 kg/m$^2$ and $CO_2$ emission was found as 5,403 kg/m$^2$. These are slightly lower than the average of the 20 selected European capitals. Depending on the floor structure, the highest natural gas consumption occurs in Bruxelles as 10.484 kg/m$^2$. Depending on the natural gas consumption, the $CO_2$ emission was calculated as 21.922 kg/m$^2$ in Bruxelles. The lowest natural gas consumption was found in Stockholm as 1.753 kg/m$^2$. Based on natural gas consumption, $CO_2$ emissions are calculated as 3.666 kg/m$^2$ in Stockholm. The average natural gas consumption for these capitals is 4.376 kg/m$^2$, and $CO_2$ emissions are 9.151 kg/m$^2$. Ankaras' natural gas consumption was found to be 3.969 kg/m$^2$ and $CO_2$ emission was calculated as 8.299 kg/m2. It is lower than the average of the 20 selected European capitals. These values are given in Figure 4.

Depending on the wall structure for the heating period, the highest coal consumption is 12.991 kg/m$^2$ in Sarajevo. Based on coal consumption, $CO_2$ emissions are calculated as 40.480 kg/m$^2$ and $SO_2$ emissions 0.083 kg/m$^2$ in Sarajevo. The lowest coal consumption was 3.548 kg/m$^2$ in Stockholm. Based on coal consumption, the $CO_2$ emission was calculated as 11.056 kg/m$^2$ and the $SO_2$ emission was 0.023 kg/m$^2$ in Stockholm. The average coal consumption for these capitals is 6.506 kg/m$^2$, $CO_2$ emissions are 20.273 kg/m$^2$ and $SO_2$ emissions are 0.042 kg/m$^2$. Ankaras' coal consumption is 7.470 kg/m$^2$, $CO_2$ emission is 23.277 kg/m$^2$ and $SO_2$ emission is 0.048 kg/m$^2$. It is higher than the average of the 20 selected European capitals. Depending on the roof structure, the highest coal consumption is 8.914 kg/m$^2$ in Sarajevo. Depending on the coal consumption, the $CO_2$ emission was calculated as 27.776 kg/m$^2$ and the $SO_2$ emission was 0.057 kg/m$^2$ in Sarajevo. The lowest coal consumption was found in Stockholm as 2.562 kg/m$^2$. Depending on the coal consumption, the $CO_2$ emission was calculated as 7.983 kg/m$^2$ and the $SO_2$ emission was 0.016 kg/m$^2$ in Stockholm. The average coal consumption for these capitals is 4.519 kg/m$^2$, $CO_2$ emissions are 14.080

