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Energy and economic analysis on the implementation of renewable energy systems that supply the thermal energy to civilian consumers

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CONTENTS

1. INTRODUCTION

Energy resources contribute to the basis of the economy of any country and play an important role in improving the standard of living. The importance of energy resources is highlighted in almost all aspects of development, and history shows that there is a very close relationship between energy resource management and economic activity. The use of renewable energies, especially solar energy in residential building applications, has gained a great global popularity that meets the goals of sustainable development and environmental conservation [28]. EU policies support the development of renewable technologies and introduce minimum thresholds for their use [10]. As a member of the European Union, Romania has the obligation to respect them and to invest in the development of this energy segment.

The high interest in renewable energies [13] has increased due to the global policy of replacing "classical" resource-depleting raw materials. For this reason, the challenge is to get a better conversion rate of solar radiation into energy.

Increasing the overall efficiency of a solar panel system [12] by improving energy capture and storing it more efficiently will result in the replacement of non-renewable energy systems with new sources.

In other words, the underlying problem of the current systems is the still insufficiently developed technological stage to achieve a good cost / benefit ratio.

However, at country level, there is no energy assessment that can lead to a national assessment of the thermal potential for different thermal solar panel configurations.

In the previous reports of the doctoral thesis, the theoretical and practical limits of the use of thermal solar panels were shown. They have shown that solar panels can be used successfully in the preparation of heating energy serving a residential consumer. However, there are 5 climatic zones in Romania, and the outdoor temperature and solar intensities vary from area to area. This highlighted the need for a nationwide study to provide an overview of the country. To the same extent, the problem of the profitability of these solar systems is compared with other systems using unconventional sources of energy or classic sources of fossil fuels.

This report aims to estimate the capacity of using solar panel systems to produce the thermal energy needed by a residential consumer. From a thermal point of view, this is done by determining the coverage levels of the solar installation and solar system efficiencies, and from the economic point of view, the installation-specific costs and recovery times of investment in solar panels have been determined.

2. EVALUATION METHODOLOGIES USED

2.1 Calculation methodology used for energy assessment

National technical regulations and European standards that use the solar energy for solar thermal panels are as follows:

SR EN 15316 / 4-3 - Energy performance of buildings - Method of calculating energy requirements and system efficiency - Part 4-3: Heat generation systems, solar thermal systems and photovoltaic systems Module M3-8-3, M8- 8-3, M11-8-3

SR EN 15316 / 6-6 - Energy performance of buildings - Method of calculating system energy performance and system efficiency - Part 6-6: Explanation and justification EN 15316-4-3 Module M3-8-3 M8-8- 3

MC 001/2006 - Methodology of Energy Performance Calculation

To determine the climatic parameters and evaluate the heating period, we used:

SR 4839 / 2014- Heating installations, Annual number of degrees-days

Annexes MC 001/2006 - Energy Performance Calculation Methodology

In this report, an improved proposal for the revised MC-001 for the determination of solar systems was used for energy determinations.

The calculation method used, applies to residential or non-residential buildings fitted with solar energy storage and use facilities for space heating and hot water.

The solar energy capture and use is typically composed of a loop containing the solar energy capture surface and a heat exchanger immersed in an accumulation tank or placed outside the tank. If the heat sink of the solar loop is placed at the bottom of the tank, the heat exchanger of the back-up source is based at the top of the tank. The thermal agent prepared in the storage tank is the thermal agent used in the consumer's central heating system if the utility is heating or hot water delivered to the consumer.

The solar collectors used can be flat-plate collectors or vacuum tubes. The storage tank generally has a volume that allows the consumer to take advantage of all the thermal energy captured by the solar loop diurnally.

The method of assessing the energy performance of a plant using the solar energy used is a monthly method described in [19] which permits each month of the year and throughout the year or season to assess the energy performance.

The method involves in the first step the sampling of a constructive-functional information about the solar energy capture surface, the pump and the heat exchanger within the solar loop. Also, information about the hot water or space heating consumer is required, such as daily consumption, heating surface and sizing temperatures. An important and distinct category of data is climate data related to outdoor temperatures and solar radiation intensities.

Once this data is known, it is proceeded to the second step - the application of the actual method, by evaluating some intermediate parameters that will continue to allow effective evaluation of the energy performance of the solar energy installation every month of the year and season and whole the year. The third step is to evaluate the system's energy performance, which is the solar loop capture efficiency, the energy coverage offered to the consumer, and the monthly, seasonal and yearly energies captured. The heat pumps use the renewable heat source around us.

The method of assessing the energy performance of the solar plant for space heating and the method of assessing the energy performance of the solar plant for DHW production have a number of common elements in each of the three mentioned steps, but will be presented independently.

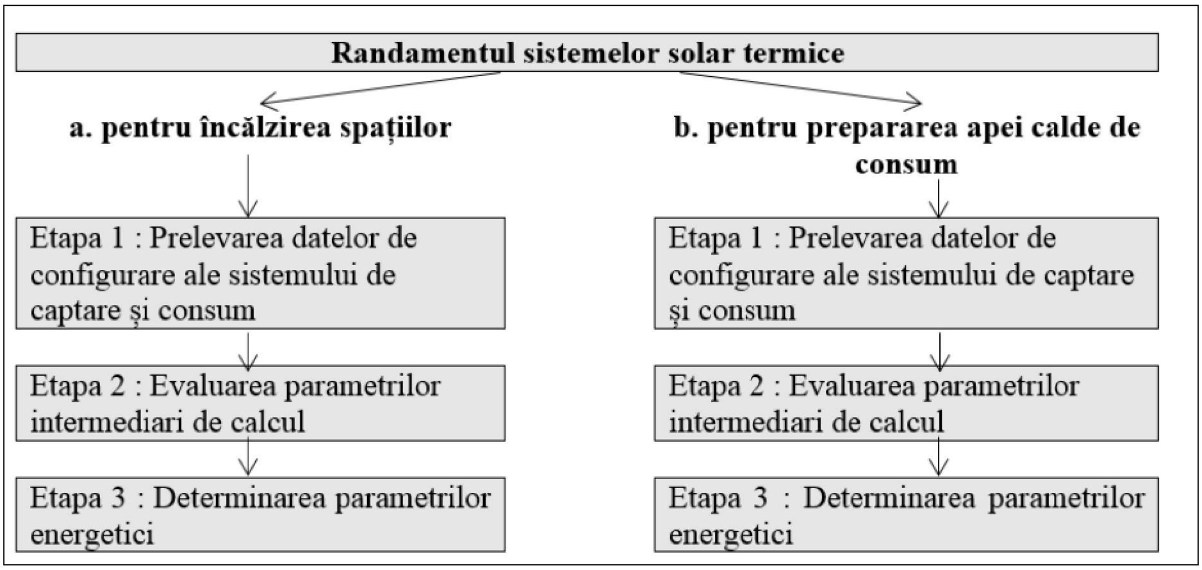

Fig. 1- Scheme of the phases according to the calculation methodology MC 001/2006

The method of assessing the energy performance of the solar energy installation is a so-called monthly method that permits each month of the year and throughout the year or season to assess the energy performance.

The method involves in the first step the sampling of a constructive-functional information about the solar energy capture surface, the pump and the heat exchanger within the solar loop. Information about the hot water or space heating consumer is also required, such as daily consumption, heating surface and sizing temperatures, etc. An important and distinct category of data is climatic data on outdoor temperatures and the intensity of solar radiation.

Once this data is known, it is proceeded to the second step - the application of the actual method, by evaluating some intermediate parameters that will continue to allow effective evaluation of the energy performance of the solar energy installation every month of the year and season and whole the year. The third stage consists of assessing the energy performance of the system that is represented by the solar loop capture efficiency, the energy coverage offered to the consumer and the monthly, seasonal and yearly captive energies.

The method of assessing the energy performance of the solar plant for space heating and the method of assessing the energy performance of the solar plant for DHW production have a number of common elements in each of the three mentioned steps, but will be presented independently.

The following data was used for the capture of the capture and consumption system configuration data:

a. The S_C-variable solar capture area according to the H / ($k_c \cdot S_c$) ratio (constant);

b. The geometric correction factor of the captured heat flux, F '= 0.9;

c. Global heat transfer coefficient of solar collectors, k_C = 2 ÷ 4 W / m^{2}K;

d. Shock absorber coefficient of absorption, α = 0.9;

e. The coefficient of transparency of the collector glazing element, τ = 0.85;

f. Angle of inclination from the horizontal plane of the collectors, φ_i = 45 °;

g. Deviation angle of the orientation of the capture surface to the South, φ_a = 0 °;

h. Heat exchanger surface in the solar loop, $S_S = 0.1 \cdot S_C$;

i. Storage tank volume, $V_a = V / S_C$ = 50 l / m^2;

j. The global heat transfer coefficient of the heat exchanger in the solar loop, k_S = 600 W / m^{2}K;

k. The flow rate of the heat transfer medium into the solar loop, G_C = 50 l / m^{2}h;

l. Surface of the consumer central heating system, S_{INC}-corresponding to 80 apartments;

m. The nominal temperatures of the heating agent at the sizing of the system, t_{T0}, t_{R0}, depending on the type of installation used, namely 50 ° C / 30 ° C or 70 ° C / 50 ° C, the hot water temperature, depending on the case, 50 ÷ 60 ° C, and the cold water temperature was considered constant throughout the year at 15 ° C;

n. Intensity of solar radiation, monthly averages, for a horizontal capture area, I_O, for the cold season months according to the Mc001 methodology of 2006;

o. Average monthly average temperatures for the cold season months according to SR 4839/2014;

In step 2 of the calculation of the intermediate calculation parameters, the following factors for the calculation of the heating case are determined:

$$E_c = \exp\left(\frac{F' \cdot k_C \cdot S_C}{1{,}163 \cdot G_C}\right) \quad (1)$$

$$E_S = \exp\left(\frac{k_S \cdot S_S}{1{,}163 \cdot G_C}\right) \quad (2)$$

$$E_{CS} = \frac{E_C \cdot (1 - E_S) + E_S \cdot (1 - E_C)}{1 - E_C \cdot E_S} \quad (3)$$

$$t_{m0} = \frac{t_{T0} + t_{R0}}{2} \tag{4}$$

$$R_{t1} = \frac{t_{m0} - t_{i0}}{t_{i0} - t_{e0}} \tag{5}$$

$$R_{t2} = \frac{t_{m0} - t_{i0}}{t_{T0} - t_{R0}} \tag{6}$$

$$H = \frac{S_{inc}}{R_{INC}} \cdot R_{t1} \tag{7}$$

$$G_{INC} = \frac{S_{inc}}{R_{INC}} \cdot \frac{R_{t2}}{1.163} \tag{8}$$

$$F_R^B = \frac{1.163 \cdot G_C}{k_C \cdot S_C} \cdot (1 - E_{CS}) \tag{9}$$

$$F_R^C = 2 \cdot \frac{H}{S_C \cdot k_C} \cdot \frac{t_{i0} - t_{e0}}{t_{T0} - t_{R0}} \tag{10}$$

$$F_R^{BC} = \left(\frac{1}{F_R^B} + \frac{1}{F_R^C} \right)^{-1} \tag{11}$$

$$F_{INC} = \frac{t_{R0} - t_{e0}}{t_{i0} - t_{e0}} \tag{12}$$

$$f_u = 0.35 + 0.71836 \cdot \exp\left[-0.1 / \left(\frac{V_a}{75 \cdot S_C} \right) \right] \tag{13}$$

Similarly, factors are calculated for the case of domestic hot water.

In the 3rd calculation step (determination of energy parameters), calculations are made to determine the monthly coverage and overall plant yield using the relationships:

$$\beta_{REF} = \frac{t_{i0} - t_e}{I} \tag{14}$$

$$\eta_{CC} = F_R^{BC} \cdot [(\alpha \cdot \tau) - k_C \cdot F_{INC} \cdot \beta_{REF}] \tag{15}$$

$$P_{CONS} = H \cdot (t_{i0} - t_e) \tag{16}$$

$$P_{CP} = S_C \cdot I \cdot \eta_{CC} \cdot f_u \tag{17}$$

$$E_{CP} = P_{CP} \cdot 24 \cdot N_{zl} \tag{18}$$

$$P_{EL} = 0.25 \cdot P_P \tag{19}$$

$$P_{CONS} = 1.163 \cdot G_{CONS} \cdot (t_c - t_r) \tag{20}$$

For heating:

$$G_{aee} = \frac{P_{cp}}{P_{cons}} \tag{21}$$

$$RND = \frac{P_{cp}}{P_I} \tag{22}$$

For DHW preparation:

$$G_{ae} = \frac{P_{cp}}{P_{cons} + P_{el}} \tag{23}$$

$$RND = \frac{P_{cp}}{P_I} \tag{24}$$

This methodology determines the energies captured and delivered to the consumer of the solar heating and DHW, the incident solar energy, the additional energy needed to meet the consumer's needs.

2.2 Calculation methodology used for the economic evaluation of the system's profitability

Under existing and ongoing proposals and methodologies, an economic calculation is described that addresses all of the solutions based on renewable resources. It is presented in this chapter. The economic study has customized the calculation formulas in this chapter and has adapted them to the requirements of the research report's objectives.

The economic analysis of a new solar investment for existing buildings is done through the economic indicators of the investment. Among the most important are the following:

• the updated net value of the additional investment due to the implementation of an energy rehabilitation / modernization project and the energy savings resulting from the implementation of the mentioned project (lei);

• duration of recovery of the additional investment due to the implementation of an energy rehabilitation / modernization project NR (years), representing the time elapsed since the investment was made in the energy modernization of a building and when its value is equal to the value of the savings achieved through the implementation of the measures of energy modernization brought to the initial moment of the investment;

• the cost of the saved energy unit is [lei / kWh], representing the ratio between the amount of additional investment due to the implementation of a rehabilitation / energy modernization project and the energy savings achieved through its implementation during the recovery period of the investment.

Depending on the values of the aforementioned economic indicators, resulting from the analysis of the various energy modernization measures of a building, the following measures will be chosen:

• Net updated value, with negative lifetime estimates for the energy modernization measures analyzed;

• investment recovery time, NR, smaller and no longer than a reference period, imposed on economic or financial grounds (by creditor or investor) or technical (estimated lifetime of the energy modernization solution);

• the cost of the saved heat unit is as low as possible and not higher than the projection at the time of the investment of the current cost of the heat unit.

The basic procedure for comparing the technical and economic effects of the application of the various energy efficient solutions in construction is the analysis of the net updated value of the costs involved in realizing the investments and exploiting the related facilities.

Net Actual Value (NAV) is the projection at time "0" of all the above mentioned costs, depending on the depreciation rate of the currency considered - in the form of the annual average depreciation.

Considering that the annual rate of depreciation of the currency is constant and that there is a uniform increase in the price of energy, the VNA characteristic of the system is given by the relation:

$$VNA = C_0 + \sum_{k=1}^{3} C_{E_k} \sum_{t=1}^{N} \left(\frac{1+f_k}{1+i} \right)^t + C_M \sum_{t=1}^{N} \left(\frac{1}{1+i} \right)^t \tag{25}$$

According to the structure of the relationship (1), the energy performance of the system must be maintained at the same value over its lifetime, N. This assumption is valid provided that periodic checks of energy performance are observed in the building monitoring activity, will also lead to troubleshooting interventions.

The heat cost increase rate is considered to have a constant value over the technical lifetime of the system.

For public sector projects (social, cultural, administrative buildings), the depreciation rate of the currency varies between 0.1 and 0.07 with the tendency to lock on the second value. For the private sector (large corporations, banks) the assumed depreciation rate exceeds 0.1. Finally, in the case of housing construction, the annual depreciation rate of the coin is in the range of 0.04 - 0.07. Significant differences between these values clearly reveal a national policy to promote energy conservation projects, especially for domestic consumers. Low values of the currency depreciation rate favor the rapid promotion of technical conservative energy solutions. Therefore, the high values of the depreciation of the currency for investments in the public sector or in the private sector that record important turnover offset the relatively low value (0.04) applied to the housing sector.

Maintenance costs represent a minor share in the structure of the relationship (1) and, if they cannot be appreciated, they can be ignored.

