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NATIONWIDE MAPPING OF OPTIMUM WALL INSULATION THICKNESSES: A STOCHASTIC APPROACH

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Abstract: Energy consumption in buildings accounts for a notable part of the primary energy consumption all over the world. The building industry also has a great potential to decrease the environmental impact by reducing greenhouse gas emissions. The national strategies of many developing countries are shaped by energy conservation issues. Improving energy efficiency and productivity is stated as one of the main elements of the Turkish national energy strategy. An efficient way to decrease energy consumption in buildings is to implement insulation on the building envelope. Identifying the optimum insulation thickness to be applied on the exterior walls is of prime importance. This study adapts a stochastic approach to determine optimum insulation thickness for 81 cities in Turkey. The stochastic approach, unlike the commonly used deterministic approach, incorporates the probabilistic nature of the process and presents the optimum insulation thickness as a probability distribution graph rather than a single value. For this purpose, a number of insulation thicknesses (1-20 cm) were regarded as the alternatives and the optimum alternative was determined based on life cycle costing analysis involving the cost of insulation application and annual energy savings. The average monthly temperature of each city and financial parameters such as the inflation and discount rates were considered as the stochastic elements. The results of the life cycle costing analysis were used to (i) identify the optimum thicknesses in each city as a probability distribution graph and (ii) generate an optimum insulation thickness map for Turkey.
Keywords: Stochastic analysis, Optimum insulation thickness, Wall insulation, Energy saving

OPTİMUM DUVAR YALITIMI KALINLIKLARININ ÜLKE ÇAPINDA HARİTALANMASI: STOKASTİK YAKLAŞIM

Özet: Binalarda enerji tüketimi tüm dünyadaki birincil enerji tüketiminin önemli bir kısmına karşılık gelmektedir. Bina sektörü ayrıca sera gazı salınımını düşürerek çevresel etkinin azaltılmasına yönelik büyük bir potansiyel teşkil etmektedir. Gelişmekte olan birçok ülkenin ulusal stratejileri enerjinin korunmasına ilişkin konularla şekillenmektedir. Enerji verimliliğinin ve üretkenliğin arttırılması Türkiye ulusal enerji stratejisinin ana unsurlarından birisi olarak belirtilmiştir. Bina kılıfına yalıtım uygulamak binalarda enerji tüketimini azaltmak için etkili bir yoldur. Dış duvarlara uygulanacak olan optimum yalıtım kalınlığının belirlenmesi önem arz etmektedir. Bu çalışmada Türkiye'deki 81 ilin optimum yalıtım kalınlığını belirlemek amacıyla stokastik bir yaklaşım benimsenmiştir. Yaygın olarak kullanılan deterministik yaklaşımın aksine, stokastik yaklaşım sürecin olasılıksal doğasını bünyesinde barındırır ve optimum yalıtım kalınlığını tek bir değer yerine bir olasılık dağılım grafiği olarak sunar. Bu amaçla, birtakım yalıtım kalınlıkları (1-20 cm) alternatif olarak kabul edilmiş ve optimum alternatif yalıtım uygulamasının maliyeti ile yıllık enerji tasarruflarını dikkate alan bir yaşam dönemi maliyet analizi yapılarak belirlenmiştir. Şehirlerin aylık ortalama sıcaklıkları ve enflasyon ile iskonto oranları gibi finansal parametreler stokastik elemanlar olarak kabul edilmiştir. Yaşam dönemi maliyet analizinin sonuçları (i) her bir şehir için optimum yalıtım kalınlığını bir olasılık dağılım grafiği olarak elde etmek ve (ii) Türkiye için bir optimum yalıtım kalınlığı haritası oluşturmak amacıyla kullanılmıştır.
Anahtar Kelimeler: Stokastik analiz, Optimum yalıtım kalınlığı, Duvar yalıtımı, Enerji tasarrufu

INTRODUCTION

The energy crisis in 1973 caused conservation of energy to be considered as a national strategy especially in developing countries that import the majority of their energy needs from abroad. Global energy consumption is mainly formed by the building and construction industry, where energy consumption has been on the rise since the 1960s (Malecite et al., 2013). Energy consumed by the buildings corresponds to more than 40% of the primary energy consumption in the United States and European Union (Cao et al., 2016). The industry also has the greatest potential for decreasing the environmental impact as it is responsible for 10% of the global greenhouse gas emissions (IEO, 2013).

The economic and population growth in Turkey has accelerated the energy demand. The energy demand in Turkey has had the highest rate of growth among OECD (Organization for Economic Co-operation and Development) countries over the last 15 years. Turkey is also one of the biggest natural gas and electricity markets in its region. The national energy strategy of Turkey is mainly shaped by the increasing energy demand and dependency on imports. The main elements of the national energy strategy include (i) prioritization of energy supply security, (ii) having environmental concerns all along the energy chain, (iii) conducting R&D on energy technologies, and (iv) improving the energy efficiency and productivity (MFA, 2021).

A crucial component of Turkey's 2023 national strategy objectives is to promote energy efficiency. The objective is to reduce the energy consumed per national income, namely energy density, by 20% from 2011 to 2023 by conducting energy efficiency studies (MENR, 2021). Reducing heating energy consumption is known to be an effective way of increasing energy efficiency in residential buildings that can operate for 70 years (Zhan et al., 2018). Heating energy consumption can be reduced to a great extent by applying optimum insulation thickness to exterior walls. Applying such insulation to the exterior walls of existing buildings can provide a great amount of energy savings in Turkey, where the majority of the buildings are uninsulated (Kurekci, 2016).

Implementation of insulation material to the exterior walls of existing buildings requires an initial investment, but it helps the building to consume significantly less energy throughout its lifetime (Caglayan et al., 2020). While increasing the insulation thickness pushes up the investment cost, it leads to greater savings in energy. In this regard, it becomes crucial to identify the insulation thickness that is economically most feasible. The optimum insulation thickness can be expressed as the insulation thickness that provides the greatest net benefit which is obtained by subtracting the cost from the savings.

The amounts of the investment cost and energy savings are the major determinants of the optimum insulation thickness. The investment cost is the cost of insulation application to the exterior walls. Expanded polystyrene, extruded polystyrene, and stone wool have frequently been selected as the insulation material in the literature. The savings are achieved by reducing the energy consumption in buildings. Electricity and natural gas have been mainly considered as the energy sources for cooling and heating, respectively. The optimization analyses have focused on certain cities representing different climate regions of Turkey.

The optimum insulation thickness has mostly been determined with the deterministic approach. Exact values have been assigned to key input parameters and the output (optimum insulation thickness) has been determined as a single value. The deterministic approach is useful if these parameters are subject to no random deviations and can be obtained without any ambiguity. Otherwise, it would be more appropriate to consider the stochastic approach where the output is presented as a probability distribution graph that describes the probability of obtaining various values.

This study adapted a stochastic approach to determine the optimum insulation thickness of a building prototype for 81 cities in Turkey. Within this context, a number of insulation thicknesses (1-20 cm) were regarded as the alternatives and the optimum alternative was determined for each city based on a life cycle costing analysis involving the insulation cost and annual energy savings. The results of the life cycle costing analysis were used to (i) identify the optimum thicknesses in each city as a probability distribution graph and (ii) generate an optimum insulation thickness map for Turkey. The average monthly temperature of each city and financial parameters such as the inflation and discount rates were considered as the stochastic elements for which historical data or future projections were obtained. The characteristics of the data (mean values, standard deviations) were identified and used for randomly generating the stochastic elements in the analysis.

The proposed study contributes to the body of knowledge in two ways: (i) achievement of reliable outputs by reflecting the uncertainty on the estimates and (ii) generation of an optimum insulation thickness map by repeating the analysis for each city in Turkey. The stochastic approach allows for random variation in stochastic elements and reflects it on the estimates. Presentation of an output as a probability distribution graph displays the most probable outcome, and more importantly, how much it can deviate. The latter implies the comprehensiveness of the study as the analysis covers all the cities. Studies in the literature have made analysis for certain cities from different climate regions. Marking all the cities of the country provides the opportunity to draw an optimum insulation thickness map.

RESEARCH BACKGROUND

Determining the optimum insulation thickness has been an attractive academic topic both in the national and international areas. Several studies have been conducted in various countries to specify the optimum insulation thickness. Daouas et al. (2010) determined the optimum insulation thickness of building walls in Tunisia. The optimum insulation thickness was determined as 5.7 cm. Liu et al. (2015) identified the optimum insulation thicknesses for three cities in the hot summer and cold winter zones of China, which were Changsha, Chengdu, and Shaoguan. While the optimum insulation thicknesses for expanded polystyrene were found to change between 8.1 cm and 10.5 cm, the optimum thicknesses for extruded polystyrene varied between 5.3 cm and 6.9 cm. Baniassadi et al. (2016) determined the optimum insulation thickness for different climatic regions of Iran. The optimum thickness was found to be greater than 6.0 cm in cold regions. Nematchoua et al. (2017) calculated the optimum insulation thickness for two cities located in two different climate regions of Cameroon, namely Yaounde and Garoua. The optimum thicknesses were calculated as 8.0 cm and 11.0 cm for Yaounde and Garoua, respectively. Jraida et al. (2017) conducted a study to identify the optimum insulation thickness in six cities in six different climate zones of Morocco. Optimum insulation thicknesses for extruded polystyrene were determined as 2.3 cm, 3.7 cm, 5.2 cm, 7.7 cm, 4.1 cm, and 5.7 cm for Agadir, Tangier, Fez, Ifran, Marrakech, and Errachidia, respectively.

Numerous studies have also been conducted to identify the optimum insulation thickness for cities representing different climate regions of Turkey. A total of four different climate regions have been defined in the 2008 version of Turkish Standard 825 (TSI, 2008). Region 1 represents the hottest regions, while Region 4 comprises the coldest ones. Even though the number of climate regions was increased to five in the 2013 version, it was not published in the official gazette. The researchers have, therefore, considered and the discussion has focused on the climate regions defined in the 2008 version. Comakli and Yuksel (2003) identified the optimum insulation thickness for the coldest cities of Turkey. The optimum insulation thicknesses were observed as 8.5 cm, 10.4 cm, and 10.7 cm for Erzincan (Region 4), Erzurum (Region 4), and Kars (Region 4), respectively. Kaynakli (2008) determined the optimum insulation thickness for a prototype building in Bursa (Region 2) for different types of fuel. The optimum thicknesses were found to be 5.3 cm, 10.5 cm, 11.2 cm, and 12.4 cm for natural gas, fuel oil, electricity, and LPG, respectively. Dombayci et al. (2017) calculated the optimum insulation thickness for a total of four cities representing the four climate regions of Turkey, namely Izmir (Region 1), Trabzon (Region 2), Ankara (Region 3), and Kars (Region 4). The optimum thicknesses for expanded polystyrene insulation were determined as 4.6 cm, 6.0 cm, 7.7 cm, and 10.7 cm for Izmir, Trabzon, Ankara, and Kars, respectively. Canbolat et al. (2018) determined the economic insulation thickness as 4.7 cm for Istanbul (Region 2). Akyuz et al. (2018) determined the optimum insulation thickness of the International Hasan Polatkan Airport terminal in Eskisehir (Region 3) for a number of insulation materials. The optimum thicknesses were found as 5.0 cm, 3.3 cm, 7.8 cm, and 9.7 cm for expanded polystyrene, extruded polystyrene, glass wool, and stone wool, respectively.

In previous studies, optimum insulation thicknesses have been determined for certain cities with a deterministic approach. The parameter values have been assumed deterministically and the results have revealed certain optimum insulation thickness values for the mentioned cities. The stochastic approach adapted in this study possessed a number of advantages over the deterministic approach. Generation of the stochastic elements based on historical data or future projections can provide more reliable outputs as the uncertainties are reflected on the estimates. The result is obtained as a probability distribution graph rather than a single value. In addition, repetition of the analysis for each city in Turkey offers the opportunity to generate an optimum insulation thickness map.

RESEARCH METHODOLOGY

This study adapts a stochastic model to determine optimum insulation thicknesses. A deterministic model represents a system where the relationships are fixed, implying that the probabilistic nature is ignored. For a set of given initial conditions, a deterministic model always performs the same way. On the other hand, a stochastic model is a mathematical representation of a system where a number of possible outputs can be generated by a given input. The randomness of the process makes the results obtained by the combination of independent factors slightly different (Leuenberger et al., 2018). The behaviours of the deterministic and stochastic models are illustrated in Figure 1 (adapted from Revelle et al., 2005).

A stochastic model possesses random variation in the inputs and forecasts the probability of various outputs. The uncertainty is built into the model through the inputs, where historical data is used to observe fluctuations. The probability distribution of the outputs reflects the random variation in the inputs and thus, the uncertainty is made explicit.

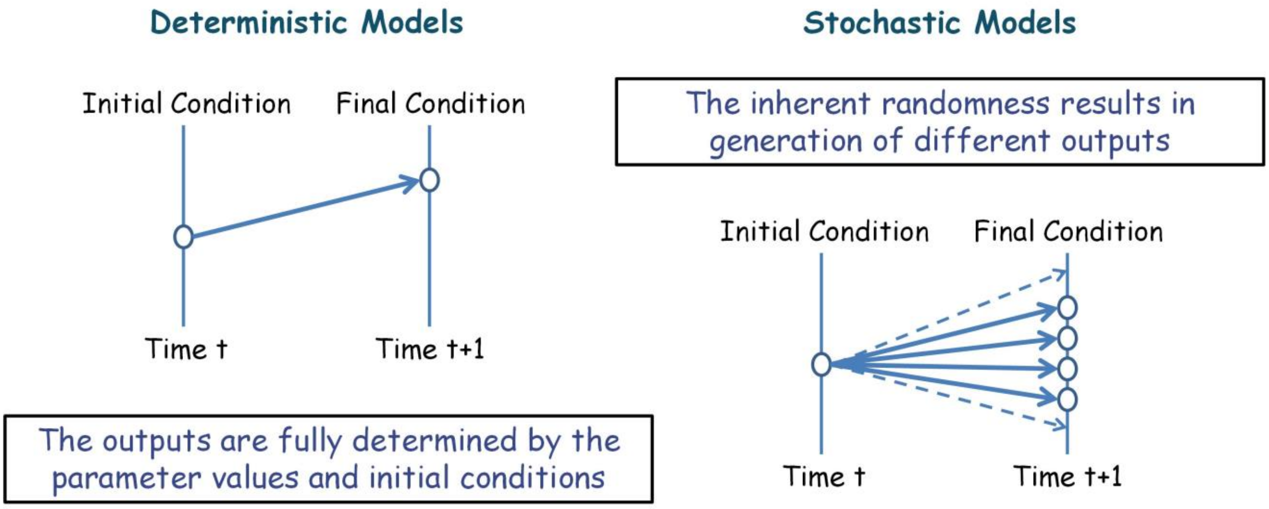

Figure 1. Deterministic vs. stochastic models

The methodology part of the research is composed of four main sections: (i) obtaining historical data and future projections for the stochastic elements, (ii) creating the building prototype, (iii) calculating annual energy requirements, and (iv) conducting life cycle costing analysis.

Obtaining Historical Data and Future Projections for the Stochastic Elements

In this study, the average monthly temperature of each city and financial parameters such as the inflation and discount rates were assumed as the stochastic elements. Inflation and discount rates are two financial parameters that influence the results of life cycle costing analysis to a great extent. These parameters have been subject to alteration in previous studies based on the time the study was conducted. Table 1 presents the inflation and discount rates used in 20 studies conducted in the last 15 years. According to the table, the inflation rate has varied between 0.00% and 11.75%, while the discount rate has ranged from 4.00% to 19.38%. Such a situation demonstrates the uncertainty within these parameters. Considering these parameters as stochastic elements and generating them based on the analysis of historical data can provide more reliable results.

Historical data was obtained for inflation and discount rates. The rate of increase in natural gas prices was considered as the inflation rate and data was acquired for the period from 01.05.2006 to 01.05.2020 from the official site of Istanbul Gaz Dagitim Sanayi ve Ticaret AS (IGDAS, 2021). The mean and standard deviation for the inflation rate were observed as 10.66% and 11.38%, respectively. The reason for such a great standard deviation might be the fact that energy prices are highly susceptible to economic and political issues. Historical data for discount rate was obtained from Interest Rate Statistics of the Central Bank of the Turkish Republic for the period from 01.01.2005 to 01.12.2019 (TCMB, 2021). The mean and standard deviation for the discount rate up to 1-year deposits were observed as 13.45% and 4.28%, respectively.

Table 1. Inflation and discount rates used in previous studies

No	Study	Inflation Rate	Discount Rate
1	Bolatturk (2006)	9.20%	17.89%
2	Dombayci et al. (2006)	0.00%	8.00%
3	Sisman et al. (2007)	9.32%	17.79%
4	Bolatturk (2008)	4.00%	5.00%
5	Ucar and Balo (2009)	5.00%	4.00%
6	Ozkan and Onan (2011)	9.67%	19.38%
7	Ekici et al. (2012)	5.00%	4.00%
8	Kaynakli (2013)	6.00%	9.00%
9	Kayfeci (2014)	5.00%	4.00%
10	Ozel et al. (2015)	8.39%	9.65%
11	Kurekci (2016)	7.91%	8.25%
12	Erturk (2016)	6.50%	13.00%
13	Kaya et al. (2016)	6.16%	13.75%
14	Kon and Yuksel (2016)	6.40%	9.00%
15	Aktemur and Atikol (2017)	8.53%	9.00%
16	Evin and Ucar (2019)	8.81%	9.00%
17	Aydin and Biyikoglu (2020)	10.35%	12.75%
18	Gulten (2020)	8.50%	10.00%
19	Aydin and Biyikoglu (2021)	10.35%	12.75%
20	Akan (2021)	11.75%	12.50%

Average monthly temperatures of each city were projected for the future period of 2021-2050 by using the supercomputers in the Center for Climate Change and Policy Studies (iklimBU) laboratory. Global Climate Models (GCMs), which project future climate conditions needed in studies examining the sectoral impacts of climate change, have low spatial resolution despite their high temporal resolution, which makes the outputs of these models inadequate in regional or local impact studies. This requirement leads researchers to downscaling approaches (i.e., dynamical, statistical, or hybrid) so that the outputs of these sophisticated tools can provide more reliable climate data at regional and local scales. Therefore, dynamical downscaling approach was applied to obtain high spatial resolution mean temperature data for Turkey, which has a high and complex topography. The dynamical downscaling approach is based on the principle of running a Regional Climate Model (RCM) that takes the lateral boundary conditions from a GCM.