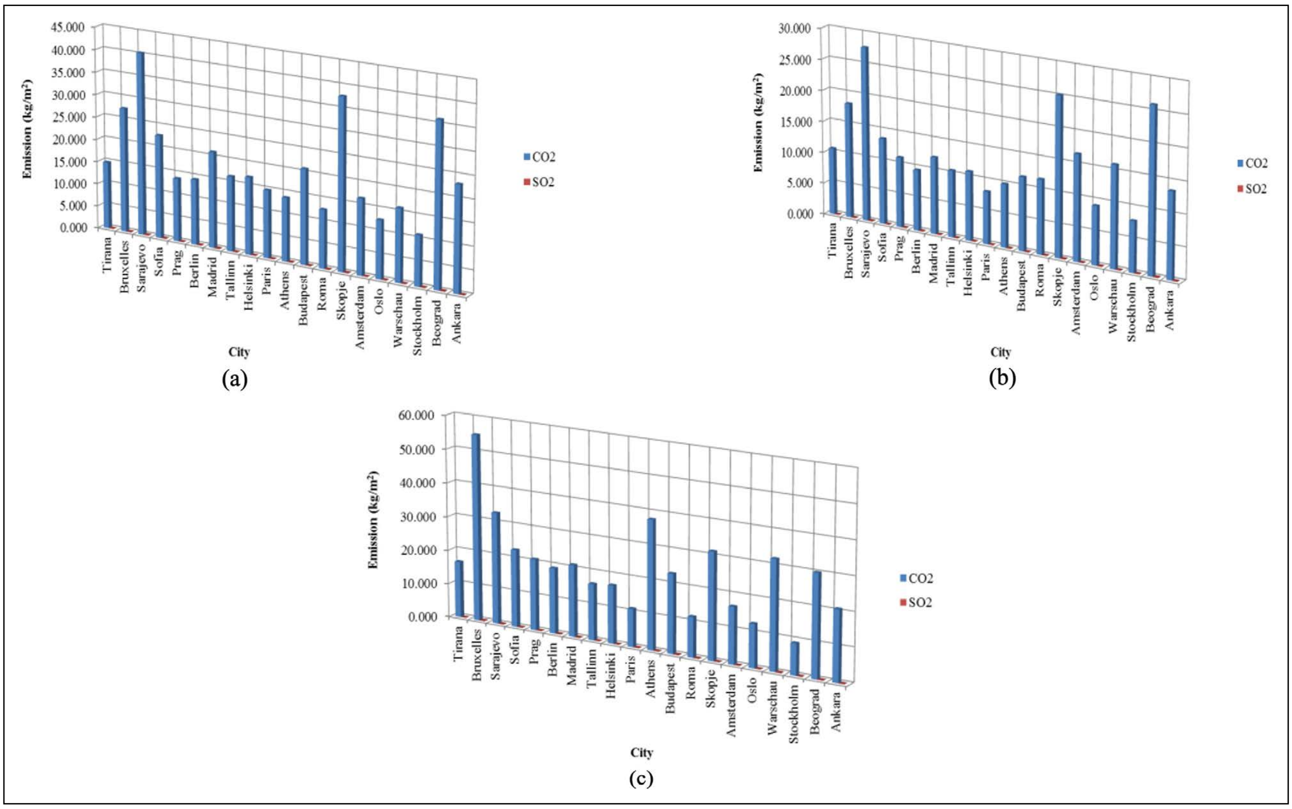


**Figure 5**. $CO_2$ and $SO_2$ emissions that will occur with the consumption of coal for heating period for **(a)** external wall area **(b)** roof area **(c)** floor area.

kg/m² and $SO_2$ emissions are 0.029 kg/m². Ankaras' coal consumption is 4.358 kg/m², $CO_2$ emission is 13.580 kg/m² and $SO_2$ emission is 0.028 kg/m². These are slightly lower than the average of the 20 selected European capitals. Depending on the floor structure, the highest coal consumption is 17.680 kg/m² in Bruxelles. Depending on the coal consumption, the $CO_2$ emission is calculated as Bruxelles 55.091 kg/m² and the $SO_2$ emission is 0.113 kg/m². The lowest coal consumption was found in Stockholm at 2.957 kg/m². Based on coal consumption, $CO_2$ emissions are calculated as 9.214 kg/m² and $SO_2$ emissions 0.019 kg/m² in Stockholm. The average coal consumption for these capitals is 7.380 kg/m², $CO_2$ emissions are 22.996 kg/m² and $SO_2$ emissions are 0.047 kg/m². Ankaras' coal consumption was found to be 6.692 kg/m², $CO_2$ emission was 20.852 kg/m² and $SO_2$ emission was 0.043 kg/m². It is lower than the average of the 20 selected European capitals. These values are given in Figure 5.

Depending on the wall structure for the heating period, the highest fuel-oil consumption is 7.618 kg/m² in Sarajevo. Based on fuel-oil consumption, $CO_2$ emissions are calculated as 24.530 kg/m² and $SO_2$ emissions 0.130 kg/m² in Sarajevo. The lowest fuel oil consumption was 2.080 kg/m² in Stockholm. Based on fuel-oil consumption, $CO_2$ emissions are calculated as 6.698 kg/m² and $SO_2$ emissions 0.035 kg/m² in Stockholm. The average fuel-oil consumption for these capitals is 3.815 kg/m², $CO_2$ emissions are 12.283 kg/m² and $SO_2$ emissions are 0.065 kg/m². Ankaras' fuel-oil consumption was 4.380 kg/m², and depending on fuel-oil consumption, $CO_2$ emission was 14.104 kg/m² and $SO_2$ emission was 0.074 kg/m². It is higher than the average of the 20 selected European capitals. Depending on the roof structure, the highest fuel-oil consumption is 5.237 kg/m² in Sarajevo. Based on fuel-oil consumption, $CO_2$ emissions were calculated as 16.863 kg/m² and $SO_2$ emissions were calculated as 0.089 kg/m² in Sarajevo. The lowest fuel-oil consumption was found in Stockholm as 1.502 kg/m². Based on fuel-oil consumption, $CO_2$ emissions are calculated as 4.836 kg/m² and $SO_2$ emissions as 0.026 kg/m² in Stockholm. Average fuel oil consumption for these capitals is 2.650 kg/m², $CO_2$ emissions are 8.533 kg/m² and $SO_2$ emissions are 0.045 kg/m². Ankara fuel-oil consumption was found to be 2.555 kg/m², and depending on fuel-oil consumption, $CO_2$ emission was found to be 8.227 kg/m² and $SO_2$ emission was 0.043 kg/m². These are slightly lower than the average of the 20 selected European capitals. Depending on the flooring structure, the highest fuel-oil consumption occurs in Bruxelles at 10.366 kg/m². Depending on the fuel-oil consumption, the $CO_2$ emission in Bruxelles is 33.379 kg/m² and the $SO_2$ emission is 0.176 kg/m². The lowest fuel-oil consumption was found in Stockholm at 1.734 kg/m². Depending on the fuel-oil con-