Taking into account the above, the relation (25) was used in the VNA calculation in the simplified form:

$$VNA = C_0 + \sum_{k} C_{E_k} X_k \tag{26}$$

In which:

$$X_k = \sum_{t=1}^{N}\left(\frac{1+f_k}{1+i}\right)^t \tag{27}$$

In order to determine the duration of recovery of the solar system investment, two VNA values specific to a classical solution and a conservative energetic solution are analyzed in parallel and having both equipment with an equal lifetime, N, the VNA related to the additional investment due to the implementation of the energy modernization projects and energy savings resulting from the implementation of the mentioned projects:

$$\Delta VNA_{(m)} = C_{(m)} - \sum_k \Delta C_{E_k} \cdot X_k \tag{28}$$

In which:

$$\Delta C_{E_k} = c_k \cdot \Delta E_k \tag{29}$$

The condition that an investment (in the energy modernization solution) to be efficient is the following:

$$\Delta VNA_{(m)} < 0 \tag{30}$$

The duration of the extra investment recovery due to the implementation of an energy modernization project NR is determined by replacing the life expectancy with NR as an unknown value in relation (28) as explained in relation (25), and by imposing the condition for recovery of the investment: $\Delta VNA_{(m)} = 0$:

$$C_{(m)} - \sum_{k=1}^{k} c_k \cdot \Delta E_k \cdot \sum_{t=1}^{N_R}\left(\frac{1+f_k}{1+i}\right)^t = 0 \tag{31}$$

The cost of the unit of energy saved by implementing the solar system (or the cost of a saved kWh) is determined with the relation:

$$e = \frac{C_{(m)}}{N \cdot \Delta E} \text{ , (Euro/kWh)} \tag{32}$$

With regard to the additional investment C (m), projected at year "0", two possible scenarios can be imagined as follows:

a. The investment beneficiary has the full amount at the time "0", in which case the NAV corresponding to the investment coincides with the value C (m);

b. The investment beneficiary does not have the amount necessary to make the investment, in which case a loan, repayable in a Nc year with a fixed annual interest, is used. d. The requisite loan condition is Nc <N, followed by duration (N - Nc) to show the net benefit of implementing energy modernization solutions.

The economic indicators on which the economic efficiency analysis of the energy modernization solutions applied to existing buildings is based are the specific cost.

• The specific cost of the amount of heat saved is determined with the relation:

$$e = \frac{C_{INV(m)} \cdot \Delta\beta}{N_S \cdot \Delta E_t} \quad [\text{Euro/kWh}] \tag{33}$$

The relationship (33) was used to estimate the cost of upgrading to solar installations, as a complement to the conclusion resulting from the evaluation of the duration of the recovery of the investment.

3. ENERGY RESULTS

3.1 Assessment of monthly energy consumption

A heat consumer for heating and domestic hot water was set up to conduct the study. It is represented by 80 apartments that form a residential building consisting of 4 blocks of 20 apartments.

For the H calculation of this building, the following scenario was made (with calculation assumptions):

• Each apartment accommodates an average of 2.5 people;

• Each person consumes 72 liters of hot water per day;

• It results in an average consumption of 180 l / day for each apartment;

• What determines a H_{acm} = 689 W / K for the whole building;

• Roll = 16000 W / K was determined by estimating a thermal heating demand; for each apartment corresponding to a Q = 7000 W.

This consumer has floor heating that works with the following temperatures: t_{T0} = 50 ° C, t_{R0} = 30 ° C. To observe how the solar systems behave at different supply temperatures, a second type of consumer operating with temperatures is simulated: t_{T0} = 70 ° C, t_{R0} = 50 ° C. The hot water distribution temperature varied between 50 ÷ 60 ° C.

A heat exchange system for the primary circuit of the solar panels with a boiler has been provided for this heating system. It is characterized by a k_S = 600 W / m^2K and has an accumulation volume relative to the capture surface, $V_a = V / S_C$ = 50 l / m^2.

Monthly energy consumption for heating and domestic hot water preparation is provided by a second system that produces thermal energy to meet consumer needs.

3.2 Energy Results for Renewable Sources for 5 Representative Cities in Romania

3.2.1. Monthly energy results for systems using renewable sources for 5 representative cities in Romania

In order to perform the following study, the MC001 calculation methodology presented in point 2.1 was chosen and representative of the residential building with 80 apartments in 3.1 with building transmittance, H_{inc} = 16000 W / K. For hot water a H_{acm} = 689 W / K was chosen for the hot water consumption of that building.

The parameter values used in this calculation were as follows:

a. The H / ($k_c \cdot S_c$) ratio = 5 for heating and H / ($k_c \cdot S_c$) = 1 for the hot water preparation;

b. The geometric correction factor of the captured heat flux, F '= 0.9;

c. Global heat transfer coefficient of solar collectors, k_C = 3 W / m^2K;

d. Shock absorber coefficient of absorption, α = 0.9;

e. The coefficient of transparency of the collector glazing element, τ = 0.85;

f. Angle of inclination from the horizontal plane of the collectors, φ_i = 45 °;

g. Deviation angle of the orientation of the capture surface to the SUD, φ_a = 0 ° (South);

h. Heat exchanger surface in the solar loop, $S_S = 0.1 \cdot S_C$;

i. Storage tank volume, $V_a = V / S_C$ = 50 l / m^2;

j. The global heat transfer coefficient of the heat exchanger in the solar loop, k_S = 600 W / m^2K;

k. The flow rate of the heat transfer medium into the solar loop, G_C = 50 l / m^2h;

l. Surface of the consumer central heating system, S_{INC}-corresponding to 80 apartments;

m. Nominal temperature of the thermal agent at the sizing of the installation, t_{T0} = 50 ° C t_{R0} = 30 ° C, the hot water temperature was 55 ° C and the cold water temperature was considered constant throughout the year at a temperature of 15 ° C;

n. Solar radiation intensities, monthly averages, for a horizontal capture area, I_O, for all months of the year, according to the Mc001 methodology of 2006;

o Average monthly average temperatures for all months of the year, according to SR 4839/2014;

Using these values, coverage rates and monthly returns were obtained for each climatic zone, represented by the following cities: Constanta (zone 1), Bucharest (zone 2), Cluj Napoca (zone 3), Predeal (zone 4), Targul Secuiesc (zone 5).

The values of the captured energy, the energy consumed by the classical source and the solar incident energy for each city were also calculated. The monthly values were represented by graphs for each case, respectively for each city and for each case of heating or domestic hot water.

Diagrams obtained for the heating situation of each city are as follows:

A1.Constanța

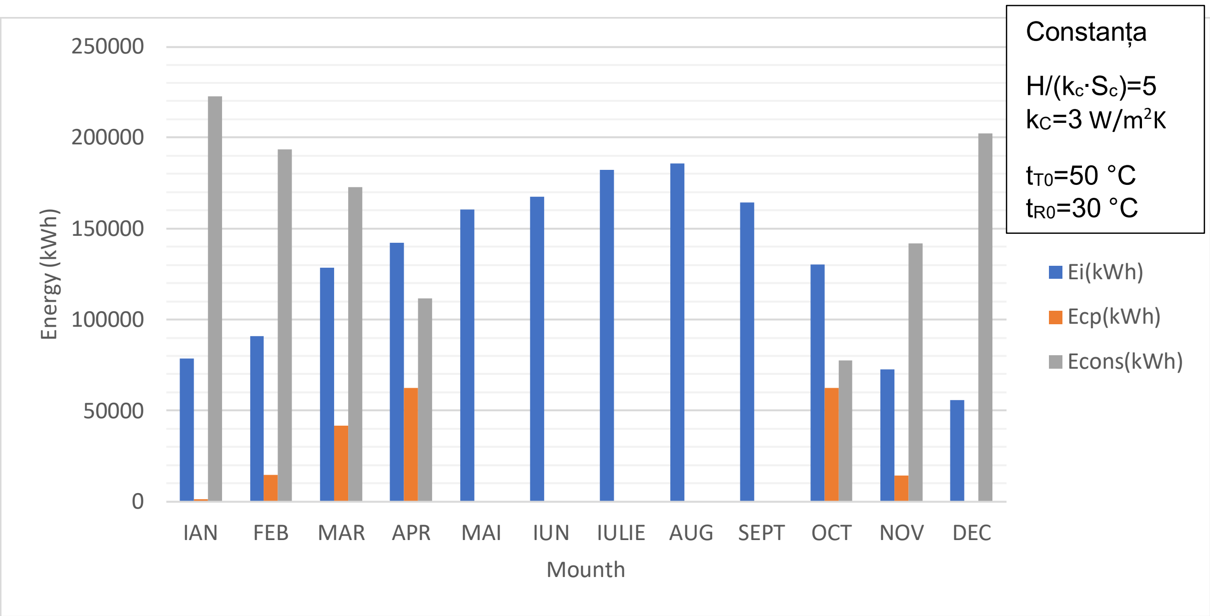

Fig. 2- Monthly calculated energy for heating, Constanta city

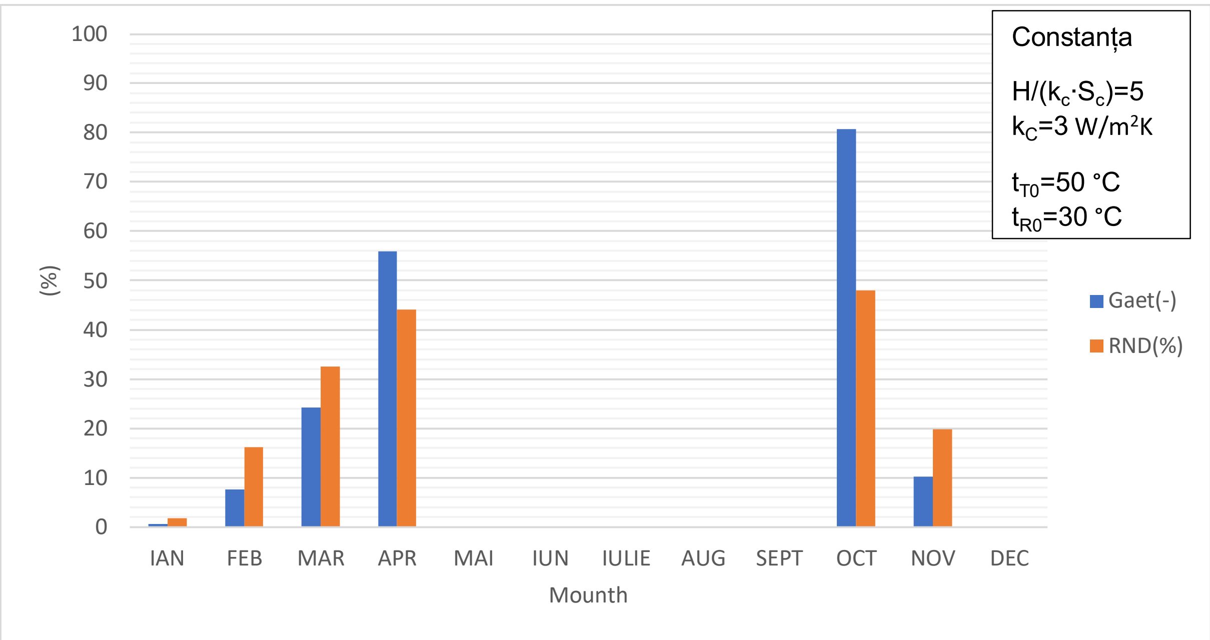

Fig. 3- Efficiency and calculated coverage for heating, Constanta city

B1.Bucharest

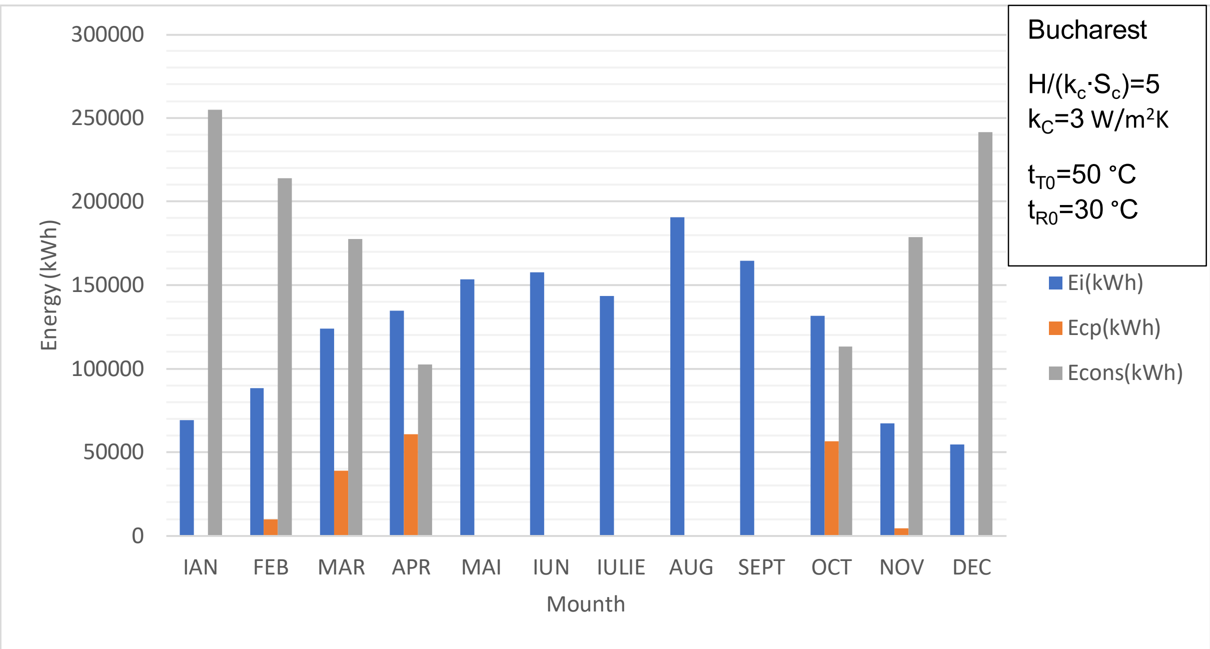

Fig. 4- Monthly calculated energy for heating, Bucharest city

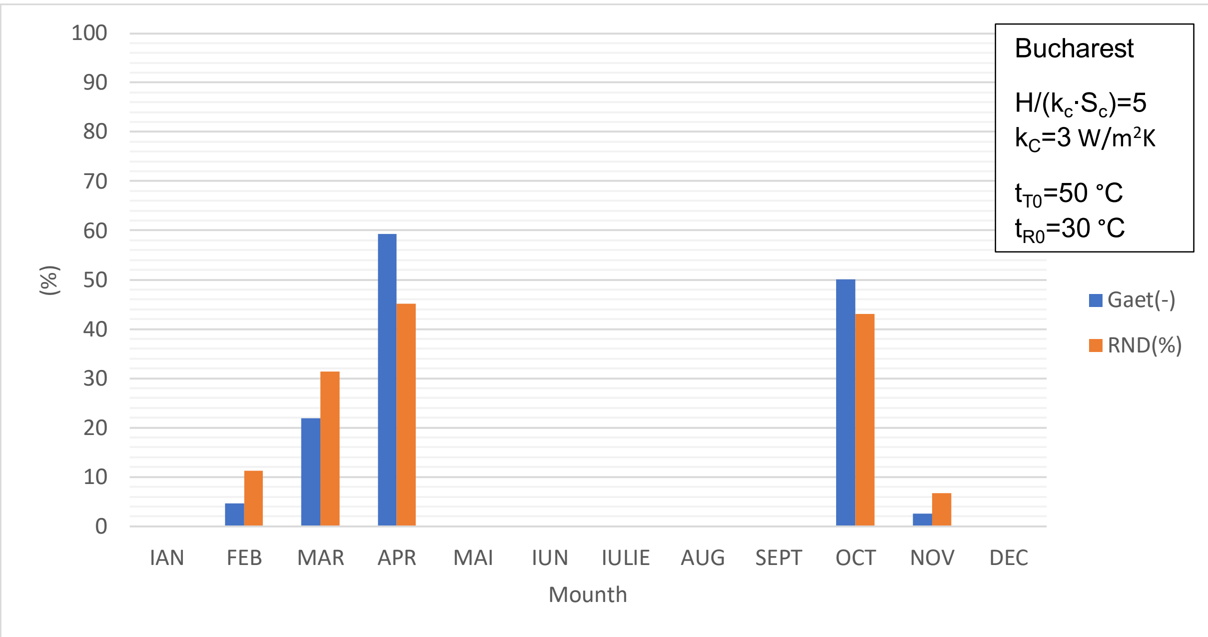

Fig. 5- Efficiency and coverage calculated for heating, Bucharest city

C1.Cluj Napoca

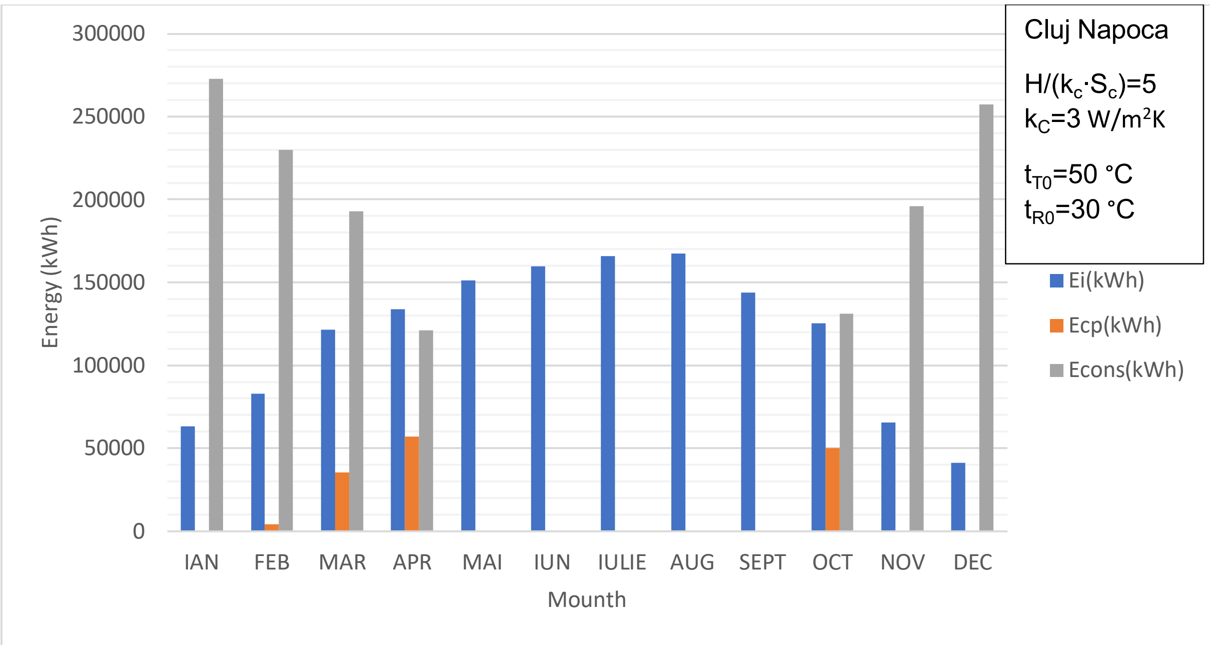

Fig. 6- Monthly calculated energy for heating, city Cluj Napoca

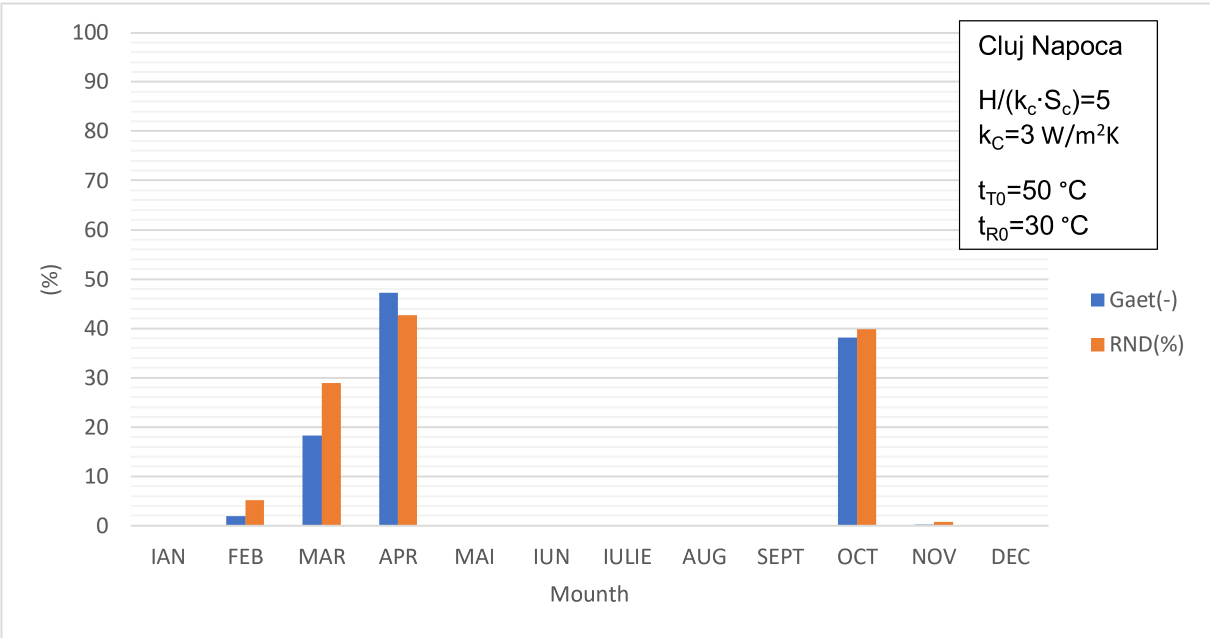

Fig. 7- Efficiency and calculated coverage for heating, city Cluj Napoca

D1.Predeal

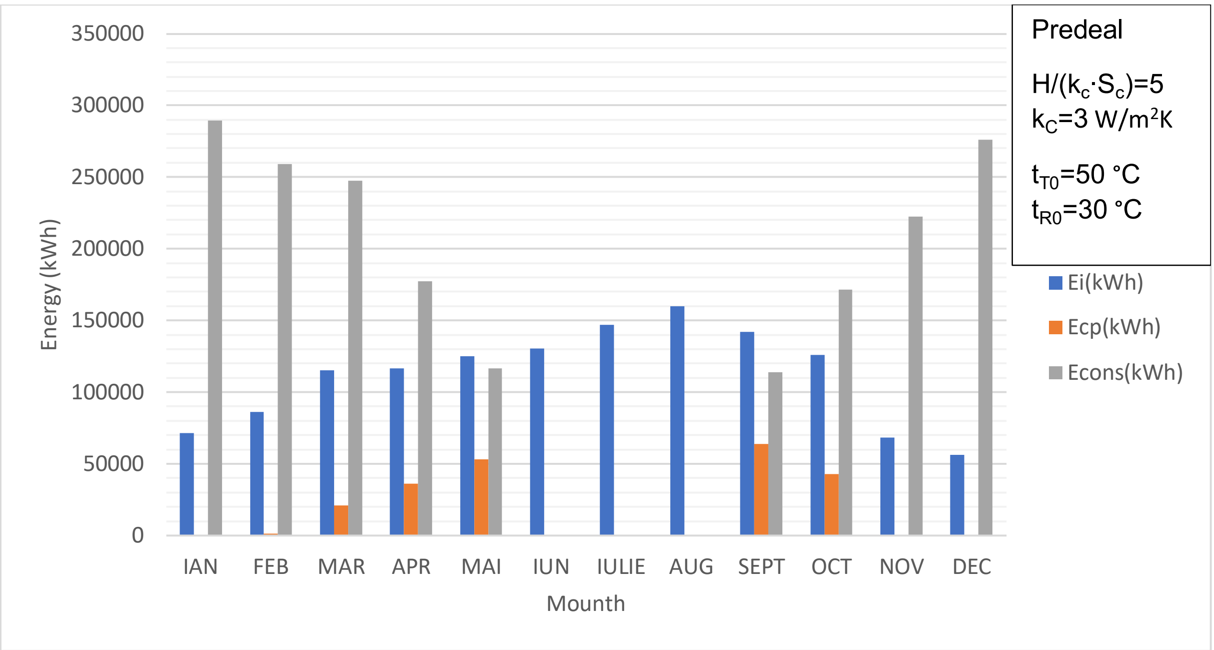

Fig. 8 - Monthly energy calculated for heating, Predeal city

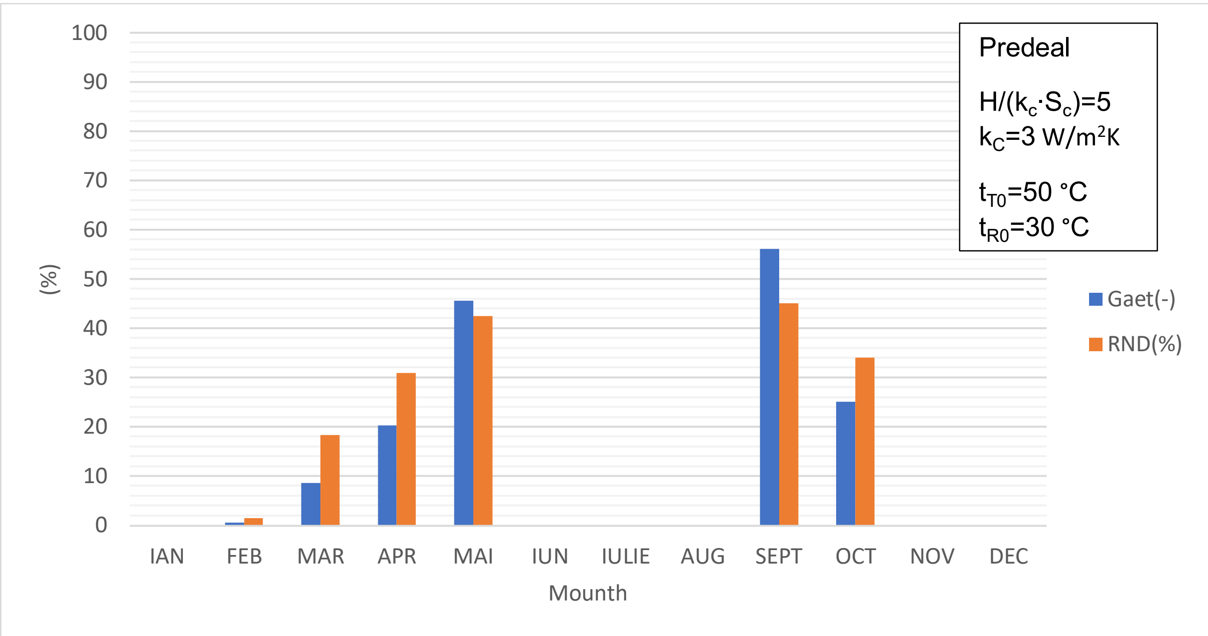

Fig. 9- Efficiency and coverage calculated for heating, Predeal city

E1.Târgul Secuiesc

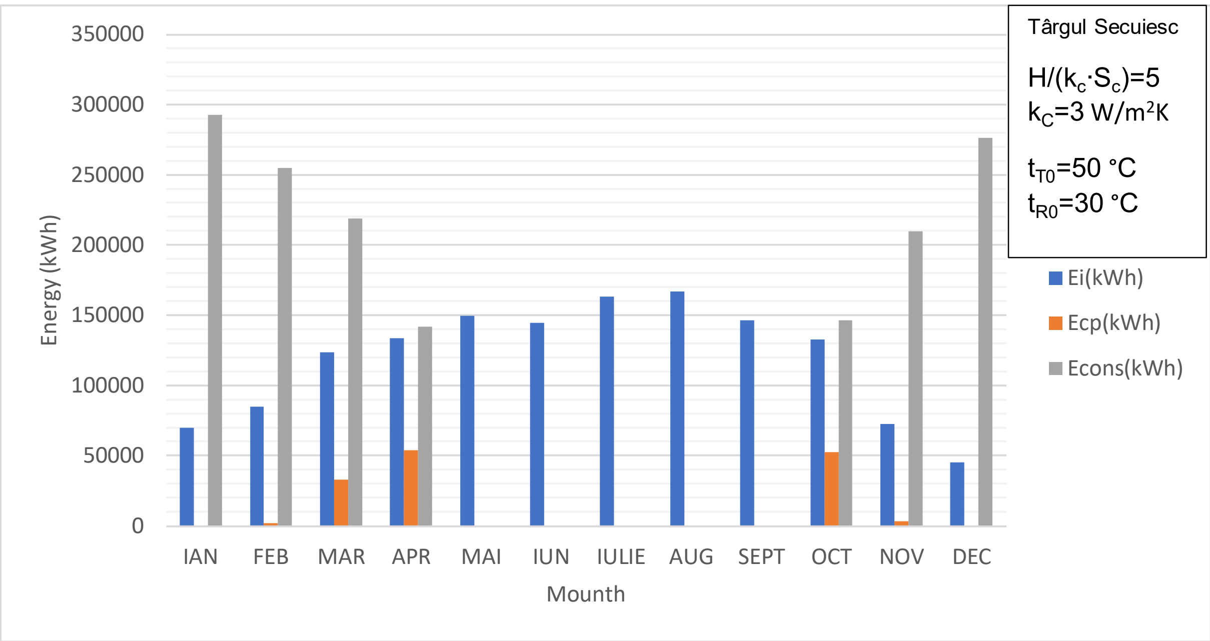

Fig. 10- Monthly calculated energy for heating, city Târgul Secuiesc

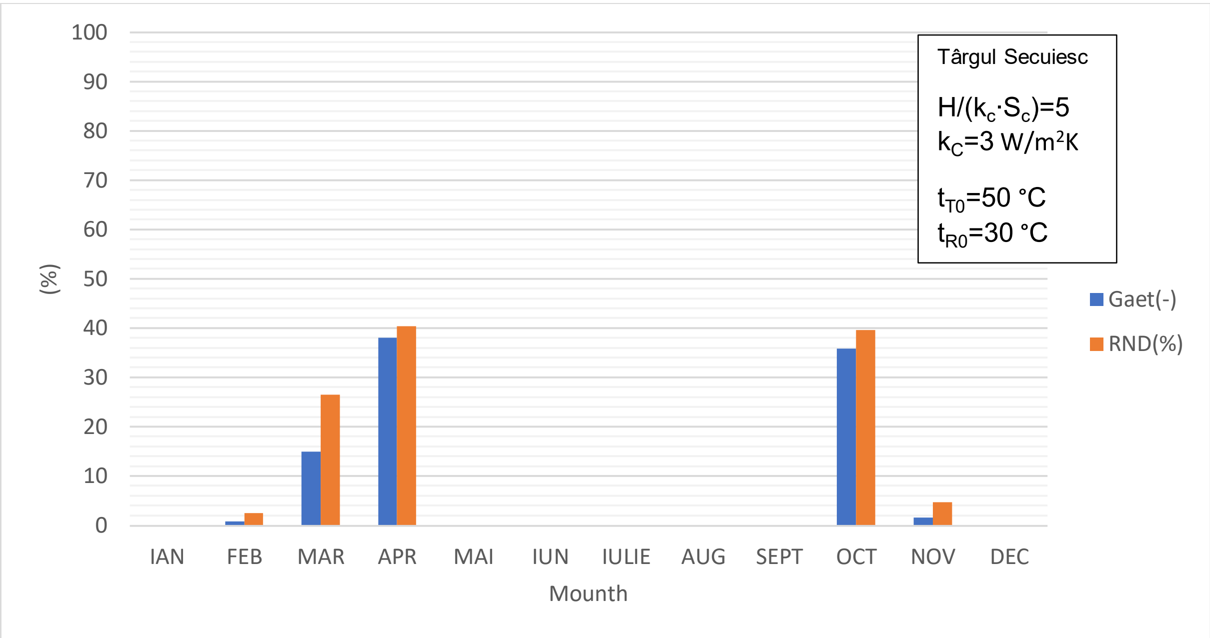

Fig. 11- Efficiency and coverage calculated for heating, city Târgul Secuiesc

The diagrams obtained for the domestic hot water preparation of each city are as follows:

A1.Constanța

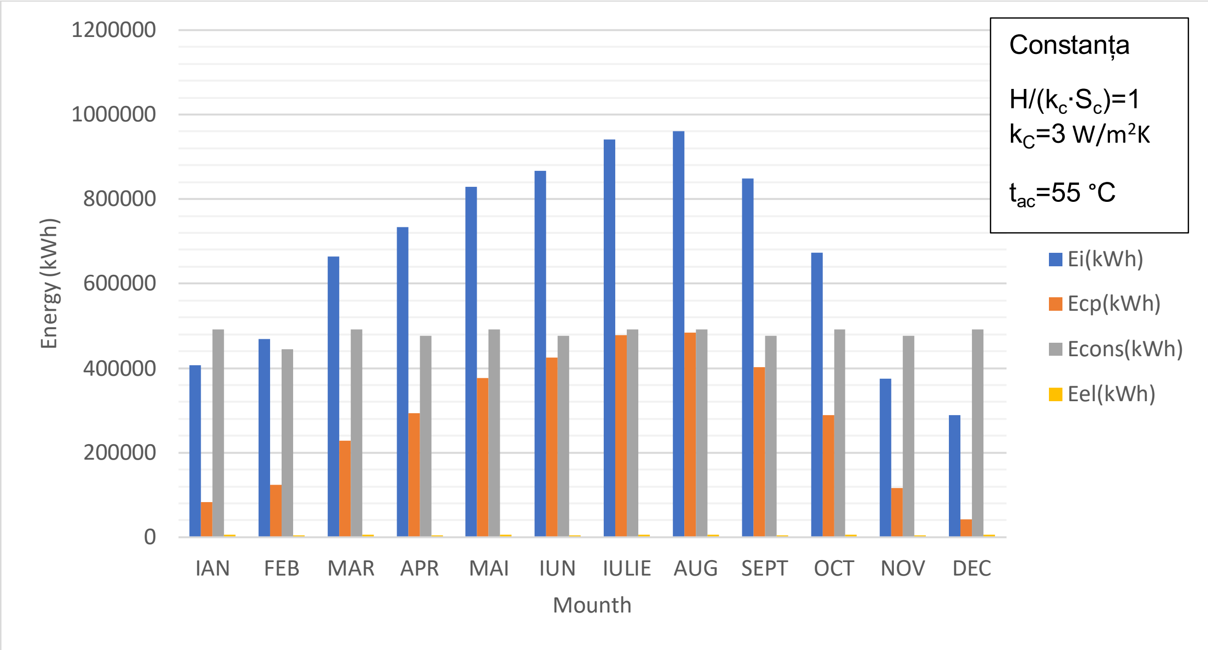

Fig. 12 - Monthly energy calculated for domestic hot water, city of Constanta

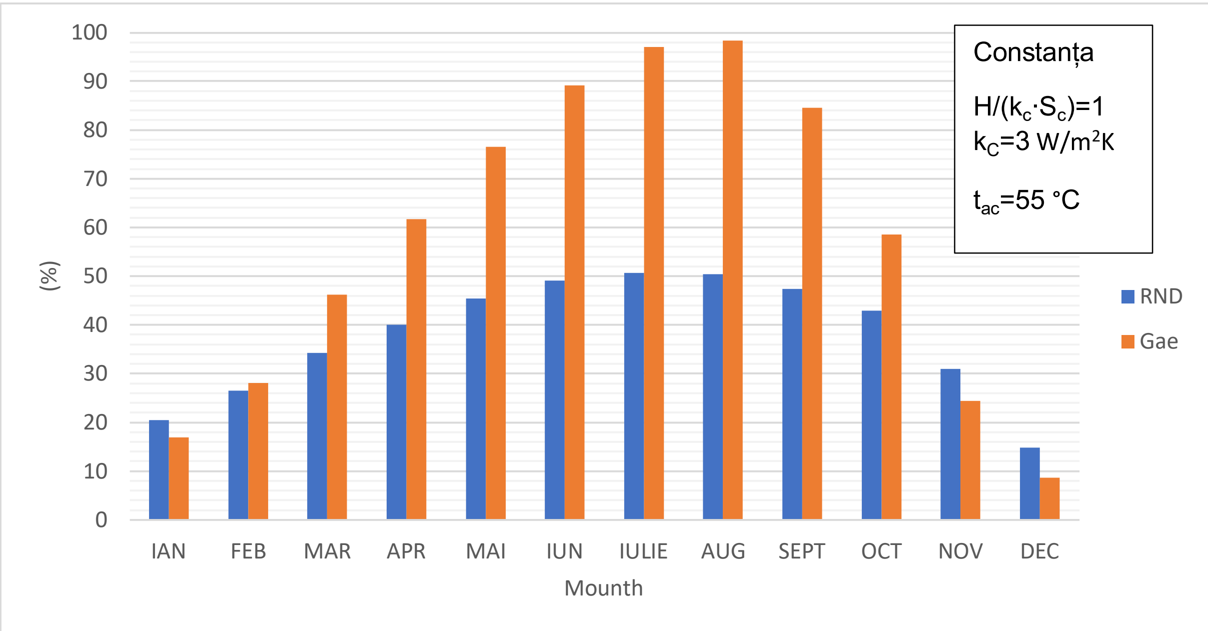

Fig. 13- Efficiency and coverage calculated for domestic hot water preparation, Constanta city