MPI-ESM-MR and RegCM4.4 model pair, which have been tested in various studies (Akbas et al., 2020; An et al., 2018, 2020; Demircan et al., 2017; Demiroglu et al., 2016, 2021; Turp et al., 2014) were preferred. The outputs of MPI-ESM-MR (Giorgetta et al., 2013), one of the GCMs developed by the Max Planck Institute for Meteorology in Germany, were given as input to the Regional Climate Model Version 4.4 (RegCM4.4, Giorgi et al., 2012) developed by the Abdus Salam International Centre for Theoretical Physics (ICTP) in Italy. In other words, low spatial resolution (approximately 210 km x 210 km grid size) data of MPI-ESM-MR, one of the most widely used models in climate change studies (Demircan et al., 2017) and has a medium level of equilibrium climate sensitivity (Sherwood et al., 2014), was dynamically downscaled to higher spatial resolution (10 km x 10 km grid size) by using RegCM4.4. RegCM (Pal et al., 2007), which has been in use for more than three decades, is one of the most widely used RCMs because it is free, easy to access, user-friendly, practical, reliable, and has a globally wide user and developer network.

Future projection (2021-2050) was realized under the Representative Concentration Pathway (RCP) 8.5 emission scenario which is referred to the business-as-usual case. RCP8.5 (Riahi et al., 2007, 2011), the most pessimistic trajectory among the RCP scenarios, predicts that the atmospheric CO_2 concentration, which reached 420 ppm at the beginning of the 2020s, will reach approximately 541 ppm in the middle of the century and 936 ppm at the end of the century. Mean and standard deviation of the climate projections are presented in Appendix A, where the numbers in parenthesis represent the standard deviations.

Creating the Building Prototype

The building prototype represented a typical nine-story residential building with a length of 25 m, width of 20 m, and total height of 27 m. The window areas for the south, north, east, and west directions were determined as 150 m^2, 60 m^2, 120 m^2, and 60 m^2, respectively. Natural ventilation was assumed for air conditioning. Figure 2 and 3 present the cross-sectional details of the uninsulated and insulated building envelope, respectively. Ceiling and basement cross sections remained the same both in the insulated and uninsulated case. The only difference existed in the exterior walls (both infilled and reinforced concrete). An expanded polystyrene insulation material was added in the insulated case at varying thicknesses. which was the main subject of the study.

Calculating Annual Energy Requirements

A matlab code combining both the annual energy requirements and life cycle costing analysis was generated. The annual energy requirement of the building was calculated according to the method described by Turkish Standard (TS) 825 “thermal insulation requirements for buildings” published by the Turkish Standards Institute (TSI, 2008). The standard considers the building geometry and the climate region of the city. The cities are labelled by four climate regions, where the first region represents the warmest and the fourth region represents the coolest cities. The annual energy requirements are calculated not for each city, but for each climate region. In this study, however, the annual energy requirement was calculated for every single city based on the values generated in line with the climate simulations prepared according to the RCP8.5 scenario. With the exception of the climate conditions of the cities, the methodology shown in TS825 was strictly followed.

According to the methodology shown in TS825, the annual heating energy consumption (Q_{year}) is obtained by adding up the monthly heating energy requirements (Q_m).

$$Q_{year} = \sum Q_m \quad (1)$$

$$Q_m = \begin{bmatrix} H * (\theta_{in} - \theta_{out}) \\ -\eta * (\varphi_{in} + \varphi_s) \end{bmatrix} * t \quad (2)$$

The specific loss (H) of the building is equal to the sum of the heat losses resulting from conduction and convection (H_{tr}) and ventilation (H_{ven}).

$$H = H_{tr} + H_{ven} \quad (3)$$

H_{tr} is equal to the sum of the products of area (A) and heat transfer coefficient (U) for the exterior wall (ew), glazing (gl), exterior door (ed), ceiling (ce), and floor (fl).

$$H_{tr} = \sum A*U = U_{ew}*A_{ew} + U_{gl}*A_{gl} + U_{ed}*A_{ed} + (0.8)*U_{ce}*A_{ce} + (0.5)*U_{fl}*A_{fl} \quad (4)$$

$$H_{ven} = (0.264)*n_a*V_{gross} \quad (5)$$

V_{gross} is the gross building volume. Air changing ratio (n_a) was considered as 0.8 for natural ventilation. The monthly average interior heat gain (φ_{in}) is obtained as in the following equation:

$$\varphi_{in} \leq 5*A_n \quad (6)$$

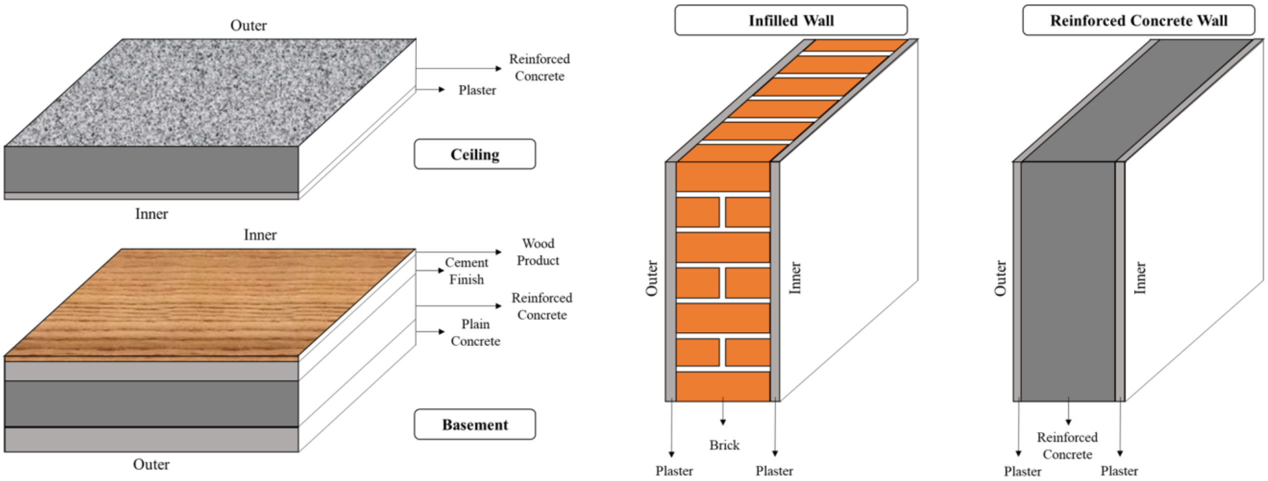

Figure 2. Cross sections of the uninsulated building envelope

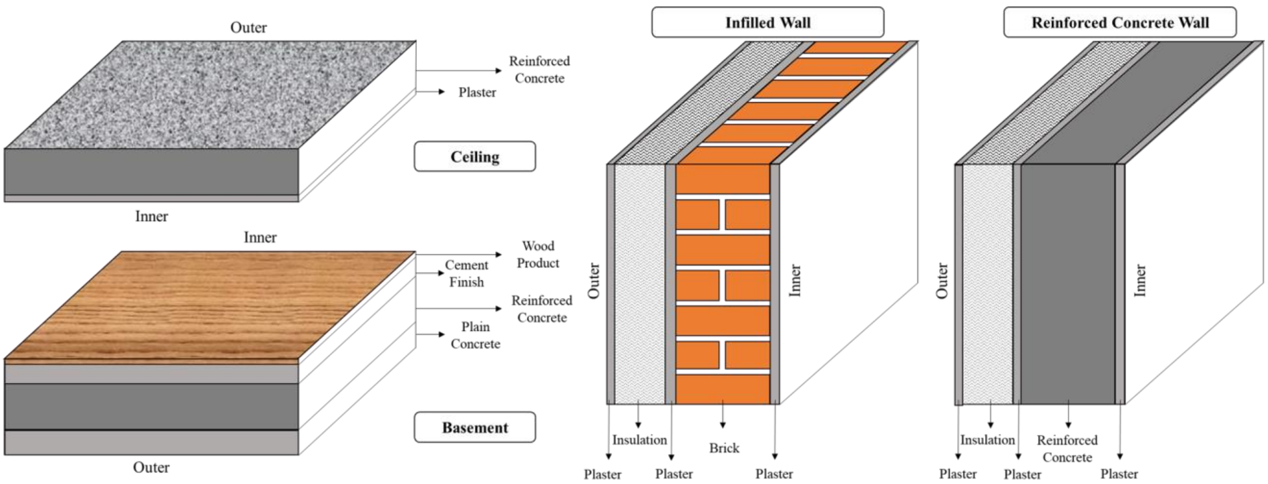

Figure 3. Cross sections of the insulated building envelope

A_n represents the building usage area and is determined by using the following equation:

$$A_n = (0.32)*V_{gross} \quad (7)$$

The monthly average solar energy gain (φ_s) is obtained as follows:

$$\varphi_{s,j} = \sum_k r_j * G_j * I_{j,k} * A_{gl,k} \quad (8)$$

r represents the monthly average shading factor of the transparent surfaces; $A_{gl,k}$ stands for the total glazing area in direction k; and G is the solar energy permeation factor of the transparent elements. r was assumed as 0.8 for the detached building.

Monthly average solar radiation intensities ($I_{j,k}$) are presented in Table 2 (TSI, 2008). TS825 assumes similar solar radiation intensities for all the cities. However, solar radiation is affected from the geographic information of cities such as altitude, latitude, and longitude (Sahin et al., 2013). The assumption of similar solar radiation might result in higher heating energy requirement (due to insufficiently calculated solar heat gain) and thicker optimum insulation thickness in cities where solar radiation is greater than the values indicated in the table.

Table 2. Monthly average solar radiation intensities (W/m^2)

	Months											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
I_{south}	72	84	87	90	92	95	93	93	89	82	67	64
I_{north}	26	37	52	66	79	83	81	73	57	40	27	22
$I_{east/west}$	43	57	77	90	114	122	118	106	81	59	41	37

The solar energy permeation factor (G) is obtained as follows:

$$G_j = F_w * g_{\perp} \tag{9}$$

The correction factor for windows (F_w) was assumed as 0.8 and the solar energy permeation factor ($g_{\perp}$) was considered as 0.75 for colourless glass. The monthly average usage factor of heat gain (η) is calculated as in the following equation:

$$\eta = 1 - e^{\left(-1/GLR\right)} \tag{10}$$

The gain/loss ratio (GLR) is determined by the following equation:

$$GLR = \frac{\left(\varphi_{in} + \varphi_s\right)}{H * \left(\theta_{in} - \theta_{out}\right)} \tag{11}$$

If gain/loss ratio becomes equal to or greater than 2.5, no heat loss occurs in the corresponding month. Inserting the gain/loss ratio formula in equation 11 into equation 10;

$$\eta = 1 - e^{\left(\frac{H*\left(\theta_{out} - \theta_{in}\right)}{\left(\varphi_{in} + \varphi_s\right)}\right)} \tag{12}$$

As suggested by the standard, the monthly average indoor temperature (θ_{in}) was considered as 19ºC. The monthly average outdoor temperatures (θ_{out}) were considered as the stochastic elements and future projection for the period of 2021-205 is presented in Appendix A.

Calculating Life Cycle Costing Analysis

The life cycle costing analysis considered the insulation cost (IC) and operational saving (OS) achieved through insulation implementation. The operational saving was obtained by taking the difference between the annual energy requirement of the uninsulated and insulated case for each insulation thickness. The cost of energy was considered as 0.02 $/kWh. The insulation cost was determined by taking offers from insulation companies (material supply + installation) and taking their average. The cost of insulation implementation is summarized in Table 3. It could be noticed that even the thinnest insulation implementation had a certain total unit cost amount mainly due to the fixed amount of installation cost for each insulation thickness. Increasing the insulation thickness generated only incremental movements in the total unit cost.

Life cycle costing analysis was conducted for insulation alternatives (1 cm to 20 cm) in each city to determine the alternative resulting in the most desired economic outcome. The insulation alternative having the highest net saving (NS) value was regarded as the optimum insulation thickness. As the stochastic elements (average monthly temperature of each city, inflation rate, discount rate) were generated 1,000 times with the mentioned means and standard deviations, optimum insulation thicknesses were also determined 1,000 times. Net saving was calculated for each alternative as follows:

$$NS = OS * PWF - IC \tag{13}$$

The present worth of the operational savings was determined by multiplying the operational saving with the present worth factor (PWF), which was calculated as follows:

$$PWF = \frac{(1+i^*)^N - 1}{r * (1+i^*)^N} \tag{14}$$

The lifespan (N) was considered as 20 years and the interest rate adapted for inflation (i*) was determined by using the following equation:

$$i^* = \begin{cases} \dfrac{i-g}{1+g} & i > g \\ \dfrac{g-i}{1+i} & i < g \end{cases} \tag{15}$$

Inflation rate (g) and discount rate (i) were the stochastic elements generated based on historical data.

FINDINGS AND DISCUSSION

The histogram of the optimum insulation thicknesses represents the probability distribution graph and is shown in Appendix B. It could be noticed that the optimum insulation thicknesses showed great variation under different scenarios. In extreme cases, the optimum thickness moved up to 20 cm insulation in the coolest cities and became even 0 cm insulation (implying the uninsulated case) in the warmest cities. It was also noticed that insulation thicknesses from 1 to 3 cm were not selected as the optimum insulation thicknesses for any city under any scenario. Within this range of thicknesses, the cost of insulation implementation was dominated by the relatively fixed amounts of installation and auxiliary items costs that overweighed the energy savings.

Figure 4 illustrates the histogram of optimum insulation thickness graphs for certain cities from four different climate regions, namely İzmir, Gaziantep, Ankara, and Kayseri. The most likely thicknesses were concentrated on 5-8 cm for İzmir, 6-10 cm for Gaziantep, 8-11 cm for Ankara, and 9-13 cm for Kayseri. For İzmir, the most frequently selected insulation thickness was 6 cm followed by 7 cm. The 6 cm insulation was selected in 218 of the 1,000 cases, corresponding to 21.8%.

The probabilities of optimum insulation thicknesses for each city are shown in percentages in Appendix C. Generation of the stochastic elements 1,000 times resulted in the determination of the optimum insulation thickness for 1,000 times in each city. A number in Table C1 and C2 represented the number of times (in percentages) the corresponding insulation thickness was selected as the optimum insulation thickness. To illustrate, it could be observed from the case of Afyonkarahisar that 9 cm insulation was selected as the optimum thickness 159 times in 1,000 trials, corresponding to 15.9% of the cases.

Table 3. Cost of insulation implementation

Insulation Thickness	Material Cost ($/m^2)	Auxiliary Items Cost ($/m^2)	Installation Cost ($/m^2)	Total Unit Cost ($/m^2)	Total Cost ($)
1 cm	0.40	2.70	4.00	7.10	18.247
2 cm	0.80	2.84	4.00	7.64	19.635
3 cm	1.20	2.98	4.00	8.18	21.023
4 cm	1.60	3.12	4.00	8.72	22.410
5 cm	2.00	3.26	4.00	9.26	23.798
6 cm	2.40	3.40	4.00	9.80	25.186
7 cm	2.80	3.54	4.00	10.34	26.574
8 cm	3.20	3.68	4.00	10.88	27.962
9 cm	3.60	3.82	4.00	11.42	29.349
10 cm	4.00	3.96	4.00	11.96	30.737
11 cm	4.40	4.10	4.00	12.50	32.125
12 cm	4.80	4.24	4.00	13.04	33.513
13 cm	5.20	4.38	4.00	13.58	34.901
14 cm	5.60	4.52	4.00	14.12	36.288
15 cm	6.00	4.66	4.00	14.66	37.676
16 cm	6.40	4.80	4.00	15.20	39.064
17 cm	6.80	4.94	4.00	15.74	40.452
18 cm	7.20	5.08	4.00	16.28	41.840
19 cm	7.60	5.22	4.00	16.82	43.227
20 cm	8.00	5.36	4.00	17.36	44.615

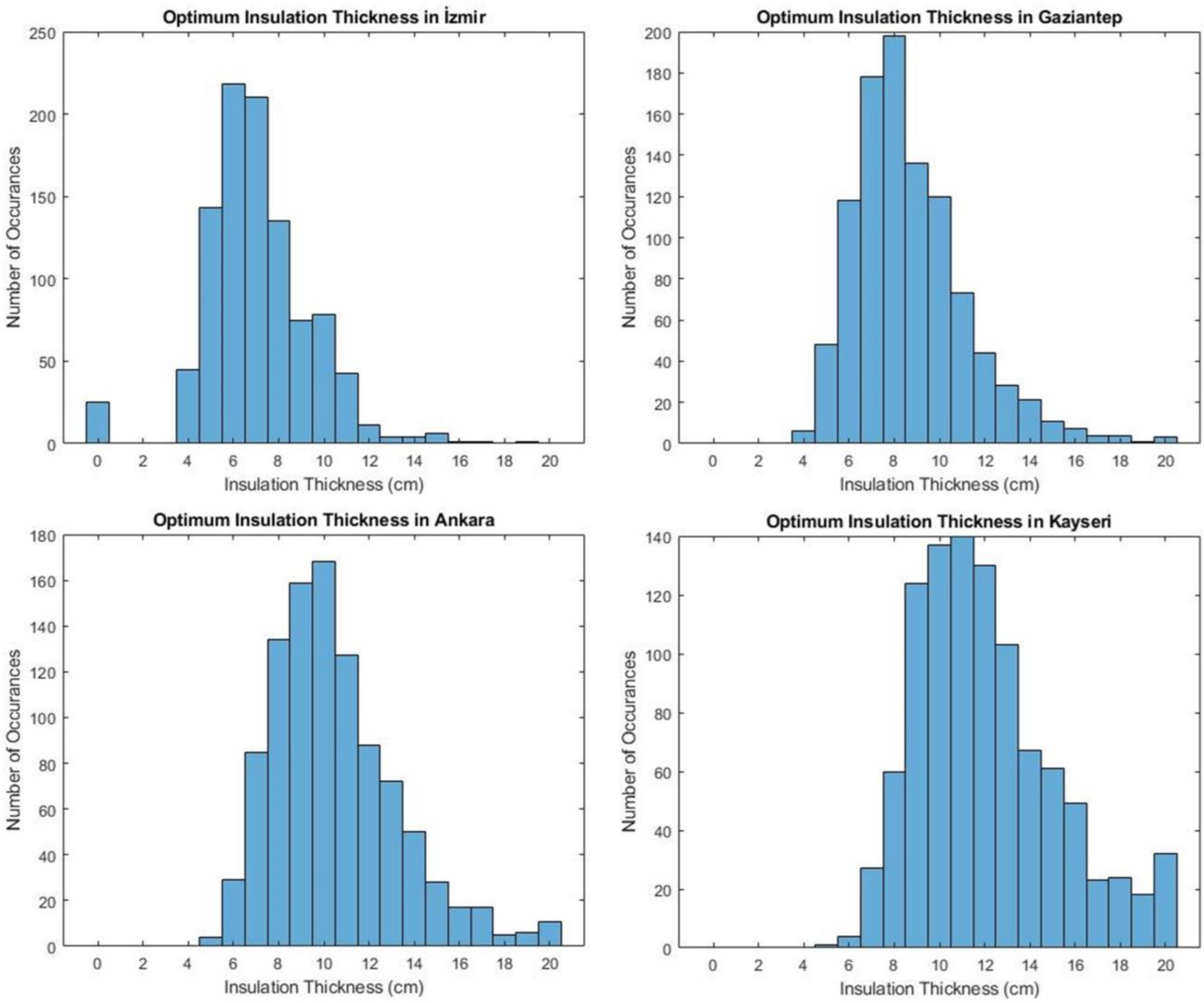

Figure 4. Optimum insulation thickness graphs for cities from four different climate regions

The expected value can be described as the weighted average of all possible values a discrete variable can take. In this case, the discrete variable was the insulation thickness and the weights were represented by the probabilities of being selected as the optimum. The expected value of optimum insulation thickness was calculated as:

$$E(X) = \sum_{i=0}^{20} x_i * p_i \\ = x_0 * p_0 + x_1 * p_1 + x_2 * p_2 + ... + x_{20} * p_{20} \quad (16)$$

where x_0, x_1, x_2, ….., x_{20} represented the insulation thicknesses (from 0 to 20 cm) and p_0, p_1, p_2, ….., p_{20} were the corresponding probabilities (or the weights).