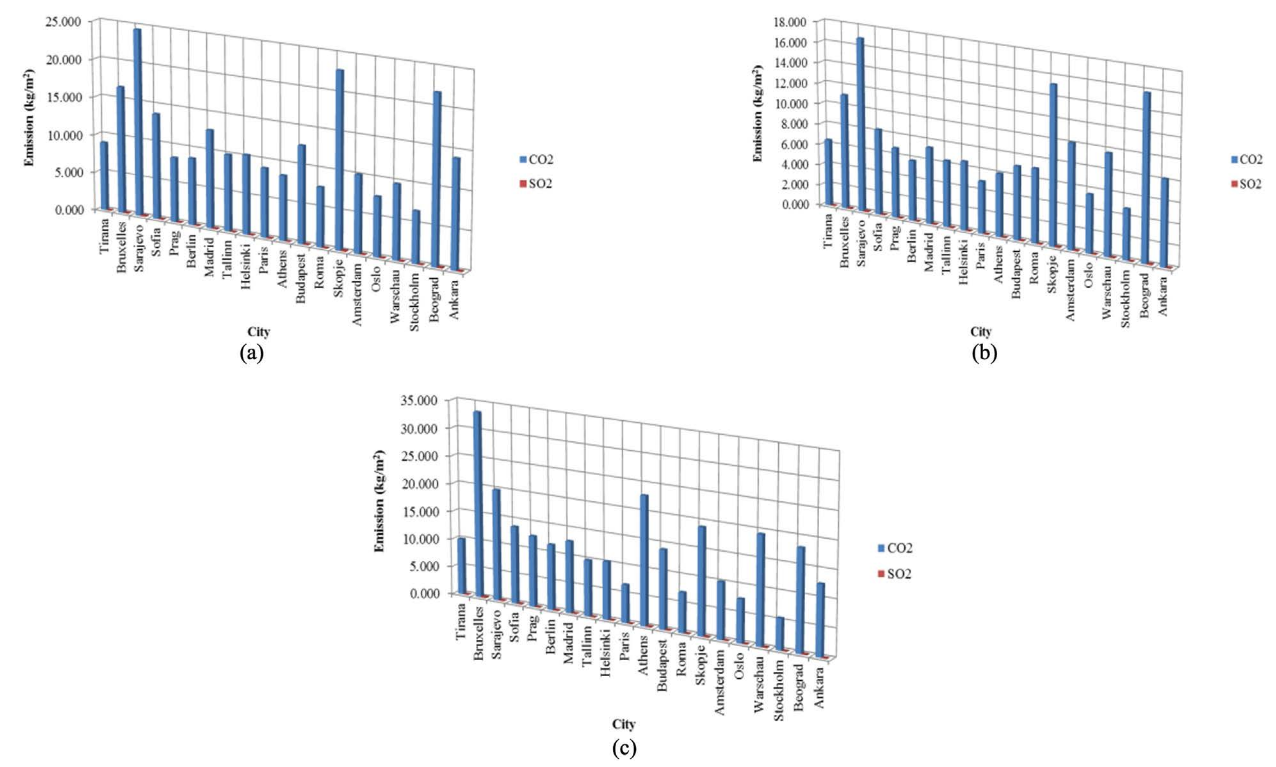


**Figure 6**. $CO_2$ and $SO_2$ emissions from fuel-oil consumption for heating period for **(a)** external wall area **(b)** roof area **(c)** floor area.

sumption, the $CO_2$ emission was calculated as 5.583 kg/m$^2$ and the $SO_2$ emission was 0.029 kg/m$^2$ in Stockholm. For these capitals, the average fuel oil consumption is 4.327 kg/m$^2$, $CO_2$ emissions are 13.933 kg/m$^2$ and $SO_2$ emissions are 0.074 kg/m$^2$. Ankara fuel-oil consumption was found to be 3.924 kg/m$^2$, and depending on fuel-oil consumption, $CO_2$ emission was 12.635 kg/m$^2$ and $SO_2$ emission was 0.067 kg/m$^2$. It is lower than the average of the 20 selected European capitals. These values are given in Figure 6.