B2.Bucharest

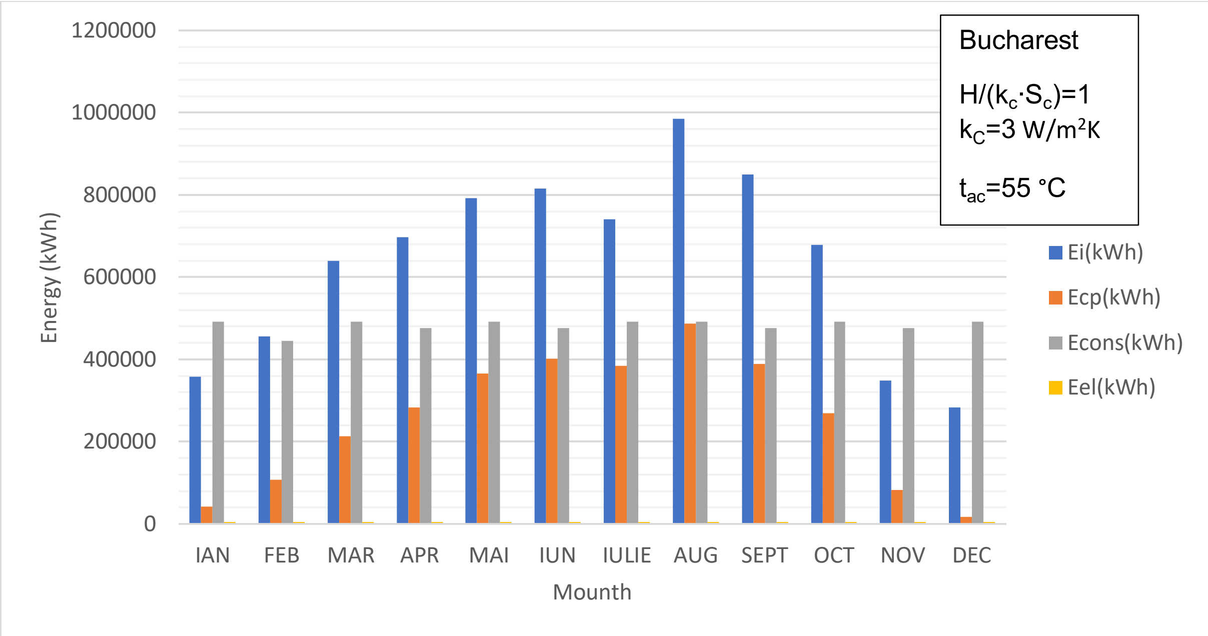

Fig. 14 - Monthly energy calculated for domestic hot water, city of Bucharest

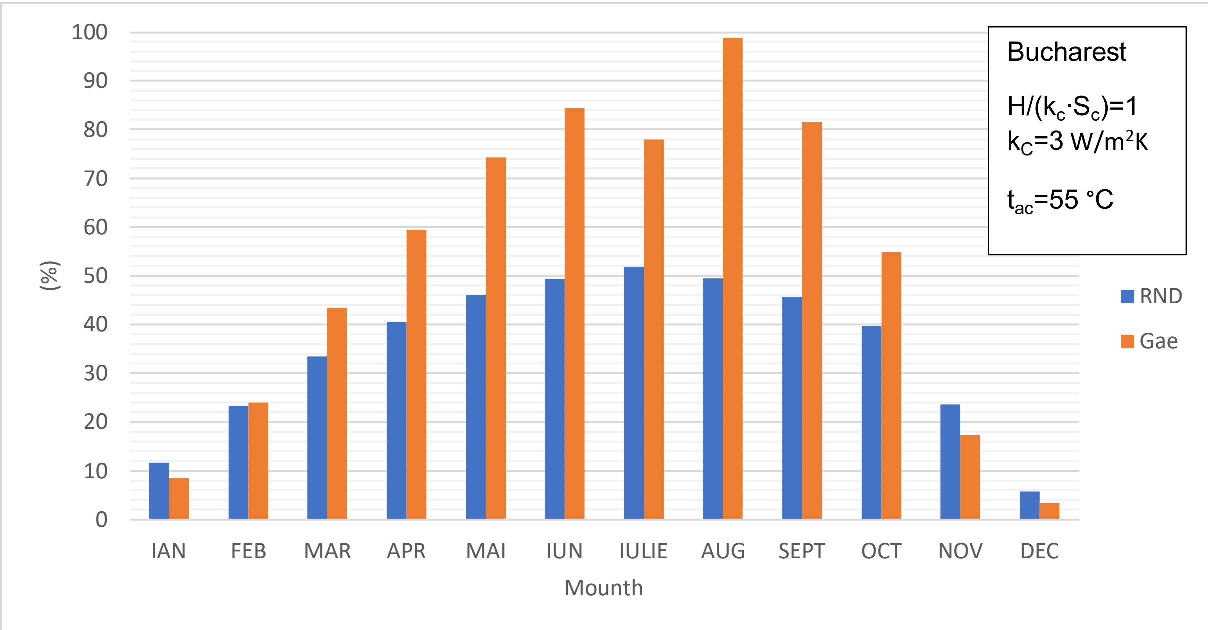

Fig. 15- Efficiency and coverage calculated for domestic hot water, Bucharest

C2.Cluj Napoca

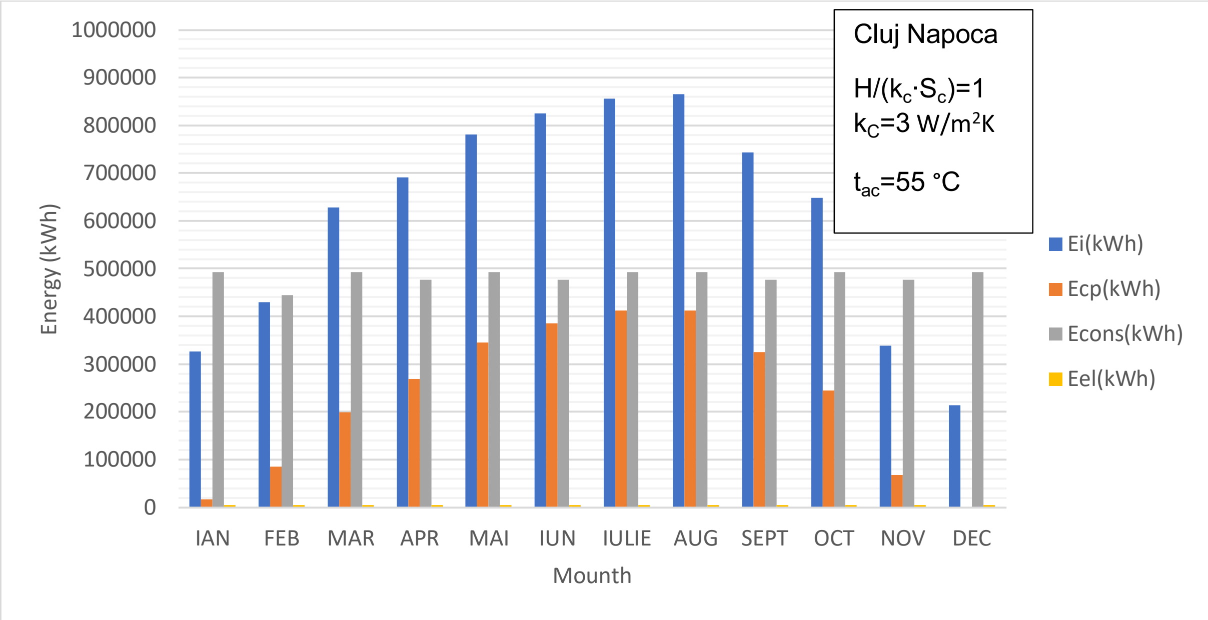

Fig. 16 - Monthly energy calculated for domestic hot water, city Cluj Napoca

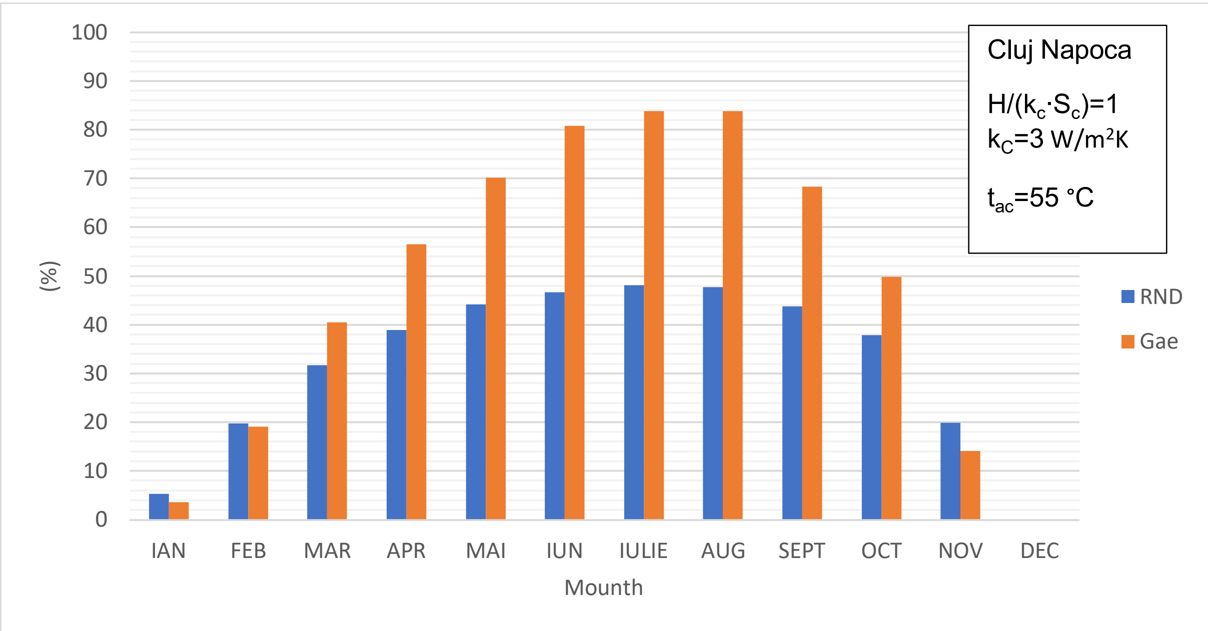

Fig. 17- Efficiency and coverage calculated for domestic hot water preparation, city Cluj Napoca

D2.Predeal

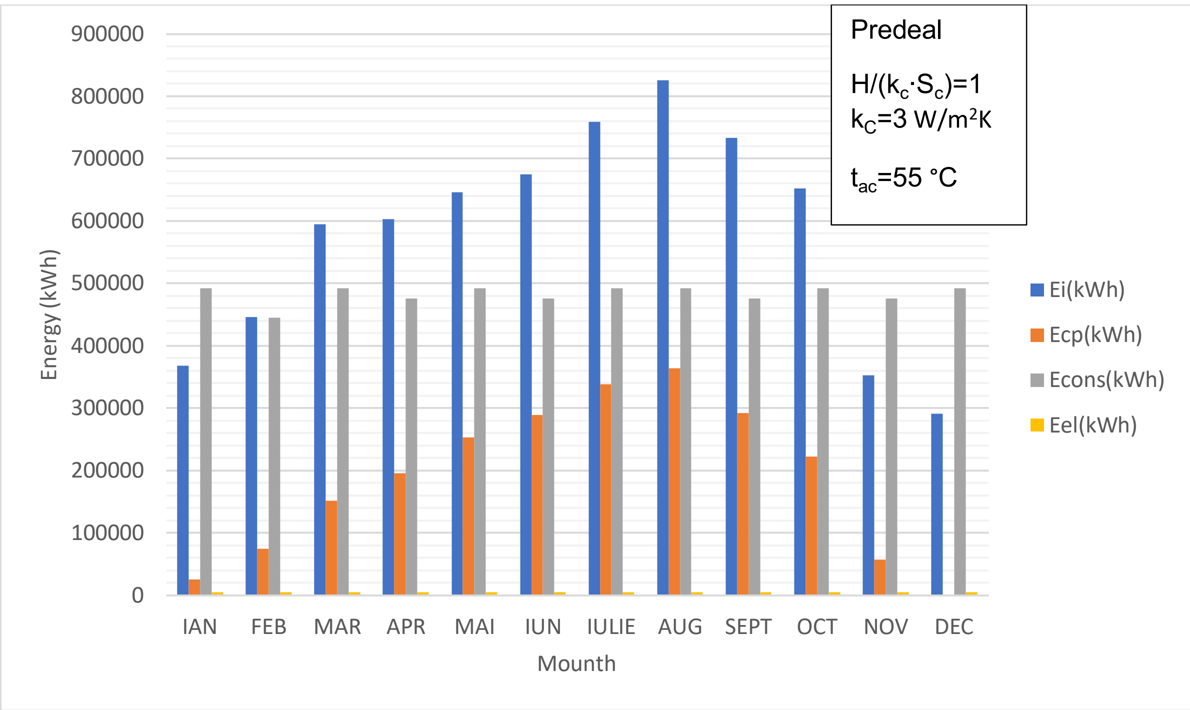

Fig. 18 - Monthly energy calculated for domestic hot water, Predeal city

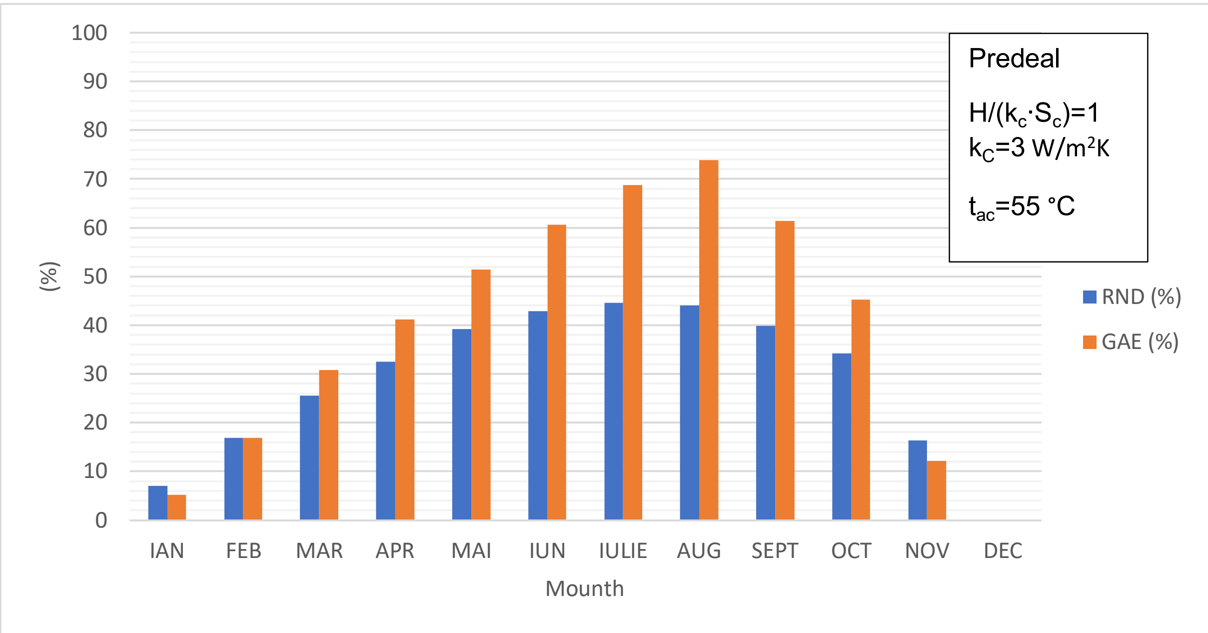

Fig. 19- Efficiency and coverage calculated for domestic hot water preparation, Predeal city