To illustrate, the expected value of the optimum insulation thickness for Van can be calculated as;

E(X) = 0*0 + 1*0 + 2*0 + 3*0 + 4*0 + 5*0 + 6*0 + 7*0.006 + 8*0.012 + 9*0.042 + 10*0.075 + 11*0.113 + 12*0.134 + 13*0.123 + 14*0.106 + 15*0.084 + 16*0.089 + 17*0.057 + 18*0.031 + 19*0.037 + 20*0.091 = 13.93 cm

Table 4 summarizes the expected values of optimum insulation thicknesses calculated for 81 cities of Turkey. A great variation was observed among the expected values of different cities. The expected value varied between 6.73 cm (for Hatay) and 14.25 cm (for Ardahan) throughout Turkey. The expected value also showed great variation among the cities in the same climate region. The expected value in Region 1, Region 2, Region 3, and Region 4 ranged between 6.73-8.97 cm, 7.16-12.26 cm, 8.65-12.73 cm, and 10.95-14.25 cm, respectively. Such a finding also pointed out the discrepancies in the categorization. For example, even though Rize was located in Region 2, the expected value of Rize (12.26 cm) was greater than that of Kastamonu (10.95 cm) in Region 4. The reason behind such an inconsistency could be the changing climate conditions. The calculations in this study were based on the climate projections for the period 2021-2050 rather than historical records.

An optimum insulation thickness map was generated for Turkey (Figure 5). The cities were painted based on their expected values of optimum insulation thickness. A total of 9 different categories were painted in 9 different colours changing from white to black, where the darker colours represented greater thicknesses. The numbers in parentheses represented the number of cities falling into that category. Hatay was the only city with the lightest colour (6 cm ≤ thickness < 7 cm), while Ardahan and Erzurum were painted with the darkest black (14 cm ≤ thickness < 15 cm). The darker colours were observed mostly in the northeast of Turkey.

CONCLUSION

In this study, a stochastic approach was adapted to determine the optimum insulation thickness of a building prototype for 81 cities in Turkey. Stochastic elements were randomly generated based on the characteristics of historical data or future projections. The optimum insulation thickness of each city was obtained as a probability distribution graph indicating the most likely thicknesses. The expected value of each probability distribution graph was calculated and an optimum insulation thickness map was generated by categorizing the cities based on their expected values. The scientific contribution of the proposed study to the body of knowledge can be summarized as reliability and comprehensiveness.

The scientific value of the study stems mainly from the reliability of the adapted stochastic approach. Previous studies have adopted the deterministic approach to calculate the optimum thicknesses, which takes into consideration various assumptions for certain parameters. Since this approach incorporates uncertainties of these parameters, there might be a problem of consistency of the obtained results. As observed in the literature, varying values have been reported for the optimum insulation thicknesses in the studies done for the same cities. The stochastic approach, on the other hand, reflects these uncertainties on the estimates and is expected to provide more accurate results.

Another notable scientific value of the study is its comprehensiveness. The optimum insulation thickness graphs were drawn and the optimum insulation thickness map was generated for 81 cities in Turkey. In previous studies, optimum insulation thicknesses have frequently been determined for a couple of cities from certain climate regions. The results have been assumed to be valid and generalized for all the cities in the same climate region. Having identified the optimum insulation thickness for all the cities in this study provided the opportunity to check whether the optimum insulation thickness varied across the cities within the same climate region.

The identified optimum insulation thicknesses showed great variation across different parts of Turkey. The results revealed that the expected values varied from 6.73 cm (Hatay) to 14.25 cm (Ardahan) depending on the climate properties of the city. Accordingly, the optimum insulation thickness map listed the cities under 9 different categories. The results also emphasized the changing climate conditions as the expected value of a city in Region 2 (Rize: 12.26 cm) was observed to be greater than the expected value of a city in Region 4 (Kastamonu: 10.95 cm). The study had a number of limitations. Firstly, the climate feature obtained for the city center was assumed to be valid for the whole city. The climate features might show variation across different parts of certain cities. Another limitation is that the method presented in TS825 focuses solely on heating and ignores cooling energies. Incorporation of cooling energies into annual energy requirements might result in slightly greater optimum insulation thicknesses in cities that belong to the climate Region 1. It should also be noted that historical data for the inflation rate was obtained from one of the distributers of natural gas (due to the availability of data) and the rate of increase in natural gas prices was determined accordingly. Collecting product-based data rather than energy cost-based data might lead to variation in results. Moreover, the assumption for the cost of natural gas reflects the situation when the analysis was conducted. The price might be subjected to variation as the energy prices are highly vulnerable to the changes in both local and global conditions.

The optimum insulation thickness map obtained as a result of this study is expected to benefit several organizations to improve the energy efficiency of buildings in Turkey. Relevant bodies may adopt the map to revise the current regulation and the recommended thickness; sector professionals may consider the thickness values proposed in this study in their practices; and investors may evaluate their insulation decisions from a financial point of view. A further study should incorporate the cooling calculations in the energy efficiency analysis. Moreover, similar studies can be conducted in other countries based on their own national standards to promote energy efficiency countrywide. Achieving the national strategic objectives requires collaborative studies on energy efficiency. Academic studies should be encouraged and supported by public bodies, non-governmental organizations, and private sector associations. The outcomes of the studies should be interpreted to create social awareness.

Table 4. Expected value of optimum insulation thickness for 81 cities

Province	Climate Region	Expected Value (cm)	Province	Climate Region	Expected Value (cm)	Province	Climate Region	Expected Value (cm)
Adana	1	8.86	Edirne	2	8.07	Malatya	3	11.22
Adıyaman	2	9.59	Elazığ	3	10.87	Manisa	2	8.27
Afyonkarahisar	3	10.59	Erzincan	4	12.95	Mardin	2	8.66
Ağrı	4	13.61	Erzurum	4	14.01	Mersin	1	8.97
Aksaray	3	10.29	Eskişehir	3	10.15	Muğla	2	7.18
Amasya	2	10.51	Gaziantep	2	8.71	Muş	4	12.70
Ankara	3	10.47	Giresun	2	11.77	Nevşehir	3	10.68
Antalya	1	8.59	Gümüşhane	4	13.61	Niğde	3	11.69
Ardahan	4	14.25	Hakkari	4	12.97	Ordu	2	10.28
Artvin	3	12.57	Hatay	1	6.73	Osmaniye	1	7.65
Aydın	1	7.61	Iğdır	3	11.99	Rize	2	12.26
Balıkesir	2	8.23	Isparta	3	10.84	Sakarya	2	8.47
Bartın	2	8.92	İstanbul	2	7.16	Samsun	2	9.28
Batman	2	9.49	İzmir	1	7.06	Şanlıurfa	2	8.18
Bayburt	4	13.75	Kahramanmaraş	2	10.95	Siirt	2	10.63
Bilecik	3	9.65	Karabük	3	10.54	Sinop	2	9.72
Bingöl	3	12.73	Karaman	3	10.97	Sivas	4	12.63
Bitlis	4	12.54	Kars	4	13.77	Şırnak	2	10.42
Bolu	3	11.38	Kastamonu	4	10.95	Tekirdağ	2	7.79
Burdur	3	10.17	Kayseri	4	12.07	Tokat	3	11.16
Bursa	2	8.76	Kilis	2	8.30	Trabzon	2	11.14
Çanakkale	2	7.48	Kırıkkale	3	10.42	Tunceli	3	12.11
Çankırı	3	11.29	Kırklareli	3	8.65	Uşak	3	9.59
Çorum	3	10.81	Kırşehir	3	10.44	Van	4	13.93
Denizli	2	9.63	Kocaeli	2	7.77	Yalova	2	7.37
Diyarbakır	2	9.58	Konya	3	10.40	Yozgat	4	11.10
Düzce	2	9.47	Kütahya	3	10.76	Zonguldak	2	8.75

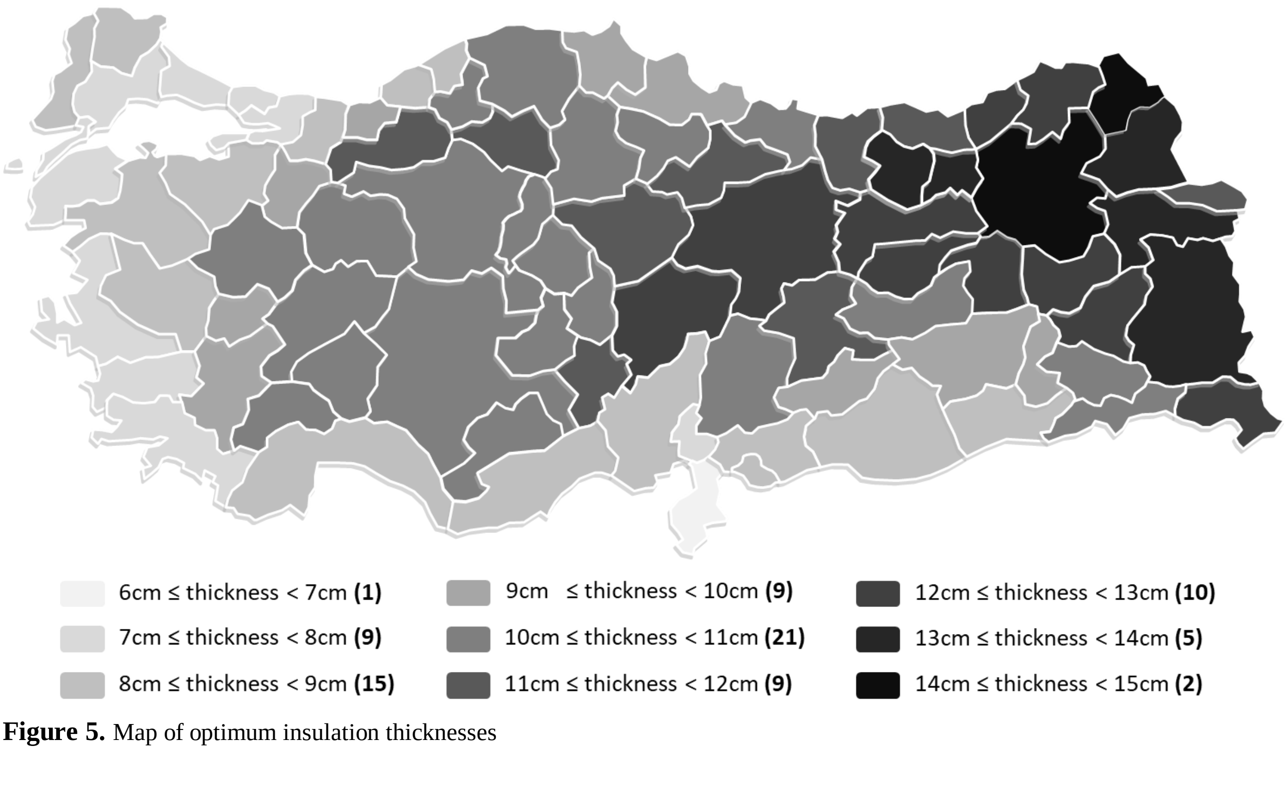

Figure 5. Map of optimum insulation thicknesses

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APPENDIX A: MEAN AND STANDARD DEVIATION OF THE CLIMATE PROJECTION

Table A1. Mean and standard deviation of the climate projection for Adana-Düzce (ºC)

Province	Jan.	Febr.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Adana	3.32 (2.62)	4.64 (3.11)	8.05 (3.31)	12.88 (3.72)	18.08 (4.18)	22.67 (3.31)	25.35 (2.24)	25.97 (2.90)	22.20 (3.34)	16.30 (3.72)	9.89 (2.94)	4.64 (2.95)
Adıyaman	1.43 (2.61)	2.98 (3.20)	6.79 (3.59)	12.53 (4.19)	18.91 (4.28)	24.33 (3.42)	27.46 (2.59)	27.44 (3.04)	23.06 (3.62)	16.10 (4.11)	8.56 (3.17)	2.85 (3.03)
Afyonkarahisar	0.89 (2.97)	1.92 (3.37)	4.83 (3.54)	9.41 (3.90)	14.98 (4.22)	19.70 (3.62)	22.54 (2.71)	22.79 (3.09)	18.16 (3.71)	11.87 (4.02)	6.46 (3.04)	2.03 (3.26)
Ağrı	-5.58 (3.42)	-4.48 (4.06)	-0.93 (3.93)	4.36 (3.56)	10.19 (3.55)	15.33 (3.32)	19.09 (3.21)	18.92 (3.15)	14.24 (3.43)	7.69 (3.73)	1.49 (3.04)	-3.85 (3.62)
Aksaray	1.11 (2.99)	2.40 (3.48)	5.82 (3.84)	10.94 (4.18)	16.42 (4.28)	21.10 (3.64)	23.90 (2.85)	24.21 (3.25)	19.66 (3.90)	13.27 (4.29)	7.21 (3.28)	2.24 (3.31)
Amasya	1.56 (2.99)	2.65 (3.58)	5.80 (3.91)	10.43 (4.10)	15.26 (4.17)	19.12 (3.75)	21.05 (3.25)	21.77 (3.74)	17.82 (4.28)	12.52 (4.19)	7.39 (3.17)	2.79 (3.21)
Ankara	0.86 (2.93)	1.96 (3.40)	5.08 (3.62)	9.76 (3.89)	15.12 (4.19)	19.84 (3.70)	22.57 (2.87)	23.00 (3.29)	18.34 (3.94)	12.05 (4.21)	6.49 (3.04)	2.00 (3.16)
Antalya	4.75 (2.46)	5.57 (2.69)	8.01 (2.99)	12.30 (3.62)	17.61 (4.14)	22.06 (3.53)	25.06 (2.43)	25.19 (2.73)	21.14 (3.19)	15.47 (3.41)	10.22 (2.66)	6.05 (2.68)
Ardahan	-6.49 (3.42)	-5.58 (4.12)	-2.38 (4.13)	2.57 (3.81)	7.98 (3.75)	12.41 (3.58)	15.51 (3.64)	15.95 (3.63)	11.63 (3.89)	5.99 (3.96)	0.49 (3.19)	-4.78 (3.69)
Artvin	-2.71 (3.24)	-1.78 (3.95)	1.26 (4.10)	6.06 (4.01)	11.21 (3.90)	14.89 (3.78)	17.19 (3.70)	17.94 (4.10)	14.27 (4.32)	9.20 (4.22)	3.97 (3.26)	-1.15 (3.51)
Aydın	6.57 (2.87)	7.36 (2.96)	9.68 (3.05)	13.84 (3.59)	19.44 (4.20)	24.76 (3.77)	27.93 (2.81)	27.84 (2.95)	23.26 (3.53)	17.15 (3.52)	11.93 (2.96)	7.71 (3.22)
Balıkesir	5.37 (3.02)	6.19 (3.20)	8.54 (3.19)	12.59 (3.47)	18.01 (3.97)	22.63 (3.46)	25.09 (2.81)	25.29 (3.01)	20.89 (3.70)	15.31 (3.53)	10.72 (2.93)	6.67 (3.25)
Bartın	4.43 (3.03)	5.25 (3.53)	7.87 (3.94)	12.04 (4.06)	16.79 (4.25)	20.70 (3.78)	22.56 (3.49)	23.13 (3.81)	19.05 (4.11)	14.35 (3.88)	10.17 (3.12)	5.78 (3.20)
Batman	1.22 (2.61)	2.88 (3.27)	6.83 (3.65)	12.68 (4.08)	19.29 (3.90)	25.20 (3.05)	28.54 (2.20)	28.25 (2.48)	23.67 (3.10)	16.46 (3.85)	8.66 (3.15)	2.66 (3.05)
Bayburt	-5.75 (3.27)	-4.61 (3.93)	-1.30 (4.00)	3.69 (3.71)	9.22 (3.89)	13.95 (3.76)	16.90 (3.61)	17.16 (3.81)	12.92 (4.03)	7.08 (3.99)	1.38 (3.17)	-4.18 (3.66)
Bilecik	2.94 (3.19)	3.92 (3.65)	6.78 (3.88)	11.13 (4.05)	16.38 (4.35)	20.55 (3.77)	22.80 (3.13)	23.16 (3.57)	18.78 (4.10)	13.27 (4.10)	8.62 (3.19)	4.22 (3.35)
Bingöl	-4.30 (3.10)	-3.01 (3.72)	0.59 (3.80)	5.98 (3.66)	12.03 (3.82)	17.97 (3.42)	21.76 (2.63)	21.61 (2.87)	16.78 (3.39)	9.89 (3.81)	3.14 (3.17)	-2.70 (3.53)
Bitlis	-3.36 (2.83)	-2.25 (3.39)	0.96 (3.44)	5.84 (3.44)	11.52 (3.46)	16.93 (2.98)	20.42 (2.39)	20.17 (2.52)	15.83 (3.00)	9.43 (3.45)	3.21 (2.83)	-1.85 (3.14)
Bolu	-0.12 (3.15)	0.84 (3.60)	3.79 (3.89)	8.22 (4.01)	13.38 (4.27)	17.82 (3.87)	20.12 (3.34)	20.73 (3.82)	16.36 (4.32)	10.80 (4.24)	5.81 (3.20)	1.20 (3.33)
Burdur	1.64 (2.79)	2.66 (3.02)	5.40 (3.32)	10.08 (3.84)	15.77 (4.21)	20.56 (3.60)	23.70 (2.50)	23.70 (2.89)	19.01 (3.43)	12.71 (3.75)	7.20 (2.93)	2.81 (3.08)
Bursa	4.68 (3.00)	5.53 (3.38)	8.12 (3.61)	12.28 (3.85)	17.56 (4.19)	21.82 (3.62)	24.05 (3.02)	24.37 (3.33)	19.99 (3.91)	14.66 (3.76)	10.18 (2.98)	5.99 (3.17)
Çanakkale	7.01 (3.27)	7.72 (3.21)	9.69 (2.89)	13.38 (2.92)	18.39 (3.41)	22.92 (3.08)	25.47 (2.54)	25.63 (2.61)	21.54 (3.22)	16.43 (3.05)	12.22 (2.98)	8.52 (3.40)
Çankırı	-0.32 (3.04)	0.68 (3.52)	3.83 (3.82)	8.44 (3.96)	13.55 (4.14)	17.99 (3.76)	20.42 (3.16)	21.02 (3.57)	16.53 (4.18)	10.78 (4.18)	5.47 (3.10)	0.94 (3.19)
Çorum	0.89 (2.92)	2.02 (3.47)	5.25 (3.81)	9.94 (4.03)	15.02 (4.20)	19.29 (3.79)	21.56 (3.17)	22.19 (3.61)	17.89 (4.19)	12.08 (4.25)	6.65 (3.13)	2.10 (3.14)
Denizli	2.80 (2.94)	3.83 (3.17)	6.60 (3.49)	11.22 (3.98)	17.01 (4.35)	22.07 (3.67)	25.16 (2.66)	25.21 (3.01)	20.49 (3.58)	14.08 (3.89)	8.46 (3.09)	3.97 (3.20)
Diyarbakır	1.13 (2.62)	2.75 (3.22)	6.65 (3.56)	12.61 (3.99)	19.26 (4.03)	25.29 (3.20)	28.71 (2.27)	28.40 (2.61)	23.67 (3.22)	16.31 (3.90)	8.51 (3.10)	2.57 (3.03)
Düzce	3.68 (3.12)	4.59 (3.61)	7.30 (4.02)	11.47 (4.13)	16.22 (4.33)	19.99 (3.78)	21.87 (3.37)	22.37 (3.77)	18.38 (4.09)	13.65 (3.97)	9.48 (3.24)	5.00 (3.29)