For the cooling period, the highest electricity consumption is 4.936 kWh/m$^2$ in Athens, depending on the wall structure. Based on natural gas consumption power plant, $CO_2$ emissions are calculated as 1.758 kg/m$^2$ and $SO_2$ emissions as 0.0000434 kg/m$^2$ in Athens. The lowest electricity consumption is 0.022 kWh/m$^2$ in Oslo. Based on natural gas consumption, $CO_2$ emissions are calculated as 0.008 kg/m$^2$ and $SO_2$ emissions as 0.0000002 kg/m$^2$ in Oslo. The average electricity consumption for these capitals is 1.254 kWh/m$^2$, $CO_2$ emission is 0.447 kg/m$^2$ and $SO_2$ emission is 0.0000110 kg/m$^2$. Ankaras' electricity consumption is 1.217 kg/m$^2$ and $CO_2$ emission is 0.433 kg/m$^2$ and $SO_2$ emission is 0.0000107 kg/m$^2$ depending on natural gas consumption. It is lower than the average of the 20 selected European capitals. Depending on the roof structure, the highest electricity consumption is 3.526 kWh/m$^2$ in Athens. Based on natural gas consumption, $CO_2$ emissions are calculated as 1.256 kg/m$^2$ and $SO_2$ emissions 0.0000310 kg/m$^2$ in Athens. The lowest electricity consumption was 0.016 kWh/m$^2$ in Oslo. Based on natural gas consumption, $CO_2$ emissions are calculated as 0.006 kg/m$^2$ and $SO_2$ emissions as 0.000001 kg/m$^2$ in Oslo. Average electricity consumption for these capitals is 0.861kWh/m$^2$, $CO_2$ emission is 0.307 kg/m$^2$ and $SO_2$ emission is 0.000076 kg/m$^2$. Ankaras' electricity consumption is 0.710 kWh/m$^2$ and $CO_2$ emission is 0.253 kg/m$^2$ and $SO_2$ emission is 0.0000062 kg/m$^2$ depending on natural gas consumption. It is lower than the average of the 20 selected European capitals. Depending on the floor structure, the highest electricity consumption is 13.399 kWh/m$^2$ in Athens. Depending on natural gas consumption, $CO_2$ emissions are calculated as 4.771 kg/m$^2$ and 0.0001179 kg/m$^2$ in Athens. The lowest electricity consumption was 0.022 kWh/m$^2$ in Oslo. Based on natural gas consumption, $CO_2$ emissions are calculated as 0.008 kg/m$^2$ and $SO_2$ emissions as 0.0000002 kg/m$^2$ in Oslo. The average electricity consumption for these capitals is 1.662 kWh/m$^2$, $CO_2$ emissions are 0.592 kg/m$^2$ and $SO_2$ emissions are 0.0000146 kg/m$^2$. Ankaras' electricity consumption is 1.091 kWh/m$^2$ and $CO_2$ emission is 0.389 kg/m$^2$ and $SO_2$ emission is 0.0000096 kg/m$^2$ depending on natural gas consumption. It is lower than the average of the 20 selected European capitals. These values are given in Figure 7.

Depending on the wall structure for the cooling period, Athens has the highest electricity consumption of 4,936 kWh/m$^2$. Depending on the coal consumption pow-