E2.Târgul Secuiesc

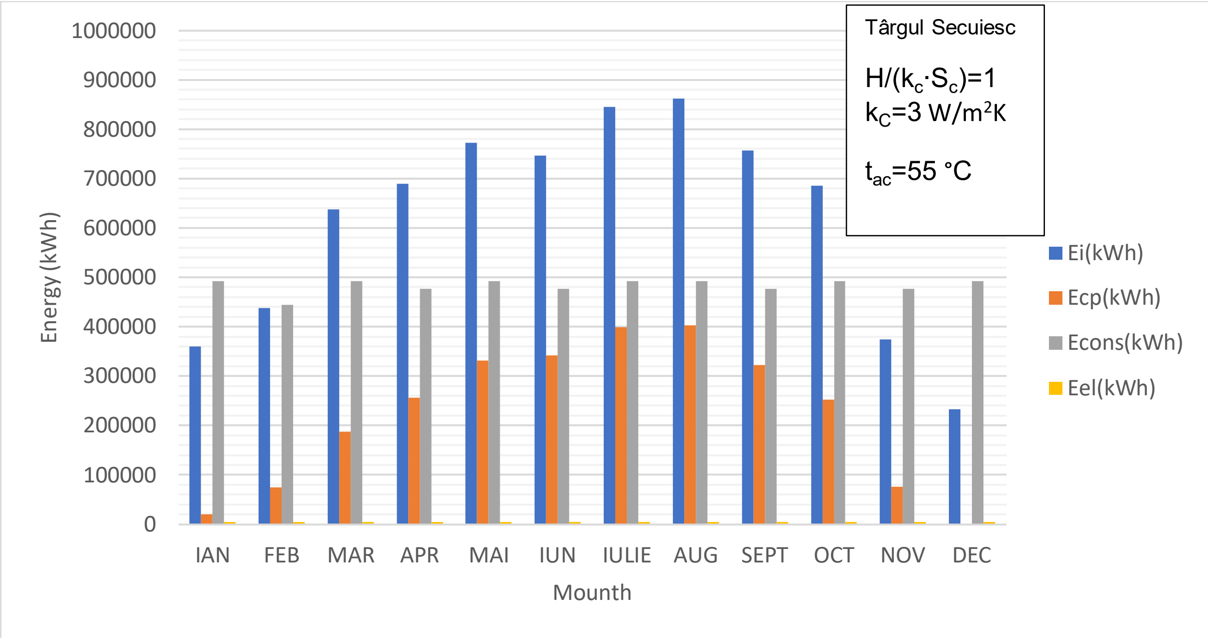

Fig. 20 - Monthly energy calculated for the domestic hot water, City Târgul Secuiesc

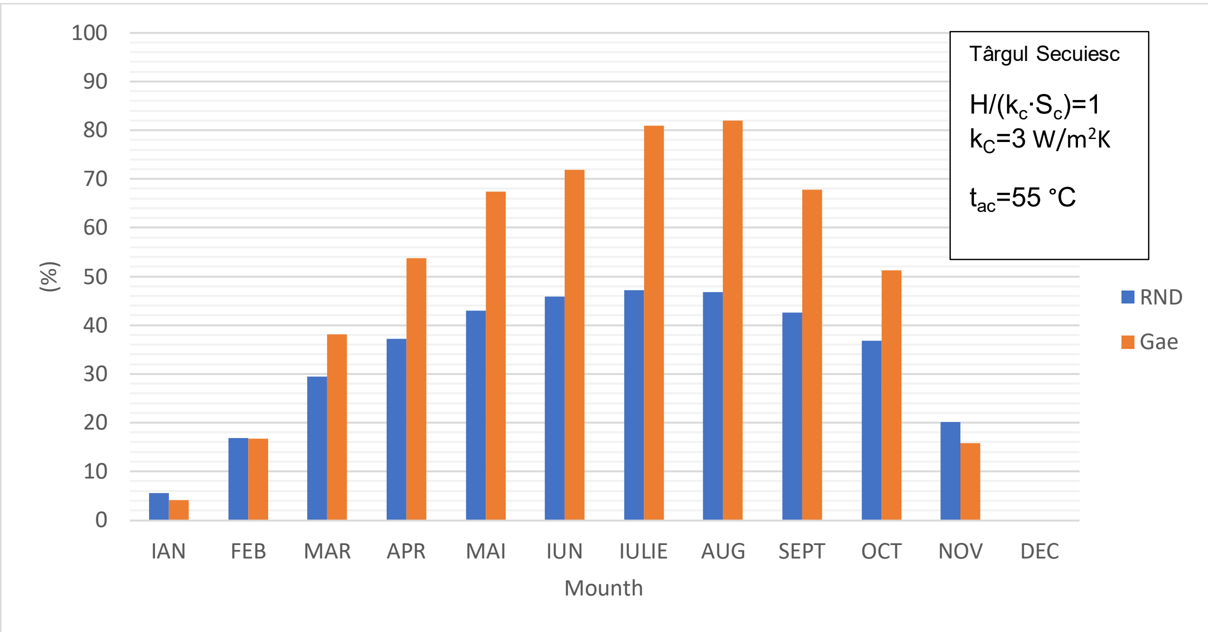

Fig. 21- Efficiency and coverage calculated for domestic hot water preparation, city Târgul Secuiesc

3.2.2 Annual energy results for systems using renewable sources for 5 representative cities in Romania

In order to carry out the following study, the MC001 calculation methodology presented in point 2.1 was chosen and a residential building with 80 apartments in paragraph 3.1 was chosen representative of the building transmittance, $H_{înc}$ = 16000 W / K. For hot water a H_{acm} = 689 W / K was chosen for the hot water consumption of that building.

The parameter values used in this calculation were as follows:

a. The H / ($k_c \cdot S_c$) ratio = 7, 5 and 3 for heating and H / ($k_c \cdot S_c$) = 3, 2 and 1 for hot water preparation;

b. The geometric correction factor of the captured heat flux, F '= 0.9;

c. Global heat transfer coefficient of solar collectors, k_C = 1,5 ÷ 4 W / m^2K;

d. Shock absorber coefficient of absorption, α = 0.9;

e. The coefficient of transparency of the collector glazing element, τ = 0.85;

f. Angle of inclination from the horizontal plane of the collectors, φ_i = 45 °;

g. Deviation angle of the orientation of the capture surface to the South, φ_a = 0 ° (South);

h. Heat exchanger surface in the solar loop, $S_S = 0.1 \cdot S_C$;

i. Storage tank volume, $V_a = V / S_C$ = 50 l / m^2;

j. The global heat transfer coefficient of the heat exchanger in the solar loop, k_S = 600 W / m^2K;

k. The flow rate of the heat transfer medium into the solar loop, G_C = 50 l / m^2h;

l. Surface of the consumer central heating system, S_{INC}-corresponding to 80 apartments;

m. Nominal temperature of the thermal agent at the sizing of the installation, t_{T0} = 50 ° C t_{R0} = 30 ° C, the hot water temperature was 55 ° C and the cold water temperature was considered constant throughout the year at a temperature of 15 ° C;

n. Solar radiation intensities, monthly averages, for a horizontal capture area, I_O, for all months of the year, according to the Mc001 methodology of 2006;

o. Average monthly average temperatures for all months of the year, according to SR 4839/2014.

Using these values, coverage rates and annual returns were obtained for each climatic zone, represented by the following cities: Constanta (zone 1), Bucharest (zone 2), Cluj Napoca (zone 3), Predeal (zone 4), Targul Secuiesc (zone 5).

The annual values were represented by graphs for each case, grouping the 5 cities for each value k_C = 1,5 ÷ 4 W / m2K and for each case of heating or domestic hot water. The graphical representation for different values of the heat transfer coefficient of the solar panels offers an overview for all types of panels that are sold on the Romanian market.

The choice of the H / (k_c · S_c) ratio for the different heating and hot water preparation cases was made to represent as realistic solar investment as possible.

Diagrams obtained for the corresponding heating case for each case (depending on the ratio H / (k_c · S_c)) are as follows:

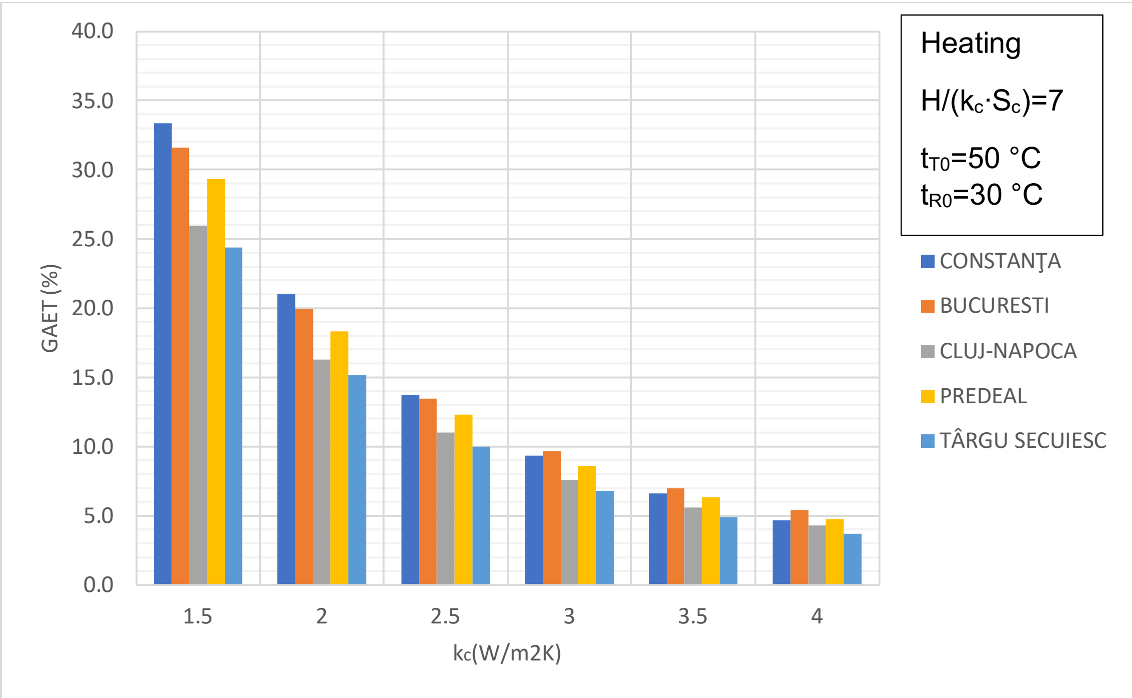

Fig. 22- Degree of coverage calculated for heating, $H/k_c \cdot S_c$=7

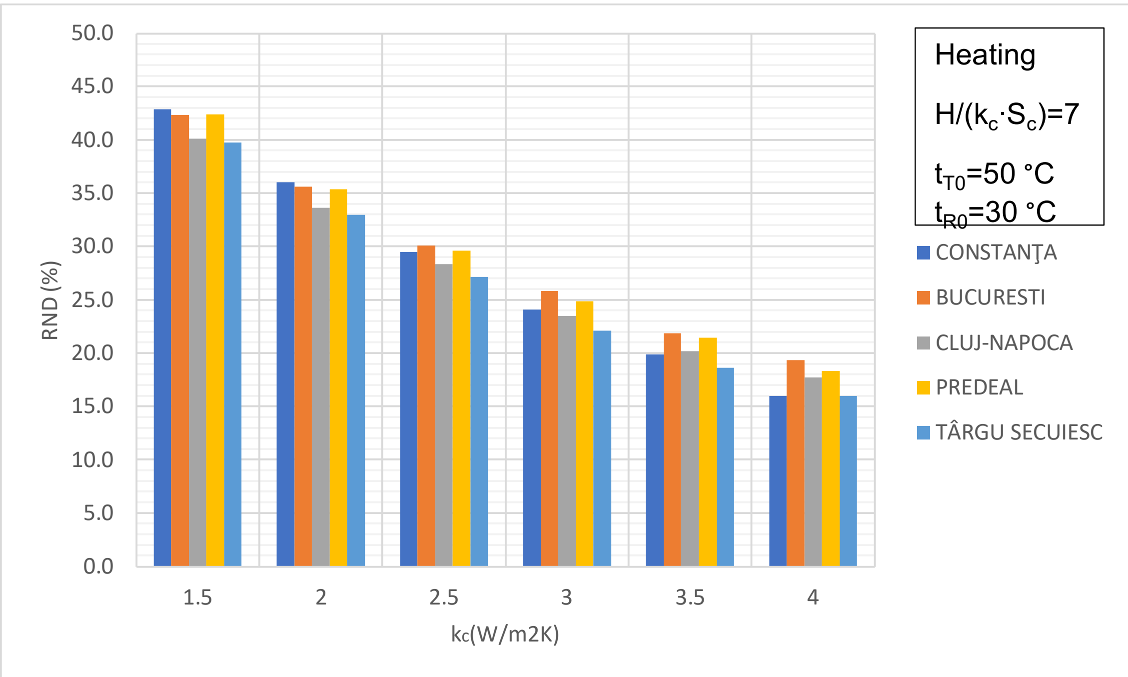

Fig. 23- Efficiency calculated for heating, $H/k_c \cdot S_c$=7

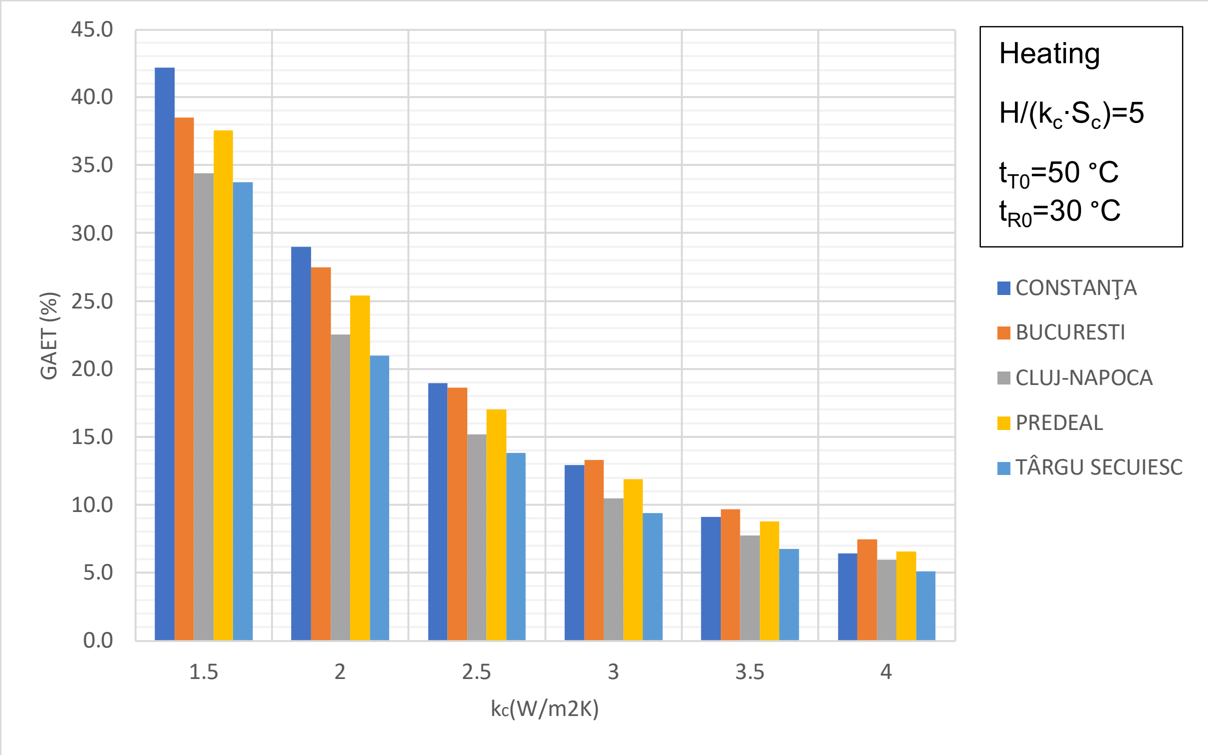

Fig. 24- Degree of coverage calculated for heating, $H/k_c \cdot S_c=5$

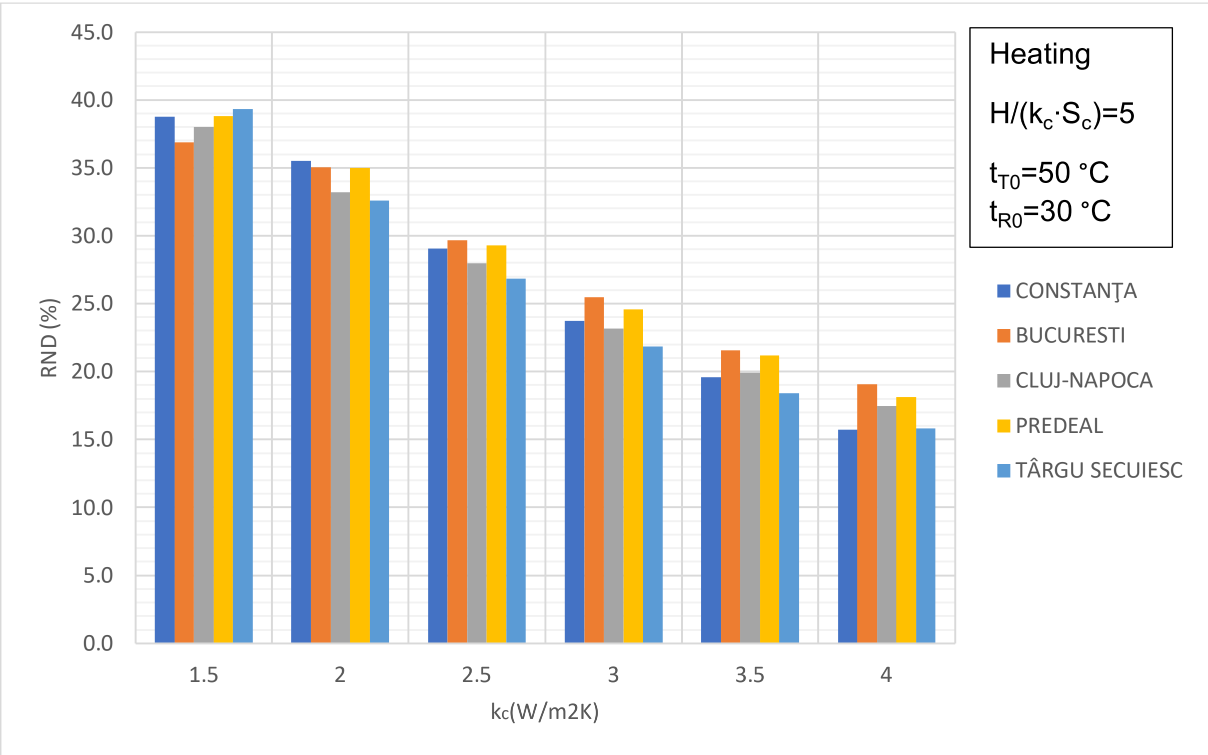

Fig. 25- Efficiency calculated for heating, $H/k_c \cdot S_c=5$

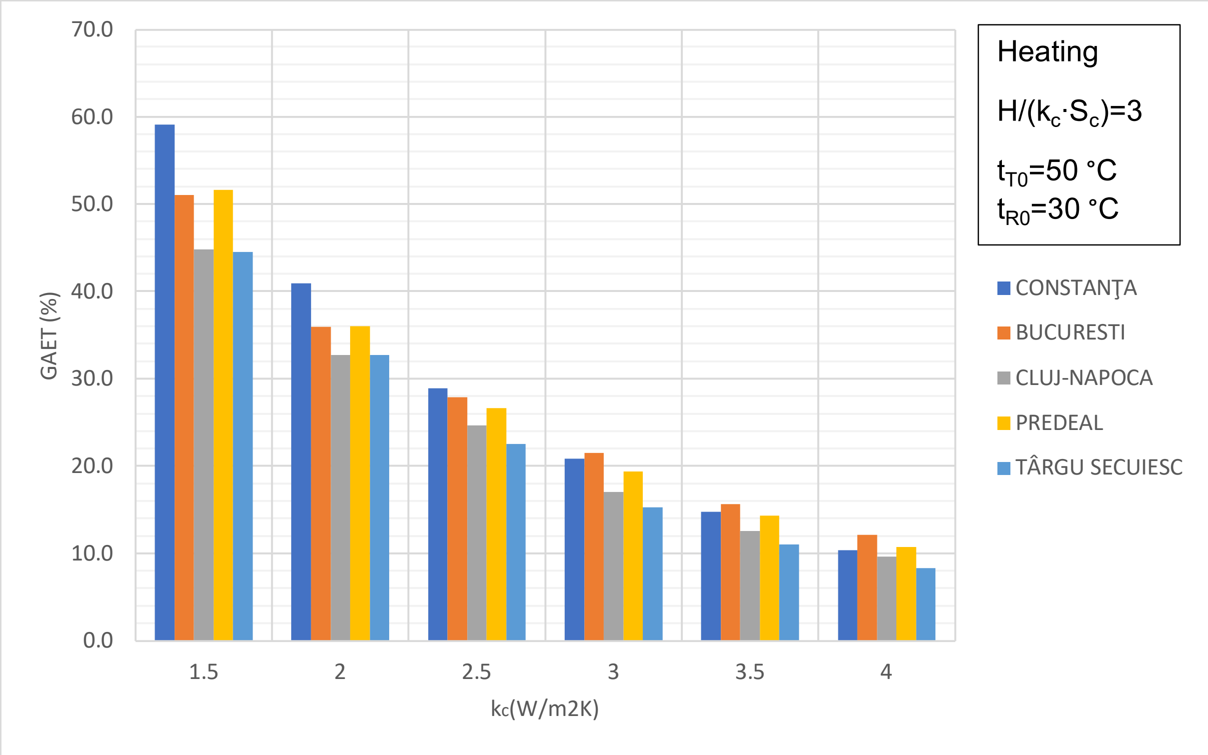

Fig. 26- Degree of coverage calculated for heating, $H/k_c \cdot S_c=3$

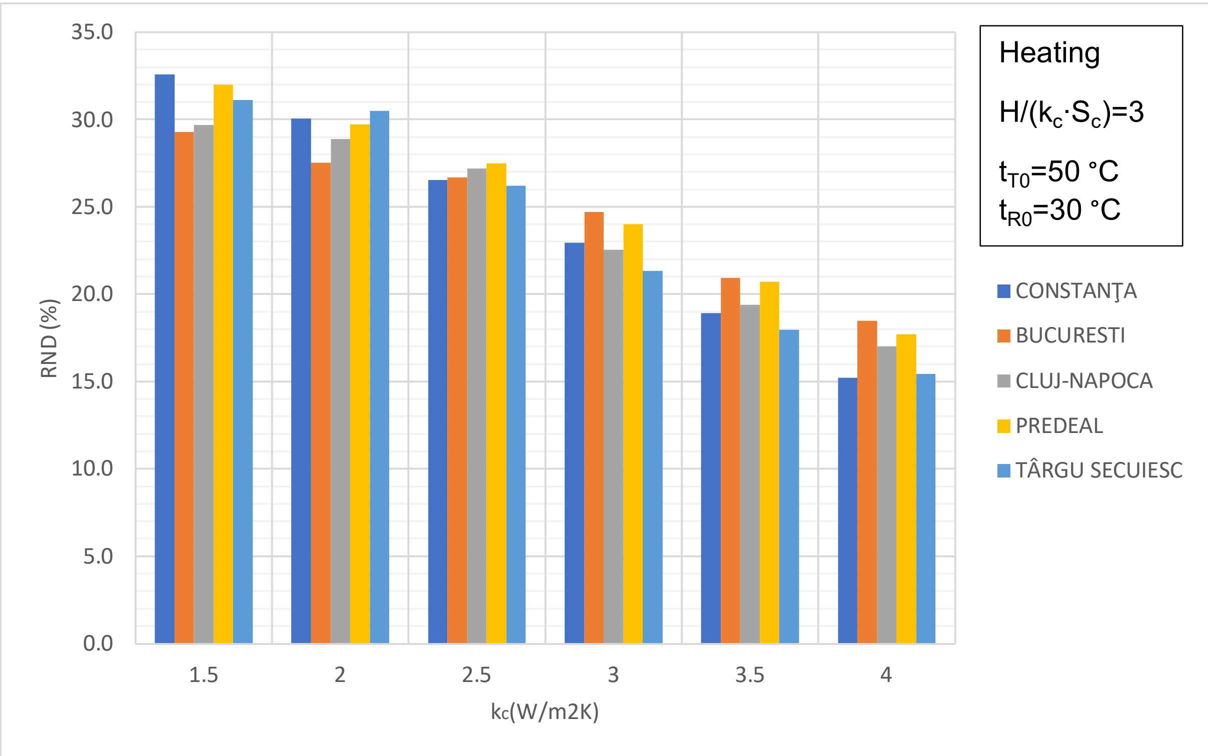

Fig. 27- Efficiency calculated for heating, $H/k_c \cdot S_c=3$

The diagrams obtained for the domestic hot water preparation in each case (depending on the H / kc · Sc ratio) are as follows:

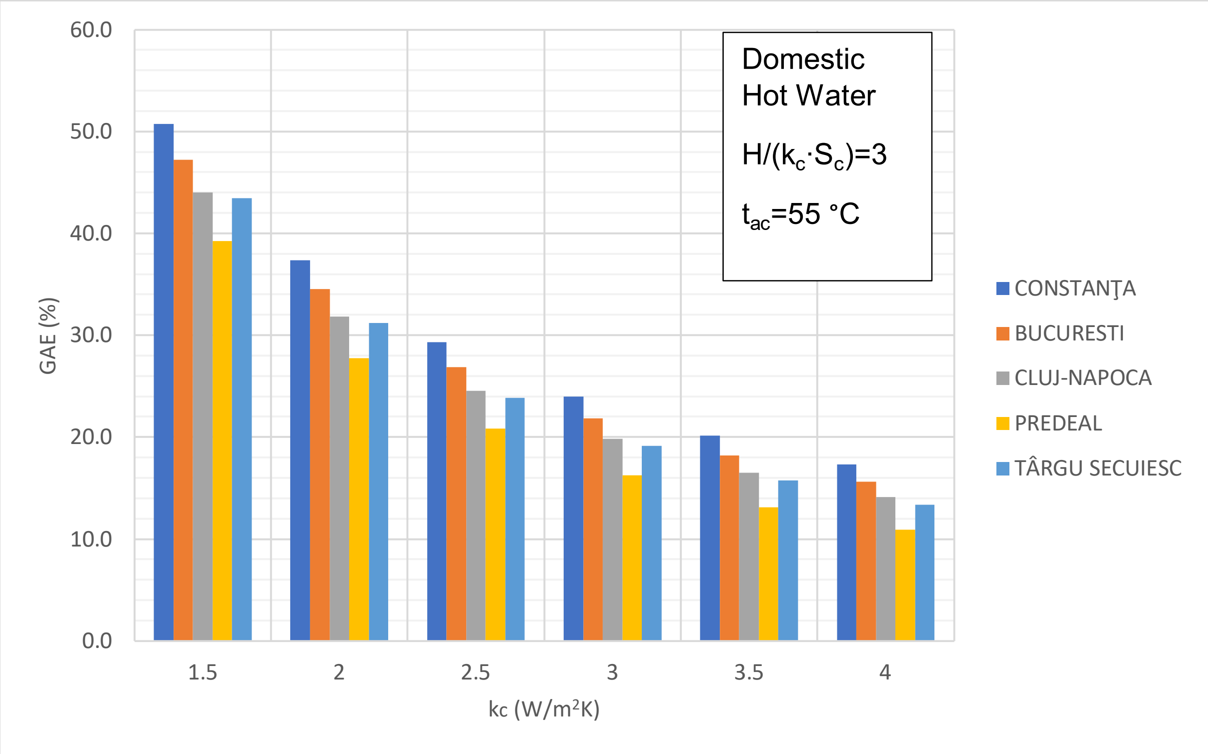

Fig. 28- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$

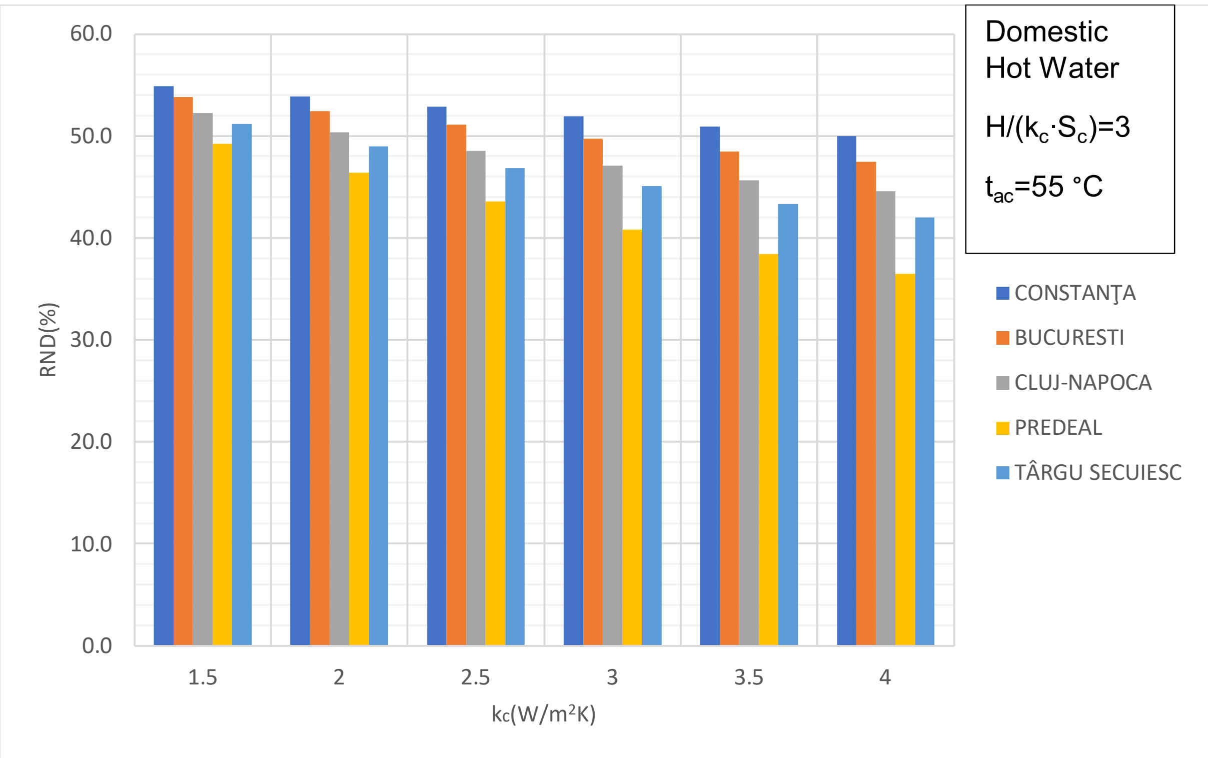

Fig. 29- Efficiency calculated for domestic hot water, $H/k_c \cdot S_c=3$

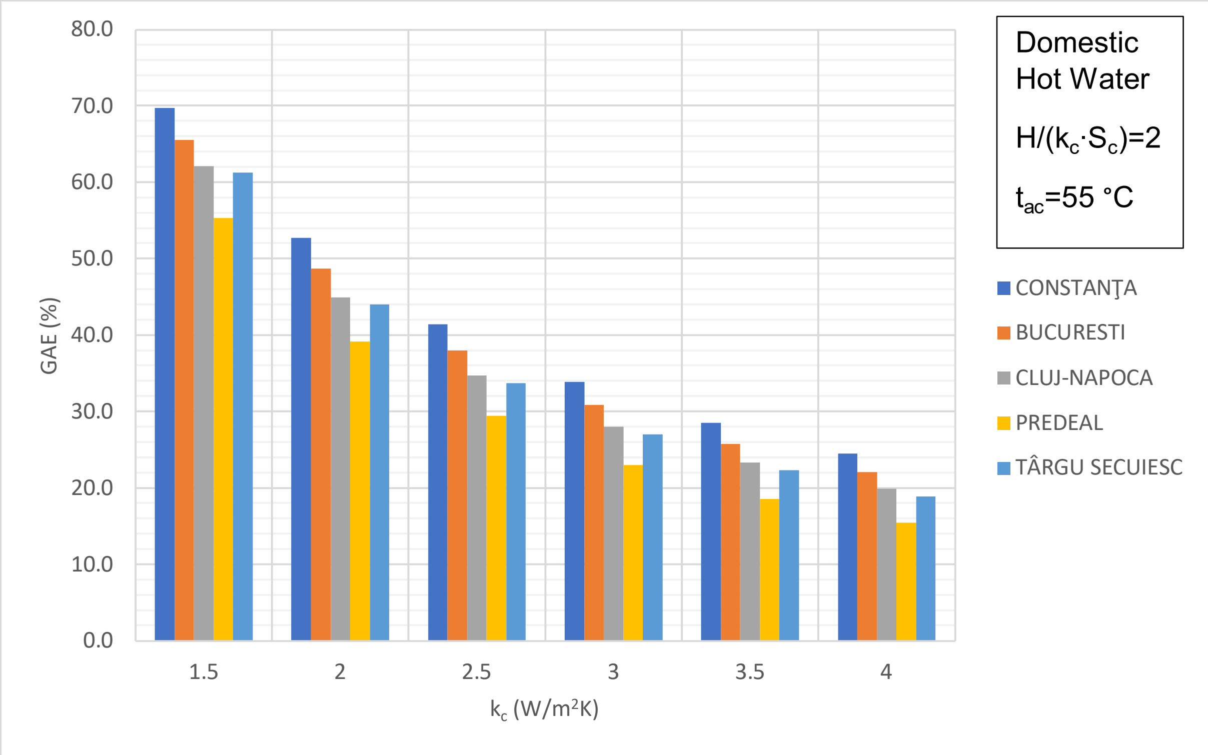

Fig. 30- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=2$

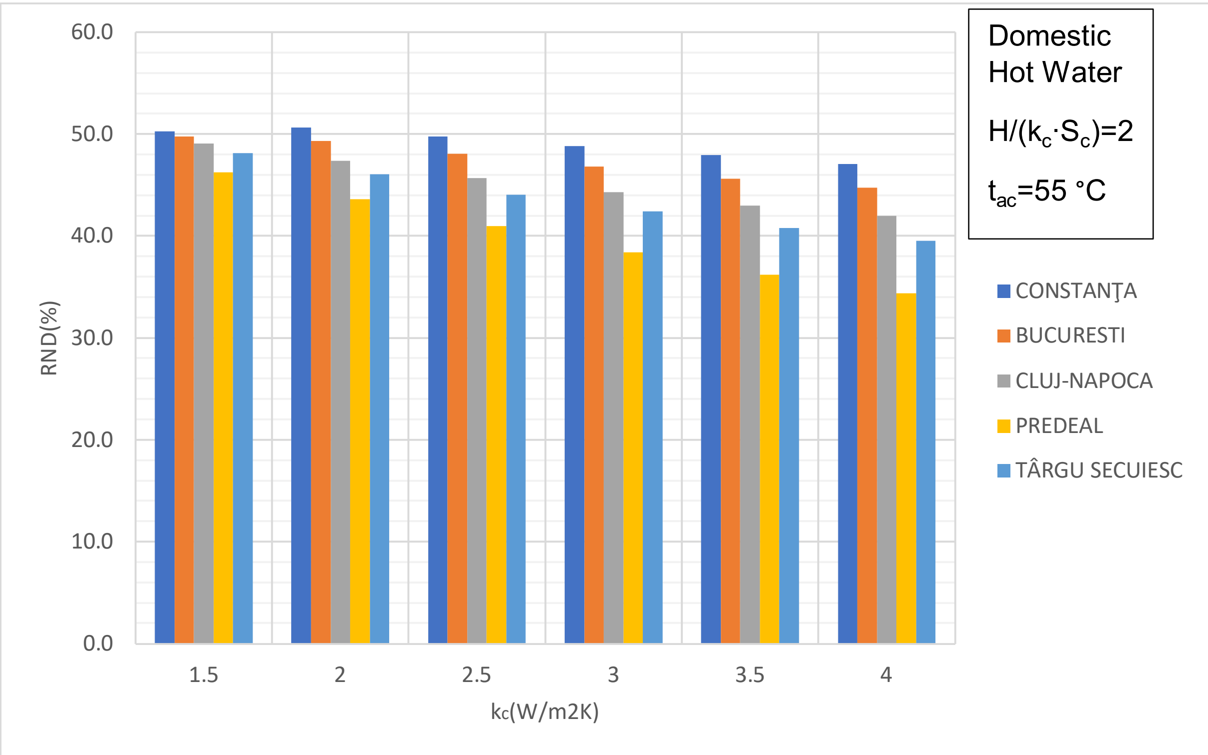

Fig. 31- Efficiency calculated for domestic hot water, $H/k_c \cdot S_c=2$

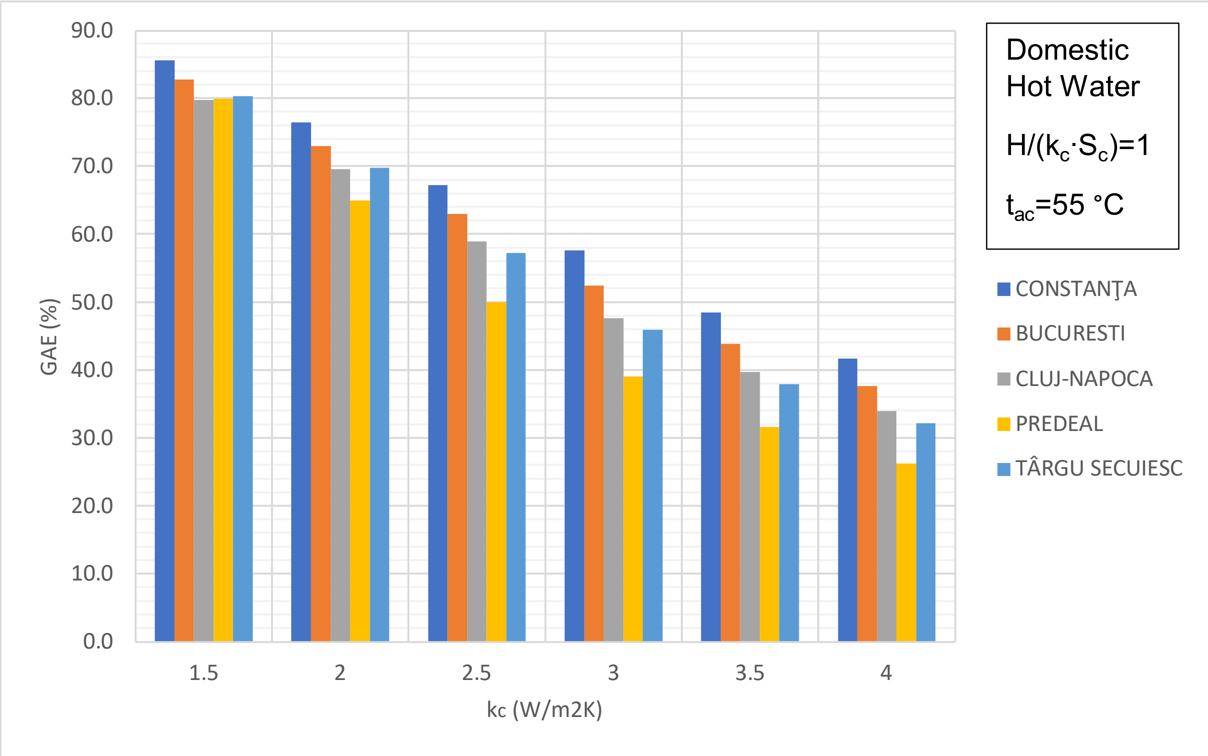

Fig. 32- Degree of coverage calculated for domestic hot water preparation, $H/k_c{\cdot}S_c=1$

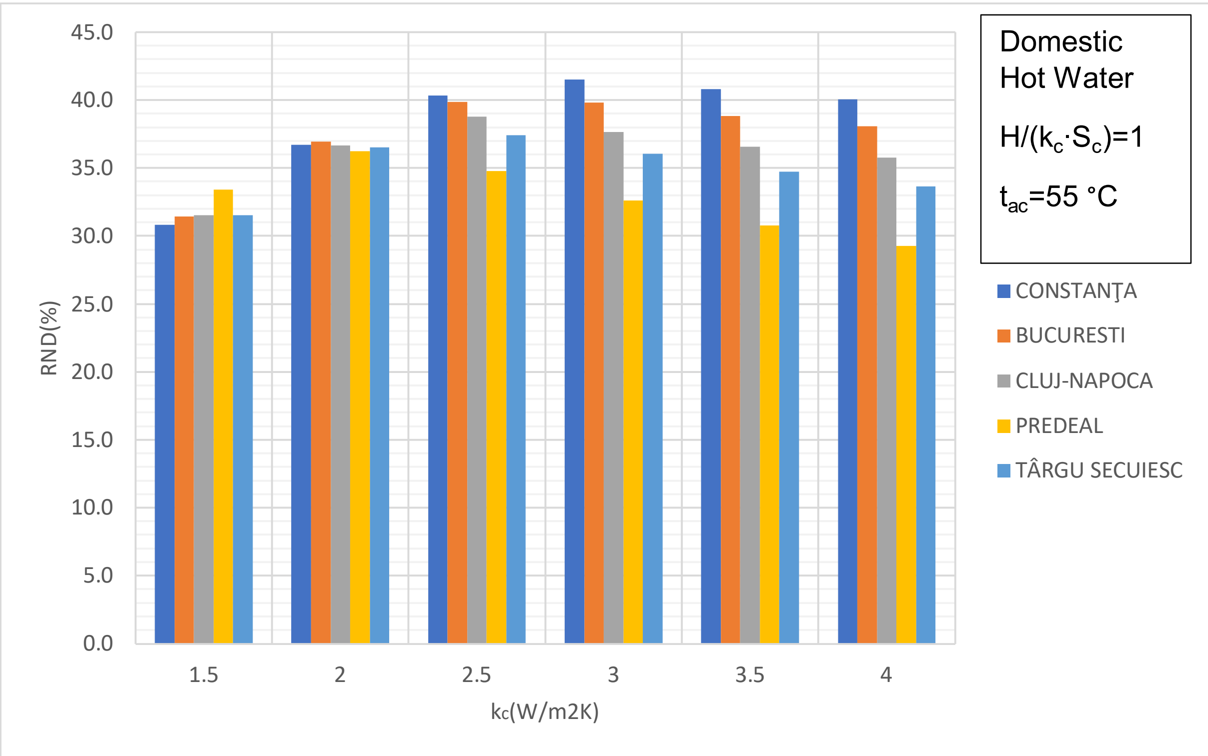

Fig. 33- Efficiency calculated for domestic hot water, $H/k_c{\cdot}S_c=1$

3.3 Energy Results for systems using Renewable Sources for 79 Cities in Romania

In order to carry out the following study, the MC001 calculation methodology presented in point 2.1 was chosen and a residential building with 80 apartments in point 3.1 was chosen representative of the building transmittance, H_{inc} = 16000 W / K. For hot water a H_{acm} = 689 W / K was chosen for the hot water consumption of that building.

The parameter values used in this calculation were as follows:

a. The H / ($k_c \cdot S_c$) ratio = 7, 5 and 3 for heating and H / ($k_c \cdot S_c$) = 3, 2 and 1 for hot water preparation;

b. The geometric correction factor of the captured heat flux, F '= 0.9;

c. Global heat transfer coefficient of solar collectors, k_C = 2 ÷ 4 W / m^2K;

d. Shock absorber coefficient of absorption, α = 0.9;

e. The coefficient of transparency of the collector glazing element, τ = 0.85;

f. Angle of inclination from the horizontal plane of the collectors, φ_i = 45 °;

g. Deviation angle of the orientation of the capture surface to the South, φ_a = 0 ° (South);

h. Heat exchanger surface in the solar loop, $S_S = 0.1 \cdot S_C$;

i. Storage tank volume, $V_a = V / S_C$ = 50 l / m^2;

j. The global heat transfer coefficient of the heat exchanger in the solar loop, k_S = 600 W / m^2K;

k. The flow rate of the heat transfer medium into the solar loop, G_C = 50 l / m^2h;

l. Surface of the consumer central heating system, S_{INC}-corresponding to 80 apartments;

m. Nominal heat sink temperatures at plant sizing, t_{T0} = 50 ° C t_{R0} = 30 ° C for one case, t_{T0} = 70 ° C t_{R0} = 50 ° C for the second case; the hot water temperature was 60 ° C for one case and 50 ° C for the second case and the cold water temperature was considered constant throughout the year at a temperature of 15 ° C;

n. For 27 cities, the solar radiation intensities, monthly averages, for a horizontal capture area, I_O, for all months of the year, according to the Mc001 methodology of 2006. And for the remaining 52 were calculated taking into account the weighted mean intestines with the inverse of the distances from the nearest 3 cities for which the data were known;

o. Average monthly average temperatures for all months of the year according to SR 4839/2014 for 77 cities and for cities with no congested values were calculated taking into account the weighted average of the temperatures with the inverse of the distances from the most suitable ones 3 cities for which data were known.

Due to the fact that in Romania there is only a limited database for the climatic values of solar radiation temperatures and intensities, it was necessary to build a database presented in Table 1. These were determined by the calculation relations (34) and (35).

Table 1

Nr. Crt.	ORAȘ	Outside temperature	Solar radiation
1	Z3 ALBA IULIA	Yes	NO
2	Z2 ALEXANDRIA	Yes	Yes
3	Z2 ARAD	Yes	NO
4	Z3 BACĂU	Yes	Yes
5	Z3 BAIA-MARE	Yes	NO
6	Z3 BÂRLAD	Yes	Yes
7	Z4 BISTRIȚA	Yes	NO
8	Z3 BOTOŞANI	Yes	Yes
9	Z4 BRAȘOV	Yes	NO
10	Z2 BRĂILA	Yes	NO
11	Z4 BUCIN	Yes	NO
12	Z2 BUCURESTI	Yes	Yes
13	Z2 BUZĂU	Yes	NO
14	Z1 CALAFAT	Yes	Yes
15	Z2 CĂLĂRAŞI	Yes	Yes
16	Z2 CAMPINA	NU	Yes
17	Z2 CARANSEBEŞ	Yes	Yes
18	Z3 CLUJ-NAPOCA	Yes	Yes
19	Z1 CONSTANŢA	Yes	Yes
20	Z2 CRAIOVA	Yes	Yes
21	Z2 CURTEA DE ARGEŞ	Yes	Yes
22	Z3 DEJ	Yes	NO
23	Z2 DEVA	Yes	NO
24	Z4 DOROHOI	NU	Yes
25	Z2 DRĂGĂŞANI	Yes	Yes
26	Z1 DROBETA TURNU SEVERIN	Yes	Yes
27	Z3 DUMBRAVENI	Yes	NO
28	Z3 FOCȘANI	Yes	NO
29	Z3 GALAŢI	Yes	Yes
30	Z2 GIURGIU	Yes	NO
31	Z2 GORGOVA	Yes	NO
32	Z2 GRIVITA	Yes	NO
33	Z1 GURA PORTIȚEI	Yes	NO
34	Z3 HOLOD	Yes	NO

Table 1-continued

Nr. Crt.	**ORAȘ**	**Temperatură exterioară**	**Intesitatea radiației solare**
35	Z3 IASI	Yes	Yes
36	Z5 JOSENI	Yes	NO
37	Z1 LUGOJ	Yes	NO
38	Z1 MANGALIA	Yes	NO
39	Z2 MEDGIDIA	Yes	NO
40	Z5 MIERCUREA CIUC	Yes	NO
41	Z1 MOLDOVA VECHE	Yes	Yes
42	Z2 ORADEA	Yes	NO
43	Z3 PĂTĂRAGELE	Yes	NO
44	Z3 PETROSANI	Yes	NO
45	Z3 PIATRA NEAMȚ	Yes	NO
46	Z2 PITEȘTI	Yes	NO
47	Z2 PLOIEȘTI	Yes	NO
48	Z4 PREDEAL	Yes	Yes
49	Z4 RADAUTI	Yes	NO
50	Z2 RÂMNICU SĂRAT	Yes	Yes
51	Z2 RÂMNICU VÂLCEA	Yes	NO
52	Z1 REȘIȚA	Yes	NO
53	Z3 ROMAN	Yes	NO
54	Z2 ROŞIORI DE VEDE	Yes	Yes
55	Z1 SAMNICOLAU MARE	Yes	Yes
56	Z3 SATU MARE	Yes	NO
57	Z1 SFÂNTU GHEORGE DELTA	Yes	NO
58	Z5 SFÂNTU GHEORGHE MUNTE	Yes	NO
59	Z3 SIBIU	Yes	Yes
60	Z3 SIGHETUL MARMATIEI	Yes	Yes
61	Z3 SINAIA	Yes	NO
62	Z2 SLATINA	Yes	NO
63	Z2 SLOBOZIA	Yes	NO
64	Z4 SUCEAVA	Yes	NO
65	Z1 SULINA	Yes	NO
66	Z2 TÂRGOVIȘTE	Yes	NO
67	Z2 TÂRGU JIU	Yes	Yes
68	Z4 TÂRGU MUREŞ	Yes	Yes
69	Z3 TÂRGU OCNA	Yes	NO
70	Z5 TÂRGU SECUIESC	Yes	Yes
71	Z3 TECUCI	Yes	NO
72	Z2 TIMIŞOARA	Yes	Yes
73	Z2 TITU	Yes	NO
74	Z2 TULCEA	Yes	NO

Table 1-continued

Nr. Crt.	ORAȘ	Temperatură exterioară	Intesitatea radiației solare
75	Z2 TURNU MĂGURELE	Yes	Yes
76	Z2 URZICENI	Yes	NO
77	Z3 VASLUI	Yes	NO
78	Z2 VIDELE	Yes	NO
79	Z2 ZALĂU	Yes	NO

$$t_0 = \frac{\frac{1}{d_1} \bullet t_1 + \frac{1}{d_2} \bullet t_2 + \frac{1}{d_3} \bullet t_3}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3}} \quad [°C] \tag{34}$$

$$I_0 = \frac{\frac{1}{d_1} \bullet I_1 + \frac{1}{d_2} \bullet I_2 + \frac{1}{d_3} \bullet I_3}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3}} \quad [W/m^2] \tag{35}$$

Using the normative values and calculating the rest of the specific climatic values, coverage rates and annual returns were obtained for 79 cities evenly distributed throughout Romania (Figure 34) for the five climatic zones:

Zone 1: Calafat, Constanţa, Drobeta Turnu Severin, Gura Portiţei, Lugoj, Mangalia Moldova Veche, Reşiţa, Sâmnicolau Mare, Sfântu Gheorghe (Delta), Sulina;

Zone 2: Alexandria, Arad, Brăila, Bucharest, Buzău, Caransebeş, Călăraşi, Câmpina, Craiova, Curtea De Argeş, Deva, Drăgăşani, Giurgiu, Gorgova, Griviţa, Medgidia, Oradea, Piteşti, Ploieşti, Râmnicu Sărat, Râmnicu Vâlcea, Roşiorii De Vede, Slatina, Slobozia, Targoviste, Targu Jiu, Timisoara, Titu, Tulcea, Turnu Magurele, Urziceni, Videle, Zalau;

Zone 3: Alba Iulia, Bacău, Baia Mare, Bârlad, Botoşani, Cluj-Napoca, Dej, Dumbraveni, Focsani, Galati, Holod, Iasi, Petarani, Petromani, Piatra Neamt, Roman, Satu Mare, Sibiu, Sighetul Marmatiei, Sinaia, Târgu Ocna, Tecuci, Vaslui;

Zone 4: Bistrita, Brasov, Bucin, Dorohoi, Predeal, Radauti, Suceava, Targu Mures;

Zone 5: Joseni, Miercurea Ciuc, Sf. Gheorghe (Mountain), Târgu Secuiesc.