Table A2. Mean and standard deviation of the climate projection for Edirne-Kütahya (ºC)

Province	Jan.	Febr.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Edirne	5.25 (4.31)	6.73 (3.85)	9.34 (3.17)	13.48 (2.89)	18.74 (3.46)	23.67 (3.31)	26.24 (2.79)	26.24 (2.86)	21.75 (3.62)	15.87 (3.62)	10.97 (3.82)	6.76 (4.27)
Elazığ	-1.04 (2.84)	0.35 (3.39)	4.06 (3.60)	9.67 (3.81)	15.86 (4.01)	21.69 (3.51)	25.27 (2.62)	25.05 (2.93)	20.29 (3.53)	13.20 (3.98)	6.12 (2.99)	0.47 (3.23)
Erzincan	-4.77 (3.18)	-3.57 (3.82)	-0.11 (3.87)	5.10 (3.73)	10.83 (3.93)	15.88 (3.69)	19.17 (3.33)	19.31 (3.53)	14.83 (3.94)	8.52 (3.99)	2.43 (3.12)	-3.20 (3.58)
Erzurum	-6.17 (3.32)	-5.07 (4.02)	-1.65 (3.99)	3.44 (3.64)	9.05 (3.66)	13.98 (3.44)	17.30 (3.22)	17.41 (3.33)	12.95 (3.61)	6.86 (3.80)	0.97 (3.14)	-4.51 (3.65)
Eskişehir	1.61 (3.09)	2.68 (3.56)	5.72 (3.76)	10.32 (4.01)	15.79 (4.30)	20.43 (3.69)	23.01 (2.88)	23.39 (3.30)	18.77 (3.93)	12.61 (4.18)	7.27 (3.18)	2.76 (3.33)
Gaziantep	3.23 (2.60)	4.80 (3.05)	8.48 (3.43)	14.06 (4.10)	20.16 (4.32)	25.30 (3.28)	28.01 (2.47)	28.35 (2.94)	24.23 (3.39)	17.45 (3.92)	9.96 (3.04)	4.46 (3.01)
Giresun	-1.09 (3.06)	-0.10 (3.70)	2.91 (3.95)	7.62 (4.00)	12.43 (4.04)	16.02 (3.73)	17.91 (3.44)	18.61 (4.00)	15.19 (4.31)	10.46 (4.09)	5.49 (3.25)	0.35 (3.41)
Gümüşhane	-4.88 (3.24)	-3.80 (3.89)	-0.58 (3.97)	4.35 (3.81)	9.76 (3.97)	13.95 (3.79)	16.47 (3.65)	16.93 (3.98)	13.02 (4.25)	7.54 (4.06)	2.05 (3.21)	-3.34 (3.60)
Hakkari	-5.05 (3.37)	-3.67 (3.89)	0.09 (3.92)	5.53 (3.78)	11.29 (3.49)	16.84 (3.04)	20.62 (2.71)	20.40 (2.62)	15.96 (3.18)	9.10 (3.59)	2.42 (3.24)	-3.29 (3.68)
Hatay	7.08 (2.53)	8.30 (2.83)	11.32 (2.97)	15.62 (3.58)	20.04 (4.11)	23.98 (3.15)	25.92 (2.31)	27.08 (3.06)	24.21 (3.16)	19.29 (3.49)	13.17 (2.78)	8.15 (2.87)
Iğdır	-2.39 (3.17)	-1.19 (3.82)	2.52 (3.79)	8.20 (3.81)	14.01 (3.65)	18.47 (3.52)	21.98 (3.90)	22.03 (3.52)	17.53 (3.84)	10.82 (4.05)	4.22 (3.04)	-0.86 (3.30)
Isparta	0.81 (2.77)	1.74 (3.06)	4.43 (3.26)	8.87 (3.75)	14.32 (4.13)	18.87 (3.55)	21.82 (2.56)	21.98 (2.95)	17.53 (3.49)	11.45 (3.82)	6.21 (2.86)	1.95 (3.02)
İstanbul	7.36 (3.09)	7.97 (3.01)	10.02 (2.87)	13.57 (2.93)	18.22 (3.29)	22.24 (2.83)	24.38 (2.38)	24.81 (2.54)	21.22 (2.87)	16.70 (2.92)	12.73 (2.93)	8.66 (3.35)
İzmir	7.63 (2.87)	8.28 (2.90)	10.26 (2.75)	13.96 (3.08)	19.23 (3.84)	24.46 (3.58)	27.44 (2.71)	27.51 (2.86)	23.11 (3.43)	17.41 (3.28)	12.77 (2.81)	8.88 (3.16)
Kahramanmaraş	-0.88 (2.97)	0.46 (3.51)	4.09 (3.63)	9.33 (3.91)	15.03 (4.17)	20.03 (3.42)	23.13 (2.49)	23.35 (3.01)	19.07 (3.58)	12.59 (3.91)	6.02 (3.04)	0.59 (3.30)
Karabük	1.31 (3.17)	2.26 (3.69)	5.18 (4.08)	9.59 (4.18)	14.53 (4.33)	18.79 (3.92)	20.83 (3.53)	21.51 (3.98)	17.17 (4.44)	12.01 (4.25)	7.26 (3.32)	2.64 (3.37)
Karaman	0.13 (3.17)	1.33 (3.59)	4.62 (3.86)	9.76 (4.15)	15.21 (4.21)	19.77 (3.50)	22.89 (2.55)	22.99 (2.90)	18.48 (3.56)	12.14 (3.97)	6.29 (3.21)	1.45 (3.43)
Kars	-5.72 (3.40)	-4.69 (4.05)	-1.28 (3.90)	3.98 (3.56)	9.70 (3.55)	14.28 (3.32)	17.61 (3.43)	17.72 (3.29)	13.21 (3.62)	7.00 (3.73)	1.13 (2.99)	-3.98 (3.56)
Kastamonu	0.89 (3.07)	1.79 (3.61)	4.70 (4.03)	9.05 (4.08)	13.85 (4.16)	17.83 (3.75)	19.74 (3.35)	20.49 (3.81)	16.38 (4.29)	11.49 (4.11)	6.81 (3.21)	2.24 (3.25)
Kayseri	-2.07 (3.25)	-0.89 (3.80)	2.63 (3.90)	7.76 (4.07)	13.18 (4.22)	17.83 (3.73)	20.80 (3.14)	21.22 (3.47)	16.86 (4.07)	10.58 (4.20)	4.59 (3.26)	-0.70 (3.58)
Kilis	4.03 (2.54)	5.59 (3.01)	9.22 (3.47)	14.68 (4.23)	20.56 (4.51)	25.55 (3.42)	28.04 (2.66)	28.61 (3.13)	24.71 (3.50)	18.17 (3.96)	10.77 (3.10)	5.23 (2.97)
Kırıkkale	1.43 (2.91)	2.60 (3.44)	5.82 (3.73)	10.67 (4.02)	15.97 (4.24)	20.55 (3.76)	23.18 (2.96)	23.63 (3.35)	19.00 (3.97)	12.70 (4.23)	7.02 (3.13)	2.49 (3.17)
Kırklareli	4.07 (4.04)	5.55 (3.74)	8.25 (3.27)	12.46 (3.11)	17.63 (3.60)	22.19 (3.36)	24.45 (2.90)	24.54 (3.04)	20.29 (3.58)	14.72 (3.59)	9.89 (3.71)	5.49 (4.07)
Kırşehir	0.65 (2.98)	1.85 (3.52)	5.22 (3.81)	10.16 (4.12)	15.58 (4.35)	20.18 (3.81)	22.84 (3.08)	23.30 (3.49)	18.74 (4.11)	12.42 (4.39)	6.52 (3.22)	1.76 (3.27)
Kocaeli	6.69 (2.81)	7.28 (3.11)	9.48 (3.32)	13.25 (3.46)	17.96 (3.72)	21.84 (3.21)	23.83 (2.73)	24.27 (2.96)	20.44 (3.31)	15.87 (3.20)	11.99 (2.77)	8.04 (2.94)
Konya	0.98 (3.03)	2.16 (3.43)	5.31 (3.71)	10.28 (4.02)	15.71 (4.14)	20.24 (3.54)	23.12 (2.67)	23.35 (3.02)	18.76 (3.69)	12.44 (4.05)	6.77 (3.14)	2.12 (3.31)
Kütahya	1.00 (3.10)	2.04 (3.48)	4.86 (3.61)	9.20 (3.92)	14.75 (4.37)	19.58 (3.76)	22.22 (2.97)	22.56 (3.43)	17.97 (4.01)	11.86 (4.11)	6.71 (3.12)	2.25 (3.37)

Table A3. Mean and standard deviation of the climate projection for Malatya-Zonguldak (ºC)

Province	Jan.	Febr.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Malatya	-1.61 (2.99)	-0.28 (3.51)	3.40 (3.66)	8.93 (3.89)	14.82 (4.06)	20.12 (3.60)	23.52 (2.90)	23.49 (3.18)	18.91 (3.79)	12.08 (4.05)	5.31 (3.03)	-0.15 (3.33)
Manisa	5.03 (2.97)	5.99 (3.13)	8.54 (3.24)	12.88 (3.72)	18.76 (4.35)	24.09 (3.79)	26.97 (2.86)	27.09 (3.22)	22.24 (3.86)	15.87 (3.87)	10.50 (3.04)	6.18 (3.29)
Mardin	2.58 (2.50)	4.43 (3.11)	8.56 (3.70)	14.71 (4.36)	21.53 (4.05)	27.36 (3.00)	30.43 (2.16)	30.24 (2.48)	25.74 (3.11)	18.37 (3.86)	10.09 (3.25)	3.94 (2.92)
Mersin	3.44 (2.57)	4.58 (2.99)	7.68 (3.36)	12.55 (3.88)	17.79 (4.25)	22.24 (3.43)	25.07 (2.37)	25.47 (2.89)	21.48 (3.30)	15.66 (3.61)	9.54 (2.88)	4.76 (2.83)
Muğla	7.35 (2.39)	7.95 (2.50)	9.94 (2.69)	13.69 (3.32)	18.82 (4.06)	23.69 (3.67)	26.90 (2.69)	26.81 (2.71)	22.87 (3.18)	17.35 (3.09)	12.54 (2.61)	8.62 (2.65)
Muş	-4.21 (3.26)	-2.93 (3.84)	0.66 (3.70)	6.03 (3.47)	12.28 (3.67)	18.08 (3.24)	21.77 (2.56)	21.44 (2.73)	16.57 (3.21)	9.67 (3.63)	3.08 (2.95)	-2.51 (3.52)
Nevşehir	0.27 (3.12)	1.49 (3.70)	4.99 (3.97)	10.09 (4.28)	15.54 (4.40)	20.18 (3.83)	22.91 (3.15)	23.34 (3.52)	18.87 (4.18)	12.56 (4.41)	6.49 (3.35)	1.45 (3.45)
Niğde	-1.83 (3.30)	-0.60 (3.80)	2.87 (3.95)	8.03 (4.20)	13.49 (4.28)	18.19 (3.66)	21.32 (2.89)	21.60 (3.20)	17.21 (3.84)	10.91 (4.14)	4.80 (3.33)	-0.44 (3.60)
Ordu	1.89 (3.04)	2.82 (3.72)	5.69 (4.05)	10.12 (4.14)	14.50 (4.11)	17.72 (3.63)	19.27 (3.24)	20.12 (3.89)	16.93 (4.26)	12.67 (4.06)	8.16 (3.33)	3.26 (3.34)
Osmaniye	5.33 (2.50)	6.87 (3.05)	10.29 (3.36)	15.03 (3.91)	19.99 (4.38)	24.18 (3.39)	26.25 (2.61)	27.26 (3.25)	24.00 (3.47)	18.58 (3.84)	12.06 (3.06)	6.57 (2.89)
Rize	-1.36 (3.23)	-0.39 (3.96)	2.55 (4.29)	7.21 (4.22)	11.93 (4.07)	15.15 (3.90)	16.80 (3.70)	17.69 (4.28)	14.60 (4.55)	10.18 (4.38)	5.31 (3.50)	0.14 (3.59)
Sakarya	5.08 (3.05)	5.94 (3.48)	8.55 (3.75)	12.64 (3.87)	17.46 (4.11)	21.17 (3.54)	23.06 (3.05)	23.46 (3.40)	19.52 (3.73)	14.72 (3.66)	10.63 (3.04)	6.35 (3.19)
Samsun	4.12 (2.96)	5.00 (3.56)	7.72 (3.84)	11.91 (3.90)	16.31 (3.92)	19.80 (3.39)	21.54 (2.96)	22.35 (3.45)	18.74 (3.87)	14.27 (3.78)	9.83 (3.09)	5.38 (3.09)
Şanlıurfa	3.59 (2.44)	5.35 (2.99)	9.31 (3.57)	15.31 (4.26)	21.91 (4.16)	27.45 (3.17)	30.33 (2.34)	30.36 (2.76)	25.98 (3.32)	18.79 (3.88)	10.79 (3.16)	4.87 (2.84)
Siirt	-0.68 (2.82)	0.86 (3.45)	4.69 (3.74)	10.29 (4.04)	16.65 (3.86)	22.53 (3.04)	25.96 (2.19)	25.72 (2.45)	21.15 (3.04)	14.16 (3.73)	6.73 (3.21)	0.86 (3.30)
Sinop	3.02 (2.95)	3.90 (3.53)	6.61 (3.88)	10.86 (3.97)	15.37 (3.99)	19.04 (3.51)	20.81 (3.13)	21.62 (3.59)	17.77 (4.00)	13.21 (3.87)	8.74 (3.09)	4.30 (3.07)
Sivas	-2.96 (3.22)	-1.83 (3.78)	1.58 (3.87)	6.73 (3.95)	12.07 (4.06)	16.43 (3.77)	19.15 (3.45)	19.61 (3.79)	15.44 (4.28)	9.46 (4.13)	3.74 (3.17)	-1.51 (3.50)
Şırnak	-0.93 (2.91)	0.71 (3.51)	4.69 (3.82)	10.43 (4.16)	16.91 (3.85)	22.78 (2.98)	26.24 (2.17)	26.02 (2.36)	21.46 (3.01)	14.31 (3.69)	6.68 (3.29)	0.68 (3.36)
Tekirdağ	5.73 (3.95)	6.95 (3.63)	9.38 (3.10)	13.38 (2.99)	18.50 (3.44)	23.02 (3.11)	25.45 (2.59)	25.58 (2.72)	21.42 (3.37)	16.04 (3.42)	11.41 (3.61)	7.13 (4.11)
Tokat	0.12 (3.15)	1.20 (3.77)	4.49 (4.11)	9.31 (4.26)	14.21 (4.29)	17.90 (3.97)	19.76 (3.59)	20.52 (4.13)	16.85 (4.62)	11.62 (4.37)	6.41 (3.33)	1.46 (3.43)
Trabzon	0.66 (3.10)	1.62 (3.83)	4.45 (4.19)	9.04 (4.27)	13.60 (4.25)	16.79 (3.94)	18.28 (3.55)	19.20 (4.23)	16.12 (4.56)	11.84 (4.32)	7.19 (3.43)	2.13 (3.45)
Tunceli	-3.28 (2.93)	-2.03 (3.53)	1.48 (3.69)	6.79 (3.68)	12.64 (3.86)	18.18 (3.55)	21.78 (2.93)	21.77 (3.18)	17.19 (3.64)	10.53 (3.93)	3.90 (3.07)	-1.74 (3.39)
Uşak	2.65 (2.91)	3.73 (3.19)	6.53 (3.42)	11.04 (3.94)	16.96 (4.47)	22.25 (3.79)	25.24 (2.85)	25.41 (3.27)	20.55 (3.83)	13.95 (4.09)	8.32 (3.06)	3.80 (3.20)
Van	-6.13 (3.31)	-5.03 (3.86)	-1.67 (3.80)	3.42 (3.45)	8.94 (3.30)	14.32 (2.94)	18.02 (2.59)	17.65 (2.56)	13.17 (2.95)	6.82 (3.35)	0.82 (2.97)	-4.41 (3.55)
Yalova	6.93 (2.72)	7.55 (3.10)	9.85 (3.41)	13.80 (3.60)	18.83 (3.91)	22.96 (3.41)	25.07 (2.89)	25.38 (3.08)	21.14 (3.53)	16.24 (3.28)	12.17 (2.71)	8.34 (2.82)
Yozgat	-0.32 (3.08)	0.83 (3.64)	4.28 (3.92)	9.20 (4.14)	14.50 (4.33)	18.87 (3.91)	21.31 (3.38)	21.90 (3.80)	17.64 (4.37)	11.58 (4.40)	5.85 (3.23)	0.93 (3.38)
Zonguldak	4.79 (3.07)	5.61 (3.56)	8.23 (3.97)	12.39 (4.08)	17.11 (4.27)	20.87 (3.71)	22.67 (3.34)	23.17 (3.69)	19.18 (3.99)	14.54 (3.84)	10.45 (3.13)	6.11 (3.22)