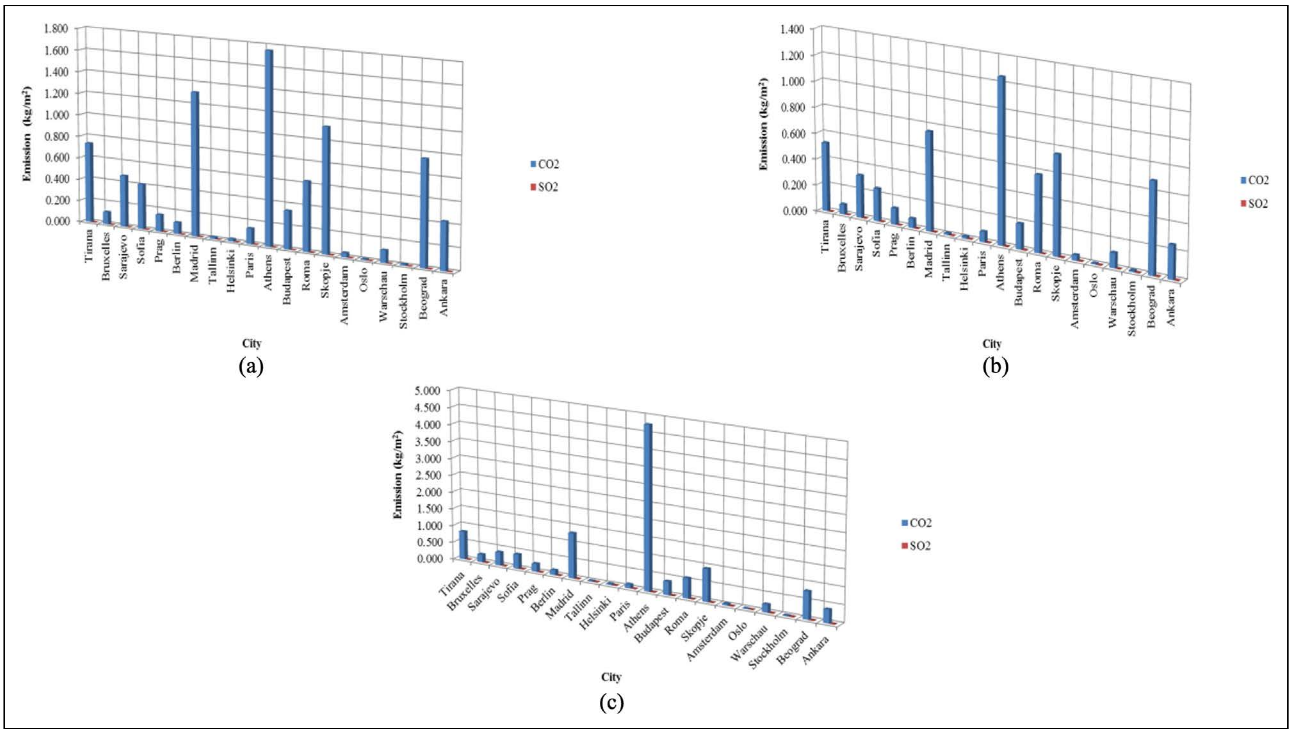


**Figure 7**. $CO_2$ and $SO_2$ emissions for electricity generated by consuming natural gas for cooling **(a)** external wall area **(b)** roof area **(c)** floor area.

er plant, the $CO_2$ emission is calculated as 3.624 kg/$m^2$ and the $SO_2$ emission is 0.0003628 kg/$m^2$ in Athens. The lowest electricity consumption is 0.022 kWh/$m^2$ in Oslo. Based on coal consumption, $CO_2$ emission is calculated as 0.016 kg/$m^2$ and $SO_2$ emission is calculated as 0.0000016 kg/$m^2$ in Oslo. Average electricity consumption for these capitals is 1,254 kWh/$m^2$, $CO_2$ emissions are 0.921 kg/$m^2$ and $SO_2$ emissions are 0.0000922 kg/$m^2$. Ankaras' electricity consumption is 1.217 kWh/$m^2$ and $CO_2$ emission is 0.893 kg/$m^2$ and $SO_2$ emission is 0.0000894 kg/$m^2$ depending on coal consumption. It is lower than the average of the 20 selected European capitals. Depending on the roof structure, the highest electricity consumption occurs in Athens, at 3.526 kWh/$m^2$. Depending on the coal consumption, the $CO_2$ emission is calculated as 2.588 kg/$m^2$ and the $SO_2$ emission is 0.0002592 kg/$m^2$ in Athens. The lowest electricity consumption was 0.016 kWh/$m^2$ in Oslo. Based on coal consumption, $CO_2$ emission is calculated as 0.012 kg/$m^2$ and $SO_2$ emission is calculated as 0.0000012 kg/$m^2$ in Oslo. The average electricity consumption for these capitals is 0.861 kWh/$m^2$, $CO_2$ emissions are 0.632 kg/$m^2$ and $SO_2$ emissions are 0.0000663 kg/$m^2$. Ankara electricity consumption is 0.710 kg/$m^2$ and $CO_2$ emission is 0.521 kg/$m^2$ and $SO_2$ emission is 0.0000522 kg/$m^2$ depending on coal consumption. It is lower than the average of the 20 selected European capitals. Depending on the floor structure, the highest electricity consumption is 13,399 kWh/$m^2$ in Athens. Depending on coal consumption, $CO_2$ emissions are calculated as 9.836 kg/$m^2$ and 0.0009848 kg/$m^2$ in Athens. The lowest electricity consumption was 0.022 kWh/$m^2$ in Oslo. Based on coal consumption, $CO^2$ emission was calculated as 0.016 kg/$m^2$ and $SO_2$ emission was calculated as 0.0000016 kg/$m^2$ in Oslo. The average electricity consumption for these capitals is 1.662 kWh/$m^2$, $CO_2$ emissions are 1.220 kg/$m^2$ and $SO_2$ emissions are 0.0001222 kg/$m^2$. Ankara electricity consumption is 1.091 kWh/$m^2$ and CO2 emission is 0.801 kg/$m^2$ and $SO_2$ emission is 0.0000802 kg/$m^2$ depending on coal consumption. It is lower than the average of the 20 selected European capitals. These values are given in Figure 8.

For the cooling period, the highest electricity consumption is calculated as 4.936 kWh/$m^2$ in Athens depending on the wall structure. Based on fuel-oil consumption power plant, $CO_2$ emissions are calculated as 2.698 kg/$m^2$ and $SO_2$ emissions 0.0002700 kg/$m^2$ in Athens. The lowest electricity consumption was 0.022 kWh/$m^2$ in Oslo. Based on fuel-oil consumption, $CO_2$ emissions are calculated as 0.012 kg/$m^2$ and $SO_2$ emissions as 0.0000012 kg/$m^2$ in Oslo. The average electricity consumption for these capitals is 1.254 kWh/$m^2$, $CO_2$ emissions 0.686 kg/$m^2$ and $SO_2$ emissions 0.0000686 kg/$m^2$. Ankaras' electricity consumption is 1.217 kg/$m^2$ and depending on fuel-oil consumption, $CO_2$ emission is 0.665 kg/$m^2$ and $SO_2$ emission is 0.0000666 kg/$m^2$. It is lower than the average of the 20 selected European capitals. Depending on the roof structure, the highest electricity consumption is 3.526 kWh/$m^2$ in Athens. Based on fuel-oil consumption, $CO_2$ emis-

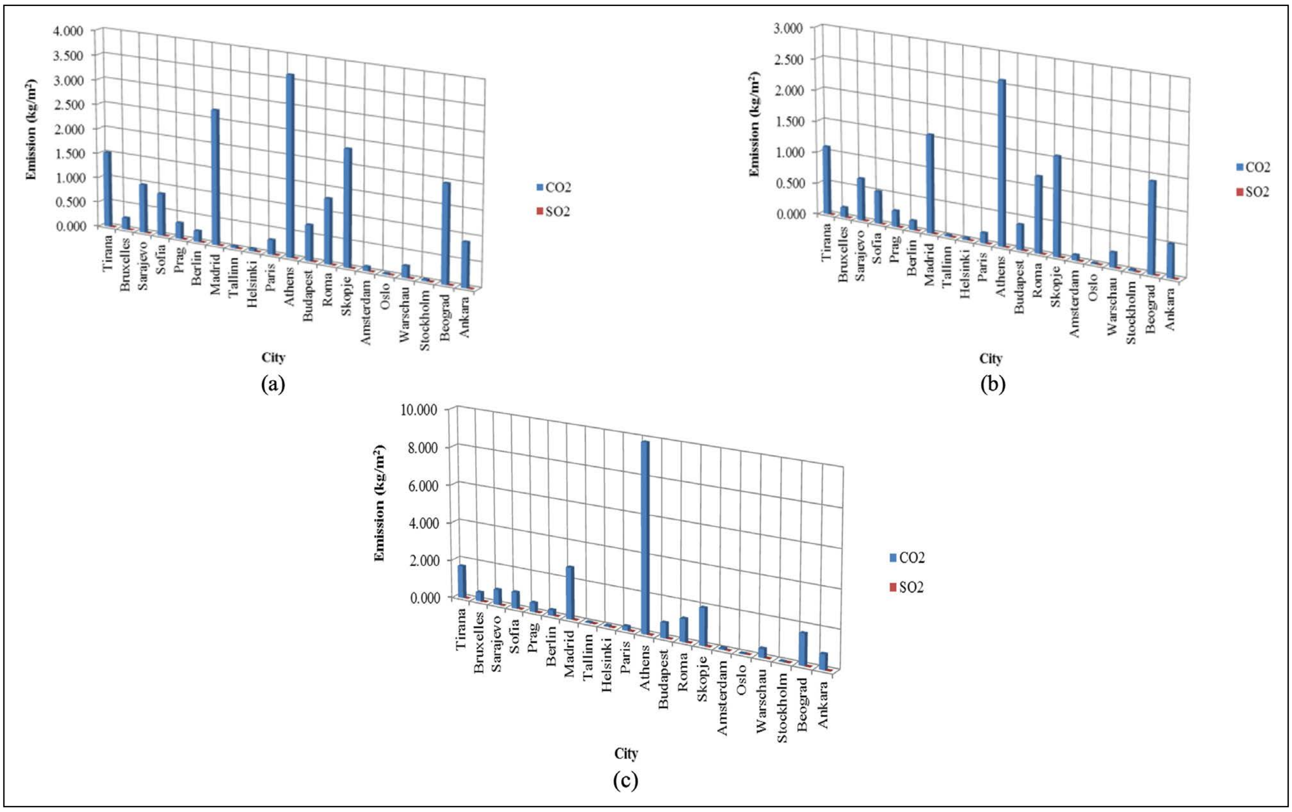


**Figure 8**. $CO_2$ and $SO_2$ emissions for electricity generated by consuming coal for cooling period **(a)** external wall area **(b)** roof area **(c)** floor area.