APPENDIX B: HISTOGRAM OF THE OPTIMUM INSULATION THICKNESSES

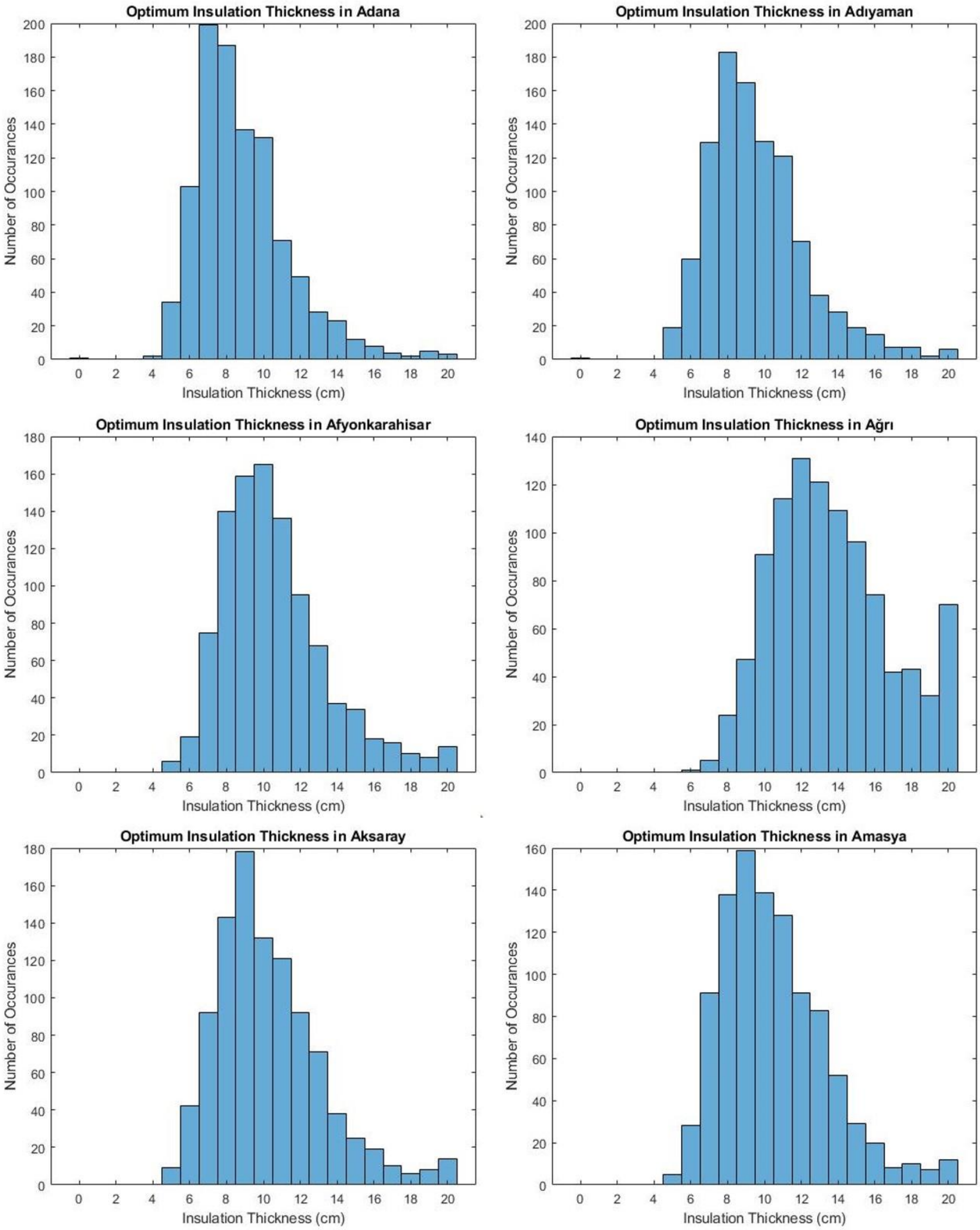

Figure B1. Optimum insulation thickness in Adana-Amasya

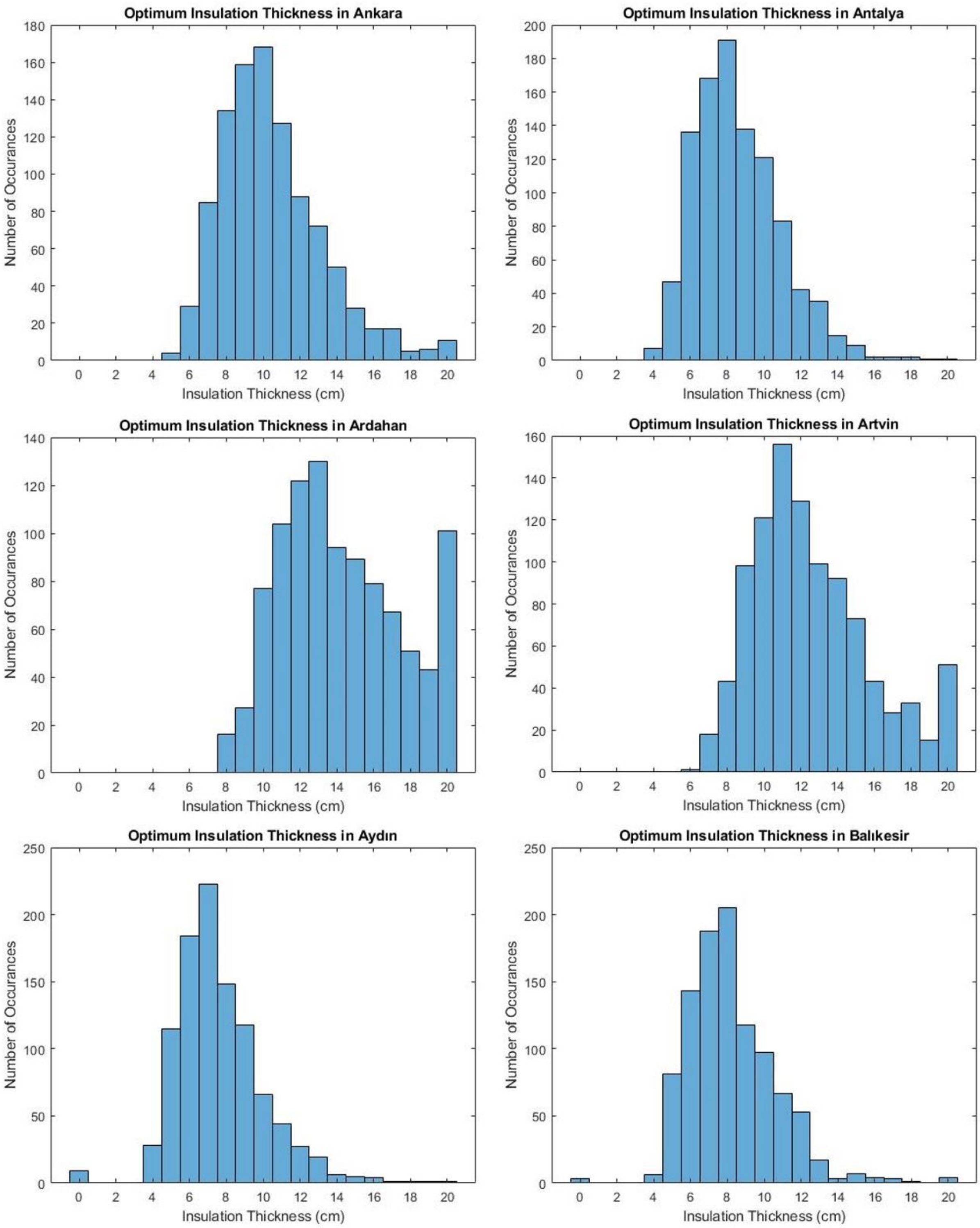

Figure B2. Optimum insulation thickness in Ankara-Balıkesir

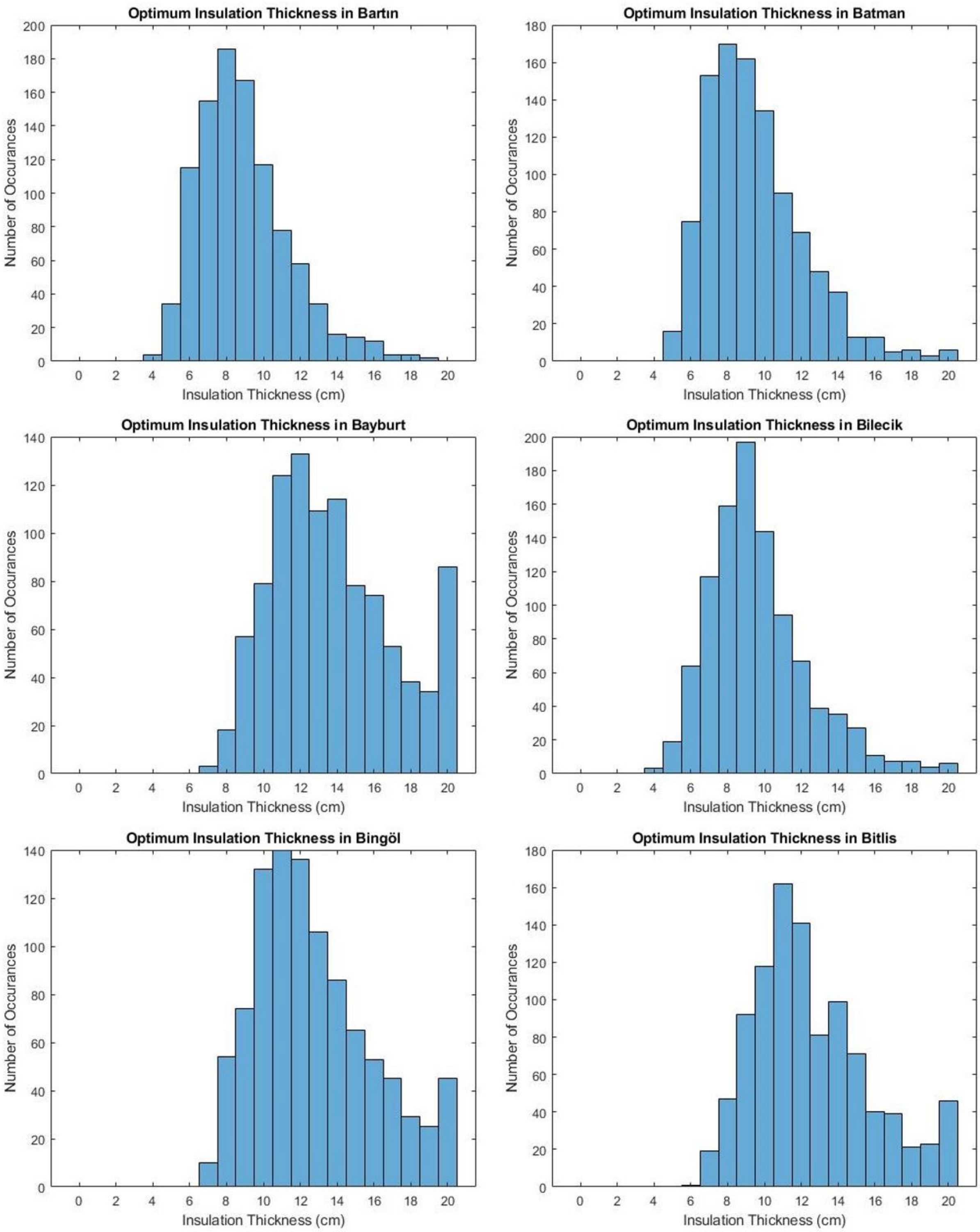

Figure B3. Optimum insulation thickness in Bartın-Bitlis

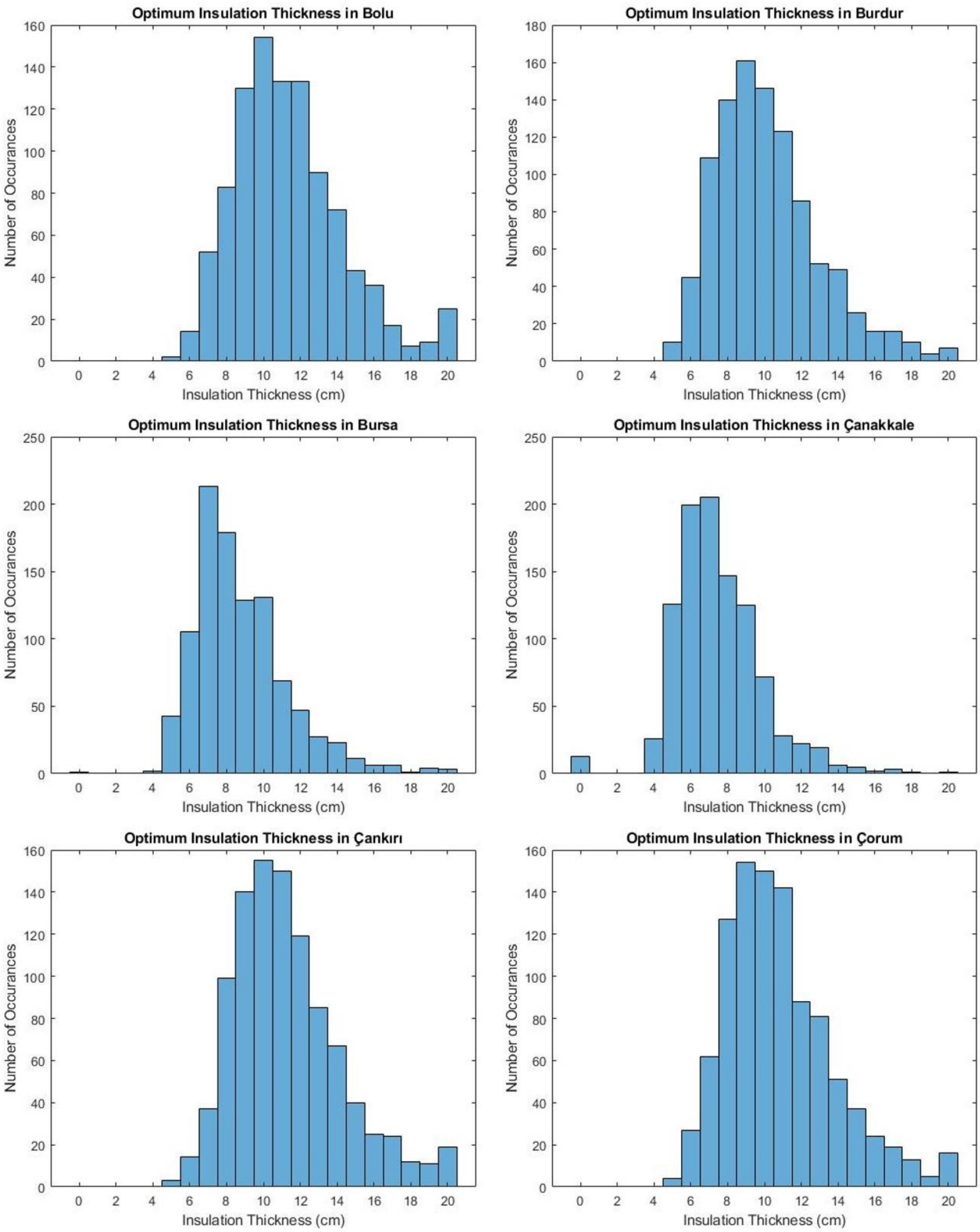

Figure B4. Optimum insulation thickness in Bolu-Çorum

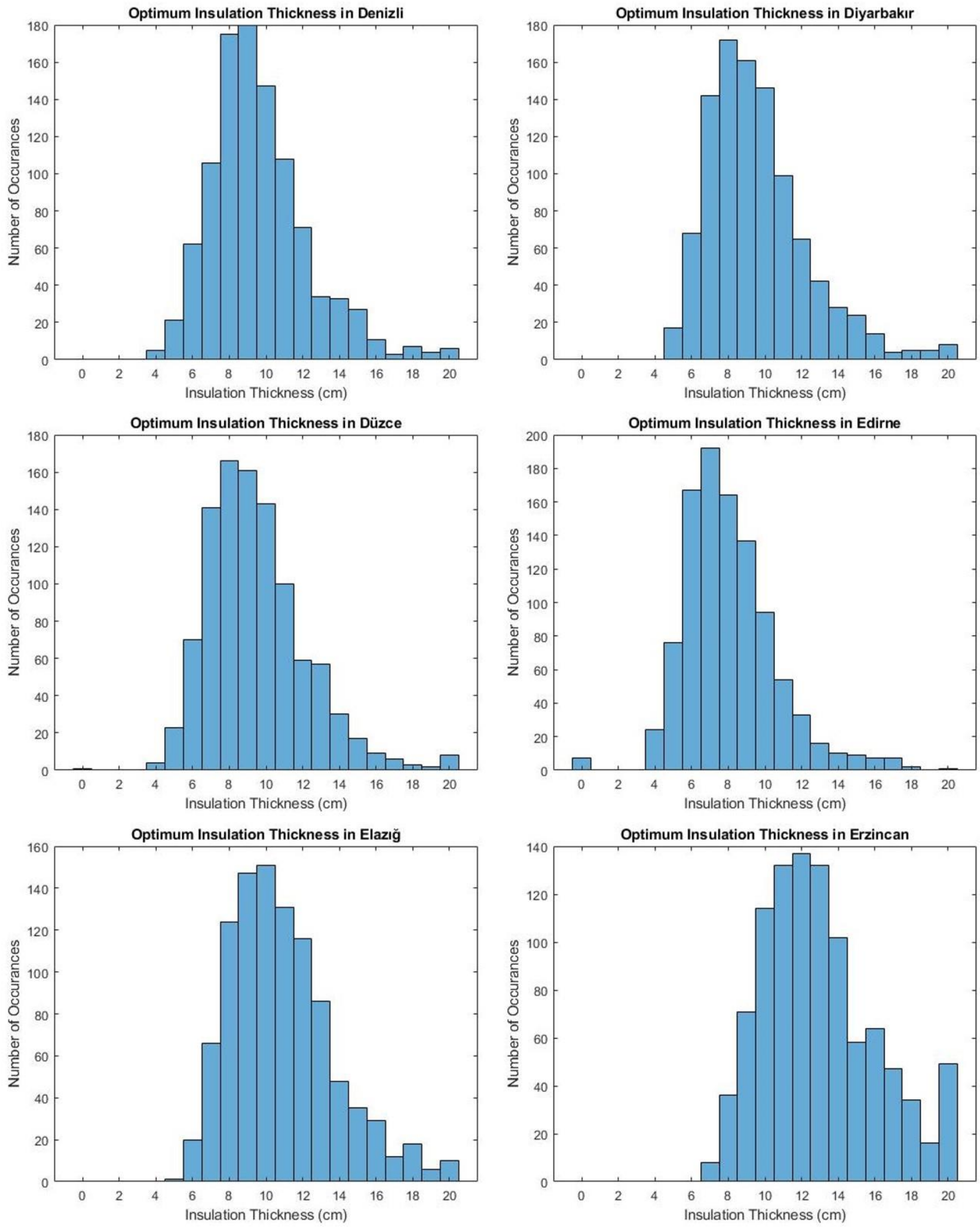

Figure B5. Optimum insulation thickness in Denizli-Erzincan

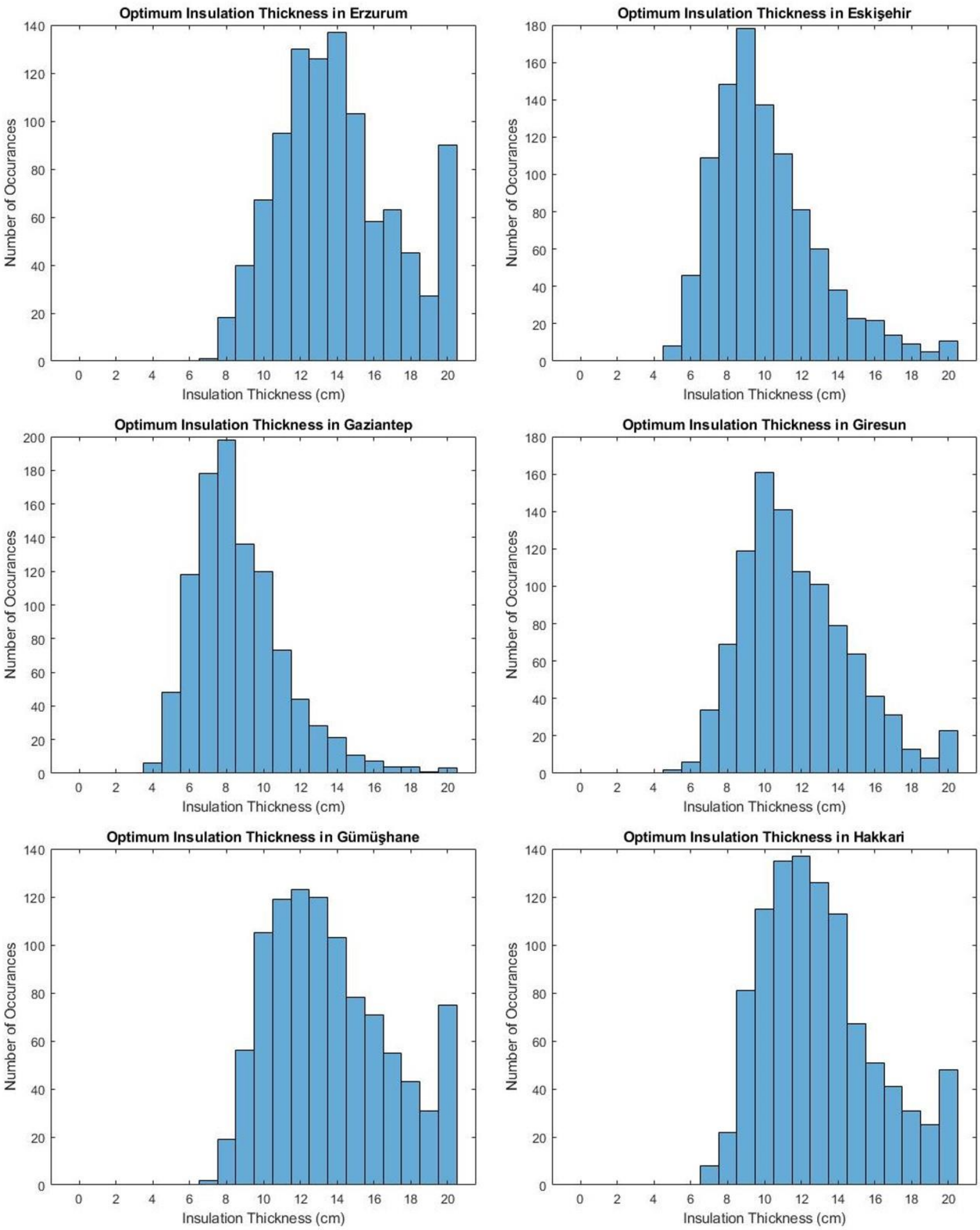

Figure B6. Optimum insulation thickness in Erzurum-Hakkari

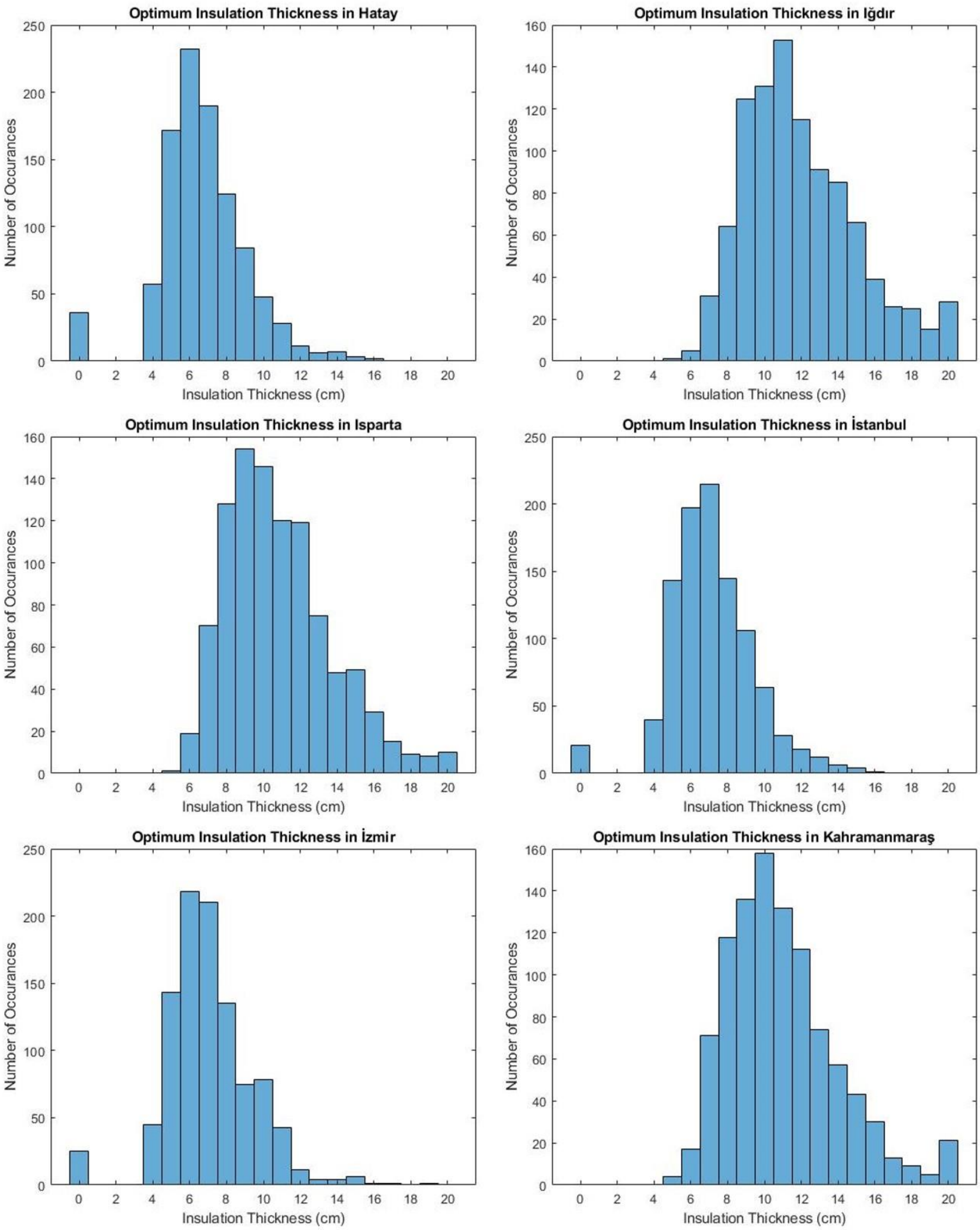

Figure B7. Optimum insulation thickness in Hatay-Kahramanmaraş

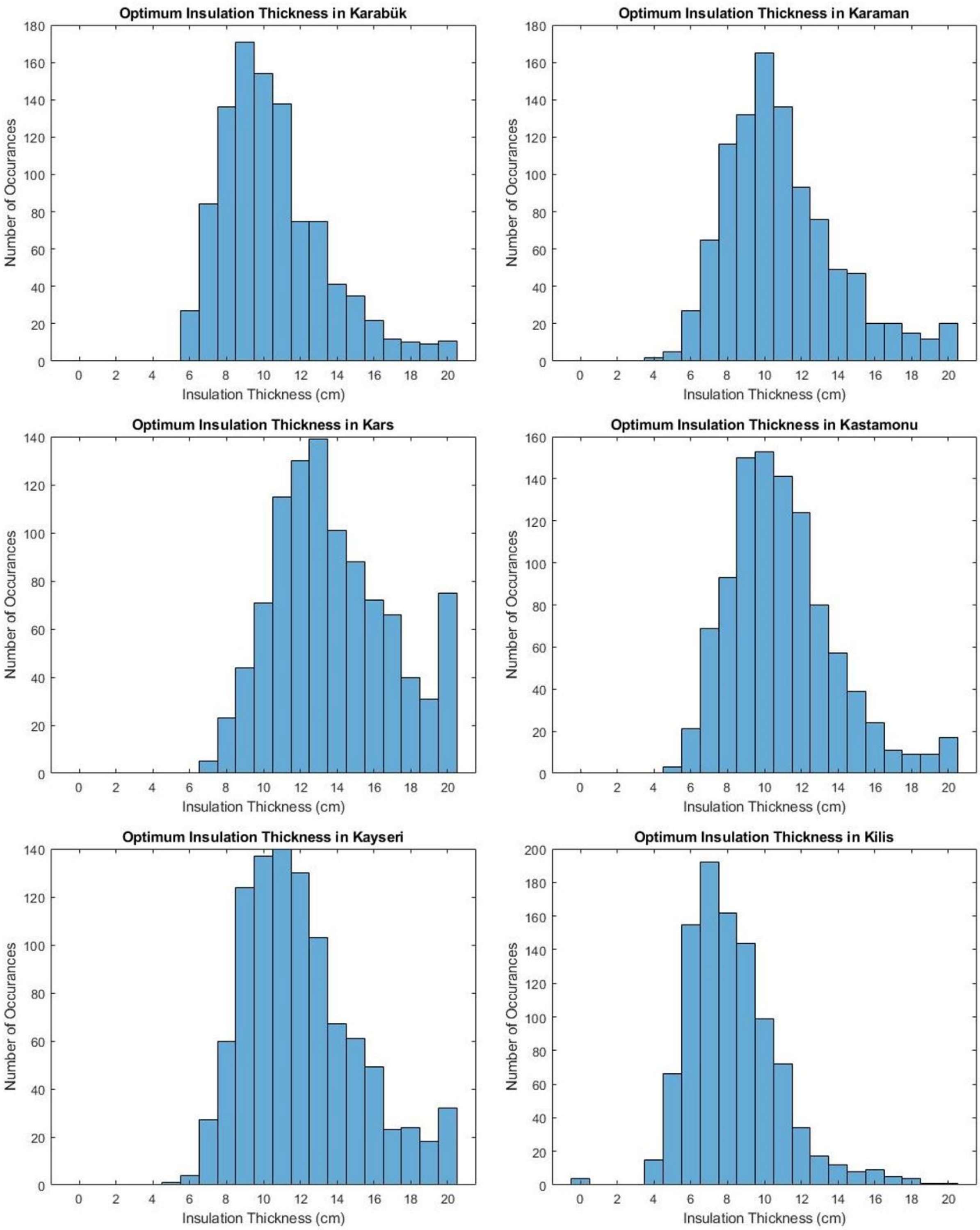

Figure B8. Optimum insulation thickness in Karabük-Kilis

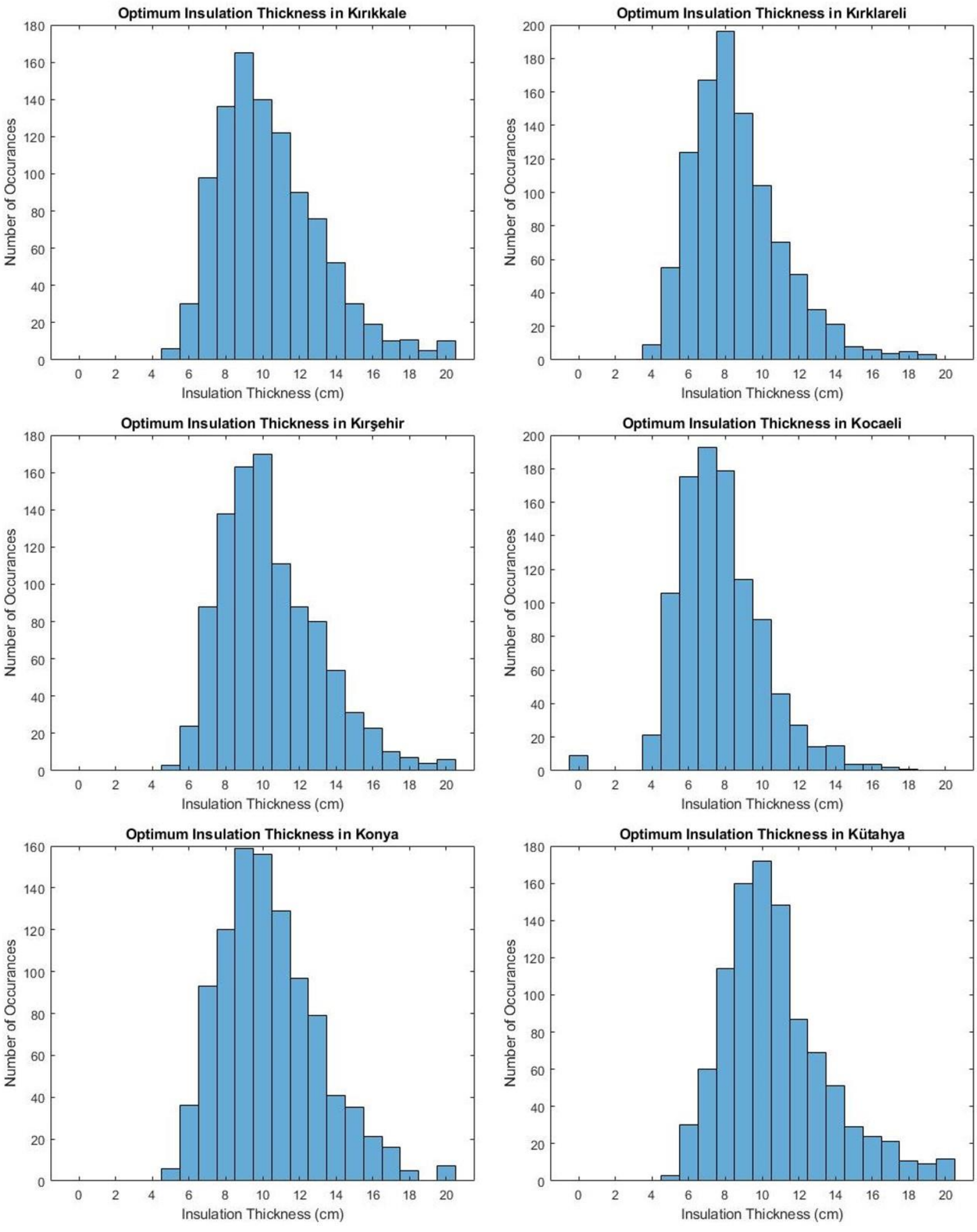

Figure B9. Optimum insulation thickness in Kırıkkale-Kütahya

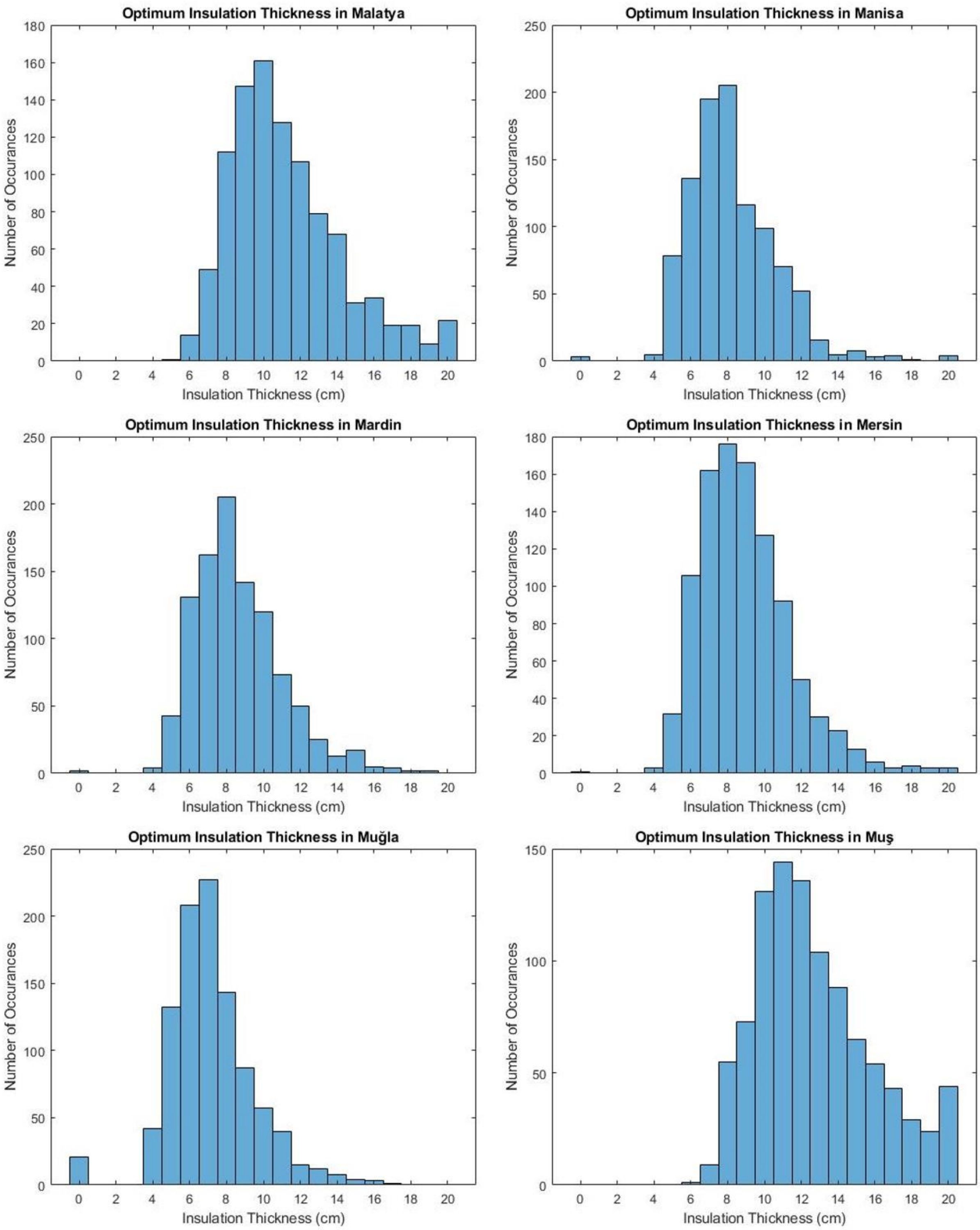

Figure B10. Optimum insulation thickness in Malatya-Muş

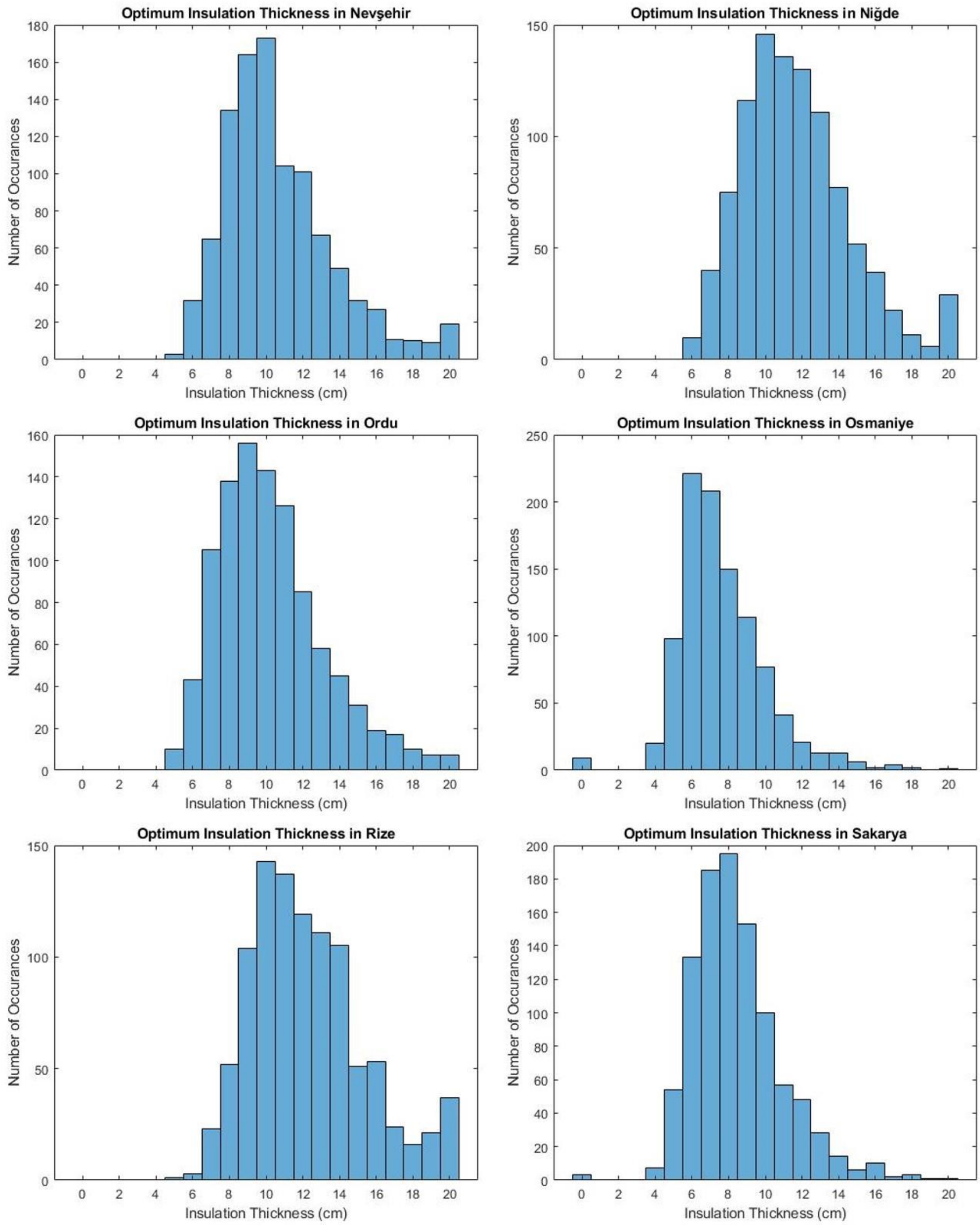

Figure B11. Optimum insulation thickness in Nevşehir-Sakarya

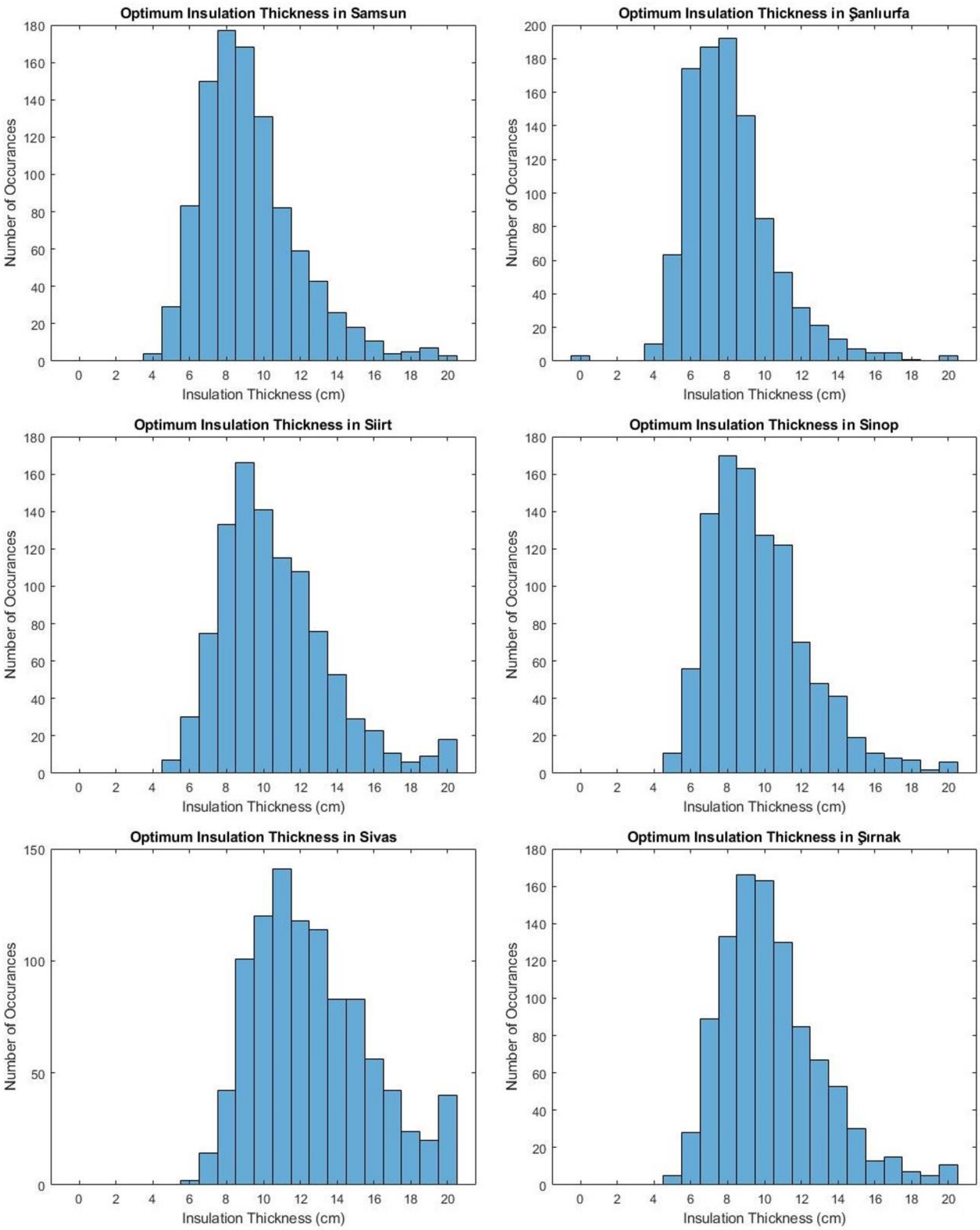

Figure B12. Optimum insulation thickness in Samsun-Şırnak

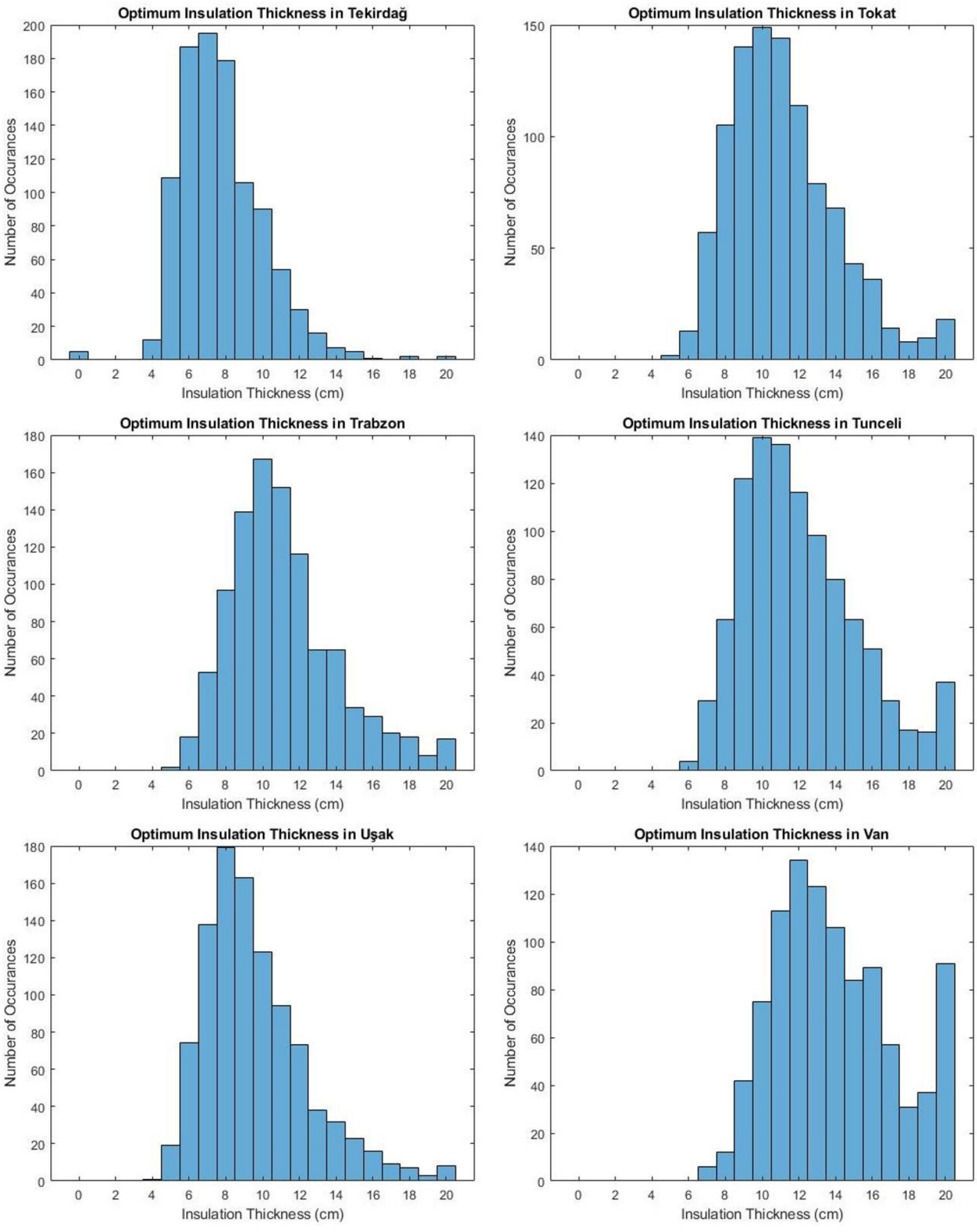

Figure B13. Optimum insulation thickness in Tekirdağ-Van

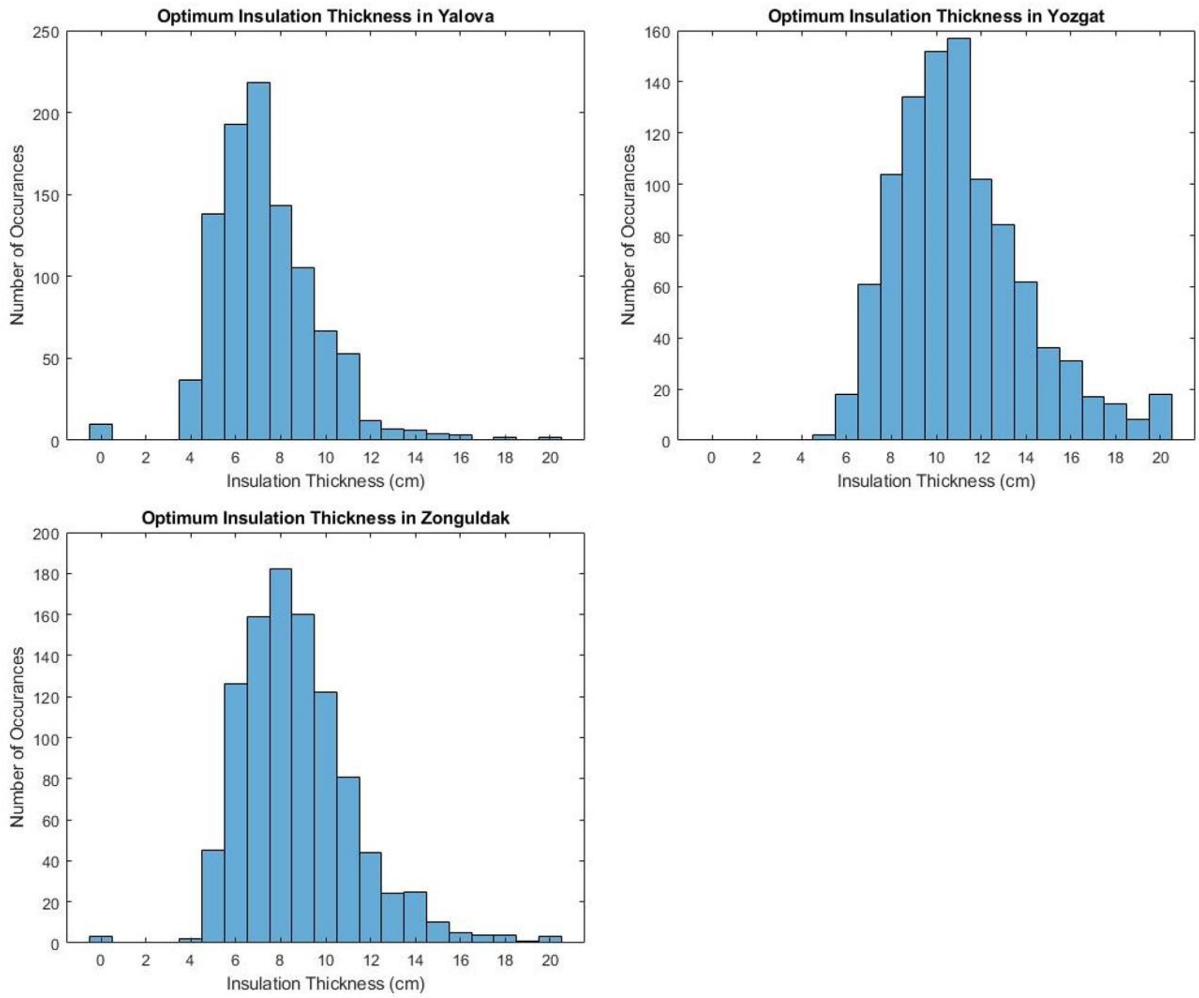

Figure B14. Optimum insulation thickness in Yalova-Zonguldak

APPENDIX C: PROBABILITIES OF OPTIMUM INSULATION THICKNESSES

Table C1. Probabilities of optimum insulation thicknesses in Adana-İstanbul

Province	Probability of Optimum Insulation Thickness (%)																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Adana	0.1	0.0	0.0	0.0	0.2	3.4	10.3	19.9	18.7	13.7	13.2	7.1	4.9	2.8	2.3	1.2	0.8	0.4	0.2	0.5	0.3
Adıyaman	0.1	0.0	0.0	0.0	0.0	1.9	6.0	12.9	18.3	16.5	13.0	12.1	7.0	3.8	2.8	1.9	1.5	0.7	0.7	0.2	0.6
Afyonkarahisar	0.0	0.0	0.0	0.0	0.0	0.6	1.9	7.5	14.0	15.9	16.5	13.6	9.5	6.8	3.7	3.4	1.8	1.6	1.0	0.8	1.4
Ağrı	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	2.4	4.7	9.1	11.4	13.1	12.1	10.9	9.6	7.4	4.2	4.3	3.2	7.0
Aksaray	0.0	0.0	0.0	0.0	0.0	0.9	4.2	9.2	14.3	17.8	13.2	12.1	9.2	7.1	3.8	2.5	1.9	1.0	0.6	0.8	1.4
Amasya	0.0	0.0	0.0	0.0	0.0	0.5	2.8	9.1	13.8	15.9	13.9	12.8	9.1	8.3	5.2	2.9	2.0	0.8	1.0	0.7	1.2
Ankara	0.0	0.0	0.0	0.0	0.0	0.4	2.9	8.5	13.4	15.9	16.8	12.7	8.8	7.2	5.0	2.8	1.7	1.7	0.5	0.6	1.1
Antalya	0.0	0.0	0.0	0.0	0.7	4.7	13.6	16.8	19.1	13.8	12.1	8.3	4.2	3.5	1.5	0.9	0.2	0.2	0.2	0.1	0.1
Ardahan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.7	7.7	10.4	12.2	13.0	9.4	8.9	7.9	6.7	5.1	4.3	10.1
Artvin	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.8	4.3	9.8	12.1	15.6	12.9	9.9	9.2	7.3	4.3	2.8	3.3	1.5	5.1
Aydın	0.9	0.0	0.0	0.0	2.8	11.5	18.4	22.3	14.8	11.8	6.6	4.4	2.7	1.9	0.6	0.5	0.4	0.1	0.1	0.1	0.1
Balıkesir	0.3	0.0	0.0	0.0	0.6	8.1	14.3	18.8	20.5	11.8	9.7	6.7	5.3	1.7	0.3	0.7	0.4	0.3	0.1	0.0	0.4
Bartın	0.0	0.0	0.0	0.0	0.4	3.4	11.5	15.5	18.6	16.7	11.7	7.8	5.8	3.4	1.6	1.4	1.2	0.4	0.4	0.2	0.0
Batman	0.0	0.0	0.0	0.0	0.0	1.6	7.5	15.3	17.0	16.2	13.4	9.0	6.9	4.8	3.7	1.3	1.3	0.5	0.6	0.3	0.6
Bayburt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.8	5.7	7.9	12.4	13.3	10.9	11.4	7.8	7.4	5.3	3.8	3.4	8.6
Bilecik	0.0	0.0	0.0	0.0	0.3	1.9	6.4	11.7	15.9	19.7	14.4	9.4	6.7	3.9	3.5	2.7	1.1	0.7	0.7	0.4	0.6
Bingöl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5.4	7.4	13.2	14.0	13.6	10.6	8.6	6.5	5.3	4.5	2.9	2.5	4.5
Bitlis	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.9	4.7	9.2	11.8	16.2	14.1	8.1	9.9	7.1	4.0	3.9	2.1	2.3	4.6
Bolu	0.0	0.0	0.0	0.0	0.0	0.2	1.4	5.2	8.3	13.0	15.4	13.3	13.3	9.0	7.2	4.3	3.6	1.7	0.7	0.9	2.5
Burdur	0.0	0.0	0.0	0.0	0.0	1.0	4.5	10.9	14.0	16.1	14.6	12.3	8.6	5.2	4.9	2.6	1.6	1.6	1.0	0.4	0.7
Bursa	0.1	0.0	0.0	0.0	0.2	4.3	10.5	21.3	17.9	12.9	13.1	6.9	4.7	2.7	2.3	1.1	0.6	0.6	0.1	0.4	0.3
Çanakkale	1.3	0.0	0.0	0.0	2.6	12.6	19.9	20.5	14.7	12.5	7.2	2.8	2.2	1.9	0.6	0.5	0.2	0.3	0.1	0.0	0.1
Çankırı	0.0	0.0	0.0	0.0	0.0	0.3	1.4	3.7	9.9	14.0	15.5	15.0	11.9	8.5	6.7	4.0	2.5	2.4	1.2	1.1	1.9
Çorum	0.0	0.0	0.0	0.0	0.0	0.4	2.7	6.2	12.7	15.4	15.0	14.2	8.8	8.1	5.1	3.7	2.4	1.9	1.3	0.5	1.6
Denizli	0.0	0.0	0.0	0.0	0.5	2.1	6.2	10.6	17.5	18.0	14.7	10.8	7.1	3.4	3.3	2.7	1.1	0.3	0.7	0.4	0.6
Diyarbakır	0.0	0.0	0.0	0.0	0.0	1.7	6.8	14.2	17.2	16.1	14.6	9.9	6.5	4.2	2.8	2.4	1.4	0.4	0.5	0.5	0.8
Düzce	0.1	0.0	0.0	0.0	0.4	2.3	7.0	14.1	16.6	16.1	14.3	10.0	5.9	5.7	3.0	1.7	0.9	0.6	0.3	0.2	0.8
Edirne	0.7	0.0	0.0	0.0	2.4	7.6	16.7	19.2	16.4	13.7	9.4	5.4	3.3	1.6	1.0	0.9	0.7	0.7	0.2	0.0	0.1
Elazığ	0.0	0.0	0.0	0.0	0.0	0.1	2.0	6.6	12.4	14.7	15.1	13.1	11.6	8.6	4.8	3.5	2.9	1.2	1.8	0.6	1.0
Erzincan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.6	7.1	11.4	13.2	13.7	13.2	10.2	5.8	6.4	4.7	3.4	1.6	4.9
Erzurum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.8	4.0	6.7	9.5	13.0	12.6	13.7	10.3	5.8	6.3	4.5	2.7	9.0
Eskişehir	0.0	0.0	0.0	0.0	0.0	0.8	4.6	10.9	14.8	17.8	13.7	11.1	8.1	6.0	3.8	2.3	2.2	1.4	0.9	0.5	1.1
Gaziantep	0.0	0.0	0.0	0.0	0.6	4.8	11.8	17.8	19.8	13.6	12.0	7.3	4.4	2.8	2.1	1.1	0.7	0.4	0.4	0.1	0.3