sions are calculated as 1.927 kg/m² and $SO_2$ emissions as 0.0001929 kg/m² in Athens. The lowest electricity consumption was 0.016 kWh/m² in Oslo. Based on fuel-oil consumption, $CO_2$ emissions are calculated as 0.009 kg/m² and $SO_2$ emissions as 0.0000009 kg/m² in Oslo. Average electricity consumption for these capitals is 0.861 kWh/m², $CO_2$ emissions are 0.471 kg/m² and $SO_2$ emissions are 0.0000471 kg/m². Ankaras' electricity consumption is calculated as 0.710 kWh/m², and depending on fuel-oil consumption, $CO_2$ emission was 0.388 kg/m² and SO2 emission was 0.0000388 kg/m². It is lower than the average of the 20 selected European capitals. Depending on the floor structure, the highest electricity consumption is 13,399 kWh/m² in Athens. Depending on fuel-oil consumption, $CO_2$ emissions are calculated as 7.323 kg/m² and 0.0007329 kg/m² in Athens. The lowest electricity consumption was 0.022 kWh/m² in Oslo. Based on fuel-oil consumption, $CO_2$ emissions are calculated as 0.012 kg/m² and $SO_2$ emissions as 0.0000012 kg/m² in Oslo. The average electricity consumption for these capitals is 1.662 kWh/m², $CO_2$ emissions are 0.908 kg/m² and $SO^2$ emissions are 0.0000909 kg/m². Ankaras' electricity consumption is 1.091 kWh/m² and $CO_2$ emission is 0.596 kg/m² and $SO_2$ emission is 0.0000597 kg/m² depending on fuel-oil consumption. It is lower than the average of the 20 selected European capitals. These values are given in Figure 9.

## 4. CONCLUSION

For the thermal conductivity coefficient 0.01–0.07 W/m.K, the minimum value of the insulation thicknesses for the external walls were calculated between 0.004–0.026 m in Skopje and Beograd, and the highest thickness were between 0.048 to 0.337 m in Oslo. The minimum value of the insulation thicknesses for the roof were calculated between 0.013–0.092 m in Beograd, and the highest thickness were between 0.075 to 0.523 m in Oslo. The minimum value of the insulation thicknesses for the floor were calculated between 0.002 to 0.013 m in Athens, and the highest thickness were between 0.063 to 0.443 m in Stockholm. This is among the average values of the 20 European capitals selected in the Ankara for the entire building envelope. The minimum insulation thicknesses are low in South-eastern Europe due to the higher thermal transmittances value of the building envelope. However, in Northern Europe and Scandinavian countries, the minimum value of the insulation to be made is high due to the lower heat transmission coefficients. This shows that these Scandinavian countries give much more importance to energy saving in buildings. In our country, this is at an average level when the selected European countries are taken into account. However, studies are needed to improve energy savings in buildings.