Giresun	0.0	0.0	0.0	0.0	0.0	0.2	0.6	3.4	6.9	11.9	16.1	14.1	10.8	10.1	7.9	6.4	4.1	3.1	1.3	0.8	2.3
Gümüşhane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.9	5.6	10.5	11.9	12.3	12.0	10.3	7.8	7.1	5.5	4.3	3.1	7.5
Hakkari	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.2	8.1	11.5	13.5	13.7	12.6	11.3	6.7	5.1	4.1	3.1	2.5	4.8
Hatay	3.6	0.0	0.0	0.0	5.7	17.2	23.2	19.0	12.4	8.4	4.8	2.8	1.1	0.6	0.7	0.3	0.2	0.0	0.0	0.0	0.0
Iğdır	0.0	0.0	0.0	0.0	0.0	0.1	0.5	3.1	6.4	12.5	13.1	15.3	11.5	9.1	8.5	6.6	3.9	2.6	2.5	1.5	2.8
Isparta	0.0	0.0	0.0	0.0	0.0	0.1	1.9	7.0	12.8	15.4	14.6	12.0	11.9	7.5	4.8	4.9	2.9	1.5	0.9	0.8	1.0
İstanbul	2.1	0.0	0.0	0.0	4.0	14.3	19.7	21.5	14.5	10.6	6.4	2.8	1.8	1.2	0.6	0.4	0.1	0.0	0.0	0.0	0.0

Table C2. Probabilities of optimum insulation thicknesses in İzmir-Zonguldak

Province	Probability of Optimum Insulation Thickness (%)																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
İzmir	2.5	0.0	0.0	0.0	4.5	14.3	21.8	21.0	13.5	7.5	7.8	4.3	1.1	0.4	0.4	0.6	0.1	0.1	0.0	0.1	0.0
Kahramanmaraş	0.0	0.0	0.0	0.0	0.0	0.4	1.7	7.1	11.8	13.6	15.8	13.2	11.2	7.4	5.7	4.3	3.0	1.3	0.9	0.5	2.1
Karabük	0.0	0.0	0.0	0.0	0.0	0.0	2.7	8.4	13.6	17.1	15.4	13.8	7.5	7.5	4.1	3.5	2.2	1.2	1.0	0.9	1.1
Karaman	0.0	0.0	0.0	0.0	0.2	0.5	2.7	6.5	11.6	13.2	16.5	13.6	9.3	7.6	4.9	4.7	2.0	2.0	1.5	1.2	2.0
Kars	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.3	4.4	7.1	11.5	13.0	13.9	10.1	8.8	7.2	6.6	4.0	3.1	7.5
Kastamonu	0.0	0.0	0.0	0.0	0.0	0.3	2.1	6.9	9.3	15.0	15.3	14.1	12.4	8.0	5.7	3.9	2.4	1.1	0.9	0.9	1.7
Kayseri	0.0	0.0	0.0	0.0	0.0	0.1	0.4	2.7	6.0	12.4	13.7	14.0	13.0	10.3	6.7	6.1	4.9	2.3	2.4	1.8	3.2
Kilis	0.4	0.0	0.0	0.0	1.5	6.6	15.5	19.2	16.2	14.4	9.9	7.2	3.4	1.7	1.2	0.8	0.9	0.5	0.4	0.1	0.1
Kırıkkale	0.0	0.0	0.0	0.0	0.0	0.6	3.0	9.8	13.6	16.5	14.0	12.2	9.0	7.6	5.2	3.0	1.9	1.0	1.1	0.5	1.0
Kırklareli	0.0	0.0	0.0	0.0	0.9	5.5	12.4	16.7	19.6	14.7	10.4	7.0	5.1	3.0	2.1	0.8	0.6	0.4	0.5	0.3	0.0
Kırşehir	0.0	0.0	0.0	0.0	0.0	0.3	2.4	8.8	13.8	16.3	17.0	11.1	8.8	8.0	5.4	3.1	2.3	1.0	0.7	0.4	0.6
Kocaeli	0.9	0.0	0.0	0.0	2.1	10.6	17.5	19.3	17.9	11.4	9.0	4.6	2.7	1.4	1.5	0.4	0.4	0.2	0.1	0.0	0.0
Konya	0.0	0.0	0.0	0.0	0.0	0.6	3.6	9.3	12.0	15.9	15.6	12.9	9.7	7.9	4.1	3.5	2.1	1.6	0.5	0.0	0.7
Kütahya	0.0	0.0	0.0	0.0	0.0	0.3	3.0	6.0	11.4	16.0	17.2	14.8	8.7	6.9	5.1	2.9	2.4	2.1	1.1	0.9	1.2
Malatya	0.0	0.0	0.0	0.0	0.0	0.1	1.4	4.9	11.2	14.7	16.1	12.8	10.7	7.9	6.8	3.1	3.4	1.9	1.9	0.9	2.2
Manisa	0.3	0.0	0.0	0.0	0.5	7.8	13.6	19.5	20.5	11.6	9.9	7.0	5.2	1.6	0.5	0.8	0.3	0.4	0.1	0.0	0.4
Mardin	0.2	0.0	0.0	0.0	0.4	4.3	13.1	16.2	20.5	14.2	12.0	7.3	5.0	2.5	1.3	1.7	0.5	0.4	0.2	0.2	0.0
Mersin	0.1	0.0	0.0	0.0	0.3	3.2	10.6	16.2	17.6	16.6	12.7	9.2	5.0	3.0	2.3	1.3	0.6	0.3	0.4	0.3	0.3
Muğla	2.1	0.0	0.0	0.0	4.2	13.2	20.8	22.7	14.3	8.7	5.7	4.0	1.5	1.2	0.8	0.4	0.3	0.1	0.0	0.0	0.0
Muş	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.9	5.5	7.3	13.1	14.4	13.6	10.4	8.8	6.5	5.4	4.3	2.9	2.4	4.4
Nevşehir	0.0	0.0	0.0	0.0	0.0	0.3	3.2	6.5	13.4	16.4	17.3	10.4	10.1	6.7	4.9	3.2	2.7	1.1	1.0	0.9	1.9
Niğde	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.0	7.5	11.6	14.6	13.6	13.0	11.1	7.7	5.2	3.9	2.2	1.1	0.6	2.9
Ordu	0.0	0.0	0.0	0.0	0.0	1.0	4.3	10.5	13.8	15.6	14.3	12.6	8.5	5.8	4.5	3.1	1.9	1.7	1.0	0.7	0.7
Osmaniye	0.9	0.0	0.0	0.0	2.0	9.8	22.1	20.8	15.0	11.4	7.7	4.1	2.1	1.3	1.3	0.6	0.2	0.4	0.2	0.0	0.1
Rize	0.0	0.0	0.0	0.0	0.0	0.1	0.3	2.3	5.2	10.4	14.3	13.7	11.9	11.1	10.5	5.1	5.3	2.4	1.6	2.1	3.7
Sakarya	0.3	0.0	0.0	0.0	0.7	5.4	13.3	18.5	19.5	15.3	10.0	5.7	4.8	2.8	1.4	0.6	1.0	0.2	0.3	0.1	0.1
Samsun	0.0	0.0	0.0	0.0	0.4	2.9	8.3	15.0	17.7	16.8	13.1	8.2	5.9	4.3	2.6	1.8	1.1	0.4	0.5	0.7	0.3
Şanlıurfa	0.3	0.0	0.0	0.0	1.0	6.3	17.4	18.7	19.2	14.6	8.5	5.3	3.2	2.1	1.3	0.7	0.5	0.5	0.1	0.0	0.3
Siirt	0.0	0.0	0.0	0.0	0.0	0.7	3.0	7.5	13.3	16.6	14.1	11.5	10.8	7.6	5.3	2.9	2.3	1.1	0.6	0.9	1.8
Sinop	0.0	0.0	0.0	0.0	0.0	1.1	5.6	13.9	17.0	16.3	12.7	12.2	7.0	4.8	4.1	1.9	1.1	0.8	0.7	0.2	0.6
Sivas	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.4	4.2	10.1	12.0	14.1	11.8	11.4	8.3	8.3	5.6	4.2	2.4	2.0	4.0
Şırnak	0.0	0.0	0.0	0.0	0.0	0.5	2.8	8.9	13.3	16.6	16.3	13.0	8.5	6.7	5.3	3.0	1.3	1.5	0.7	0.5	1.1
Tekirdağ	0.5	0.0	0.0	0.0	1.2	10.9	18.7	19.5	17.9	10.6	9.0	5.4	3.0	1.6	0.7	0.5	0.1	0.0	0.2	0.0	0.2
Tokat	0.0	0.0	0.0	0.0	0.0	0.2	1.3	5.7	10.5	14.0	14.9	14.4	11.4	7.9	6.8	4.3	3.6	1.4	0.8	1.0	1.8
Trabzon	0.0	0.0	0.0	0.0	0.0	0.2	1.8	5.3	9.7	13.9	16.7	15.2	11.6	6.5	6.5	3.4	2.9	2.0	1.8	0.8	1.7
Tunceli	0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.9	6.3	12.2	13.9	13.6	11.6	9.8	8.0	6.3	5.1	2.9	1.7	1.6	3.7
Uşak	0.0	0.0	0.0	0.0	0.1	1.9	7.4	13.8	17.9	16.3	12.3	9.4	7.3	3.8	3.2	2.3	1.6	0.9	0.7	0.3	0.8
Van	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.2	4.2	7.5	11.3	13.4	12.3	10.6	8.4	8.9	5.7	3.1	3.7	9.1
Yalova	1.0	0.0	0.0	0.0	3.7	13.8	19.3	21.8	14.3	10.5	6.7	5.3	1.2	0.7	0.6	0.4	0.3	0.0	0.2	0.0	0.2
Yozgat	0.0	0.0	0.0	0.0	0.0	0.2	1.8	6.1	10.4	13.4	15.2	15.7	10.2	8.4	6.2	3.6	3.1	1.7	1.4	0.8	1.8
Zonguldak	0.3	0.0	0.0	0.0	0.2	4.5	12.6	15.9	18.2	16.0	12.2	8.1	4.4	2.4	2.5	1.0	0.5	0.4	0.4	0.1	0.3