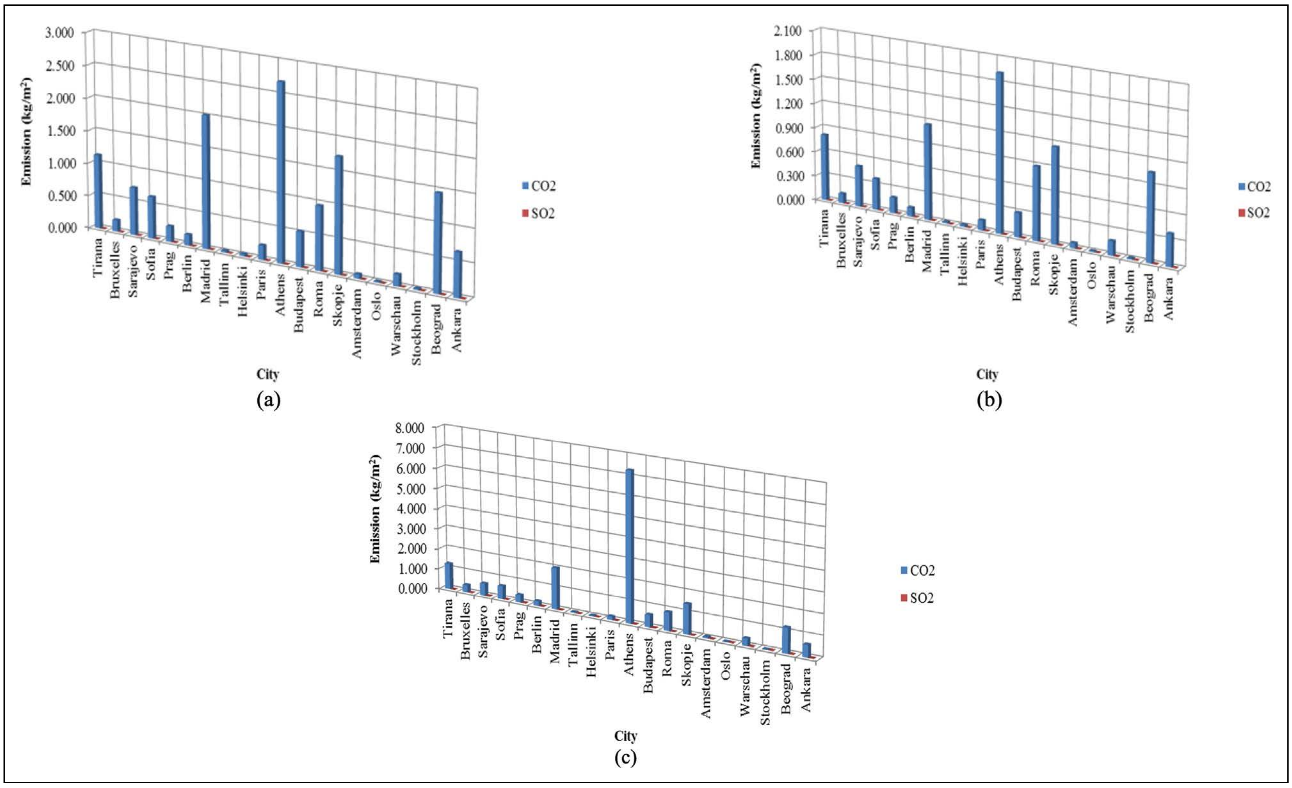


**Figure 9**. $CO_2$ and $SO_2$ emissions for electricity generated by consuming Fuel-oil for cooling period **(a)** external wall area **(b)** roof area **(c)** floor area.

The highest heating degree-day value was determined as 5021 in Oslo, the capital of Norway, and the lowest was 1413 in Athens, the capital of Greece. Requirements and/or recommendations thermal transmittances value for building envelopes are given in the study. Accordingly, it has been calculated that Sarajevo, the capital of Bosnia-Herzegovina, has the highest fuel consumption and the highest $CO_2$ and $SO_2$ emissions for three building components and three fuel types for heating. Although the heating degree-day value of Oslo is high, the thermal transmittances value of the building envelope are kept low, and fuel consumption and therefore emission amounts are low. However, in Sarajevo, the highest fuel consumption and emission amount occurs because an appropriate balance is not established between the heating degree-day and the thermal transmittance value of the building envelope. In Ankara, better results were obtained in terms of fuel consumption and emissions among the 20 selected European capitals. This shows that there is a more balanced situation between the heating degree-day and the building envelope thermal transmittance values. However, when we look at capital cities such as Oslo and Stockholm, it is seen that the thermal transmittance value of the building envelope should be reduced. $CO_2$ and $SO_2$ emissions do not include emissions during the production, transportation, and installation of insulation and materials. It covers only the $CO_2$ and $SO_2$ emissions that will occur as a result of the burning of fuels such as coal, natural gas, and fuel-oil fuels for heating and cooling purposes.

The highest cooling degree-day value was determined as 734 in Athens, the capital of Greece, and the lowest as 13 in Oslo, the capital of Norway. Accordingly, it has been calculated that the highest electricity consumption for three building components and three fuel types for cooling and the highest associated $CO_2$ and $SO^2$ emissions occur in Athens, the capital of Greece. In this case, it is seen that a balance cannot be achieved between both the cooling degree-day value of Athens and the thermal transmittance values of the building envelope. It was determined that the lowest electricity consumption occurred in Oslo, the capital of Norway. It is seen that a balance has been achieved between the cooling degree-day and the thermal transmittance values of the building envelope in Oslo. Ankara, on the other hand, achieved slightly better results than the average values in terms of electricity consumption and emissions among the 20 selected European capitals. This shows that there is a more balanced situation between the cooling degree-day and the building envelope thermal transmittance value. The effect of pollutant emissions such as $CO_2$ and $SO_2$ released into the atmosphere depending on the thermal transmittance value of the building envelope of Ankara, the capital of our country, was investigated and compared with the capitals of other European countries. In this respect, the study has contributed to the literature with a new perspective. The adequacy of the standards in our country on the combustion of the fuels required for the energy needs of the buildings and the effect of pollutant emissions on the atmosphere has been examined. The important parameter here is the building envelope thermal transmittance values.

As a result, the emissions of fuels to be used when heating and cooling buildings are a very effective parameter in global heating. It is very important to reduce the heat losses of buildings in the formation of these emissions. The most effective way to reduce this is to reduce thermal transmittance values by insulating. With the lower thermal transmittance values of the building envelopes, there will be less heat loss and therefore less emission to the environment. For this purpose, it is considered to carry out different studies on what can be done to reduce building heat losses for future studies. For example, green roof applications, the use of ecological thermal insulation materials, the use of new technological thermal insulation materials with low heat conductivity coefficient, increasing the use of renewable energy such as sun and wind in buildings can be counted.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

## PEER-REVIEW

Externally peer-reviewed.

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