The annual values were represented by graphs for each case, consisting of 18 distinct cases and for each case of heating or domestic hot water preparation. The variation of the thermal transfer coefficient of the solar panels gives an overview of all types of panels that are sold on the Romanian market. Solar panels with vacuum tubes have a heat transfer coefficient close to 2, while flat plate solar panels have a thermal transfer coefficient close to 4. This study included the use of both types of solar panels for both heating and cooling domestic hot water preparation.

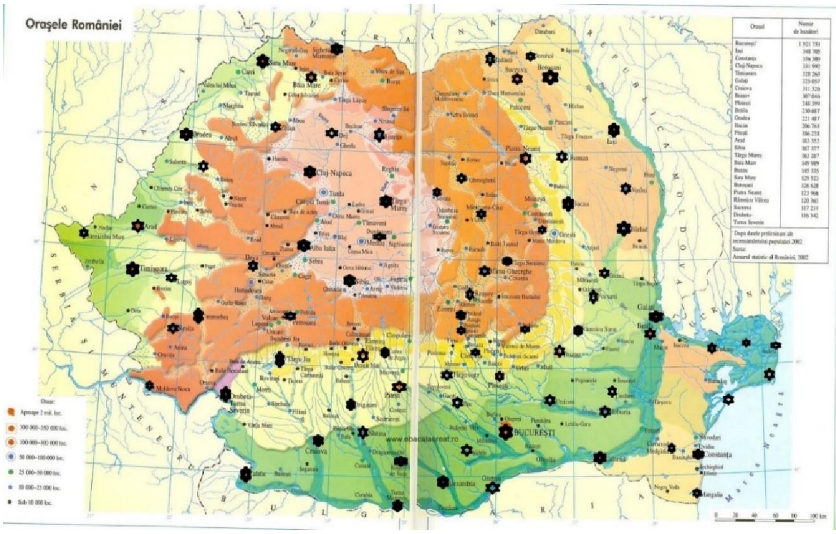

Fig. 34- Map of Romania with the 79 cities of the study

The choice of the H / ($k_c \cdot S_c$) report for the various hot water heating and hot water was done to represent as realistic as possible solar investment for the chosen objective (residential building with 80 apartments). Thus, for heating, due to very large capture surfaces, higher ratio values were chosen (3.5.7), which implies a lower degree of coverage. For domestic hot water, values of 1.2 and 3 were chosen to provide a higher degree of coverage.

The variation of heating temperatures supply temperature allows the study of two different heating solutions, one of low temperature (t_{T0} = 50 ° C, t_{R0} = 30 ° C) and one average temperature (t_{T0} = 70 ° C, t_{R0} = 50 ° C). This variation is independent of the heating resistance of the consumer due to the fact that a constant H has been chosen for all heating cases.

The variation in domestic hot water supply temperature indicates possible scenarios of hot water supply from 50 ° C to 60 ° C.

The unobtrusive choice of cities (Figure 34) ensures homogeneity for all regions of Romania. The differences between the different cities are both in the climate data presented in Table 1, but also in different climatic zones involving different outside calculation temperatures.

The monthly determination method used the number of days in SR 4839/2014 corresponding to the N_{20}^{12} value. Thus, the corresponding calculation months for heating were determined for each city.

Diagrams obtained for each case (depending on H / ($k_c \cdot S_c$) ratio, k_C variation, supply temperature variation) are as follows:

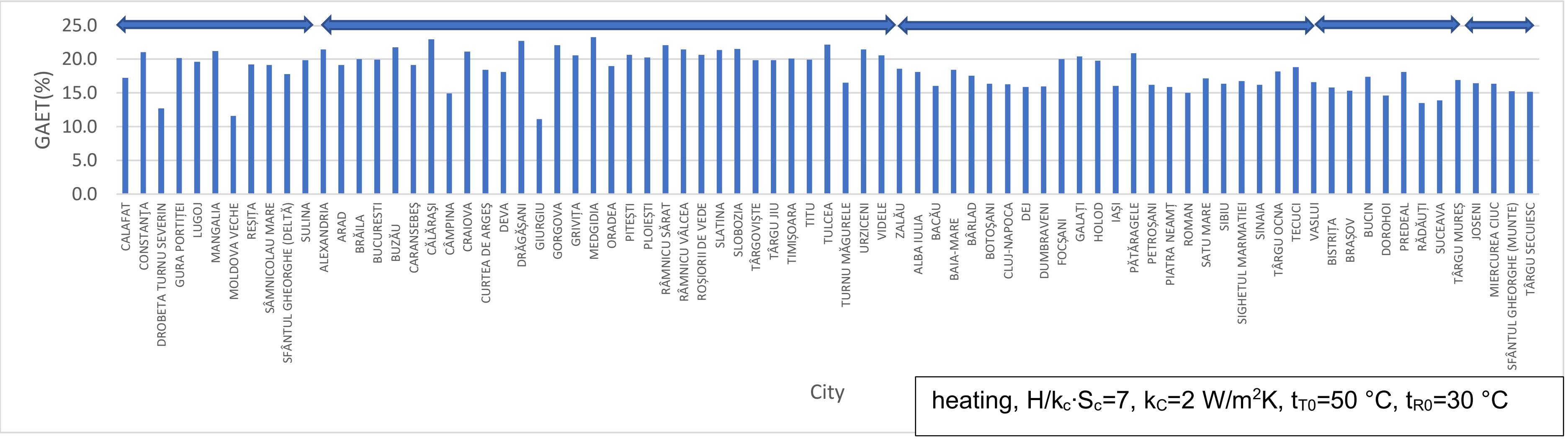

Fig. 35- Degree of coverage calculated for heating, $H/k_c \cdot S_c=7$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

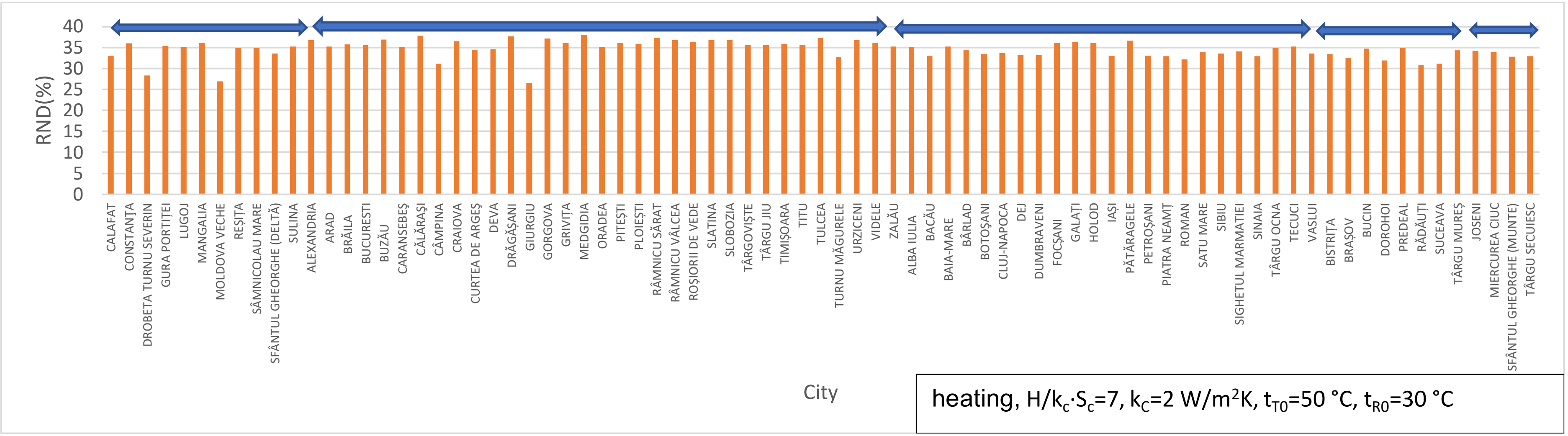

Fig. 36- Efficiency calculated for heating, $H/k_c \cdot S_c=7$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

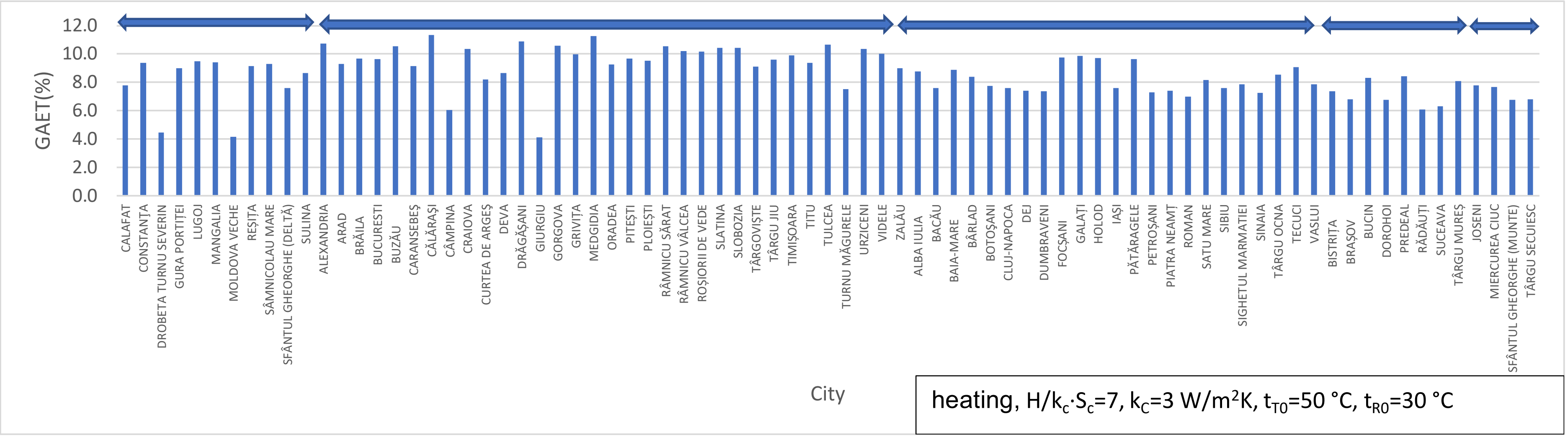

Fig. 37- Degree of coverage calculated for heating, $H/k_c \cdot S_c=7$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

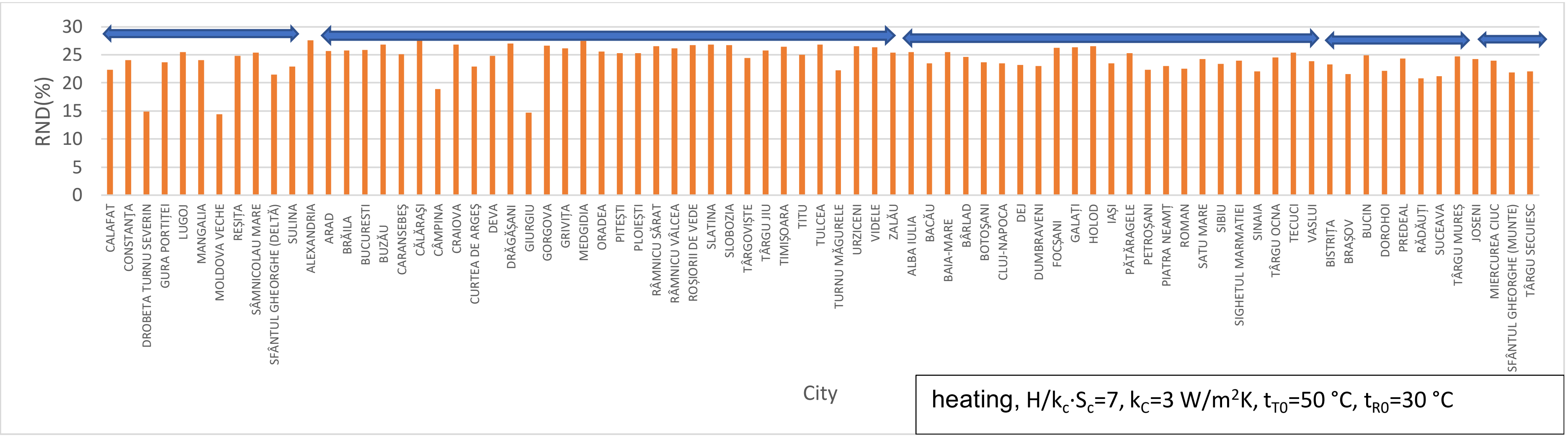

Fig. 38- Efficiency calculated for heating, $H/k_c \cdot S_c=7$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

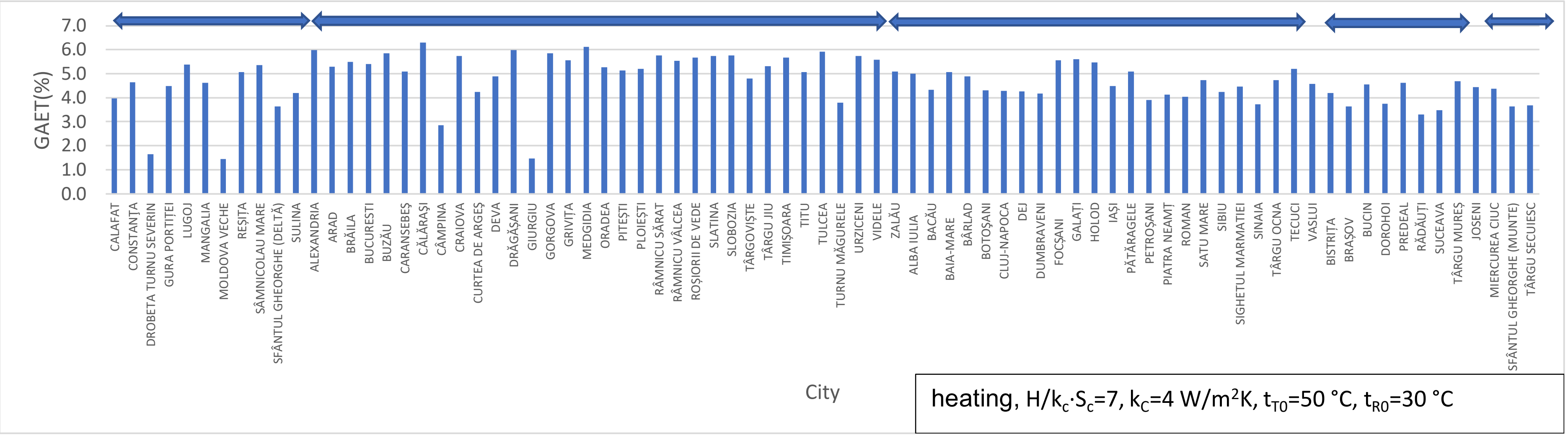

Fig. 39- Degree of coverage calculated for heating, $H/k_c \cdot S_c=7$, $k_C=4\ W/m^2K$, $t_{T0}=50$ °C, $t_{R0}=30$ °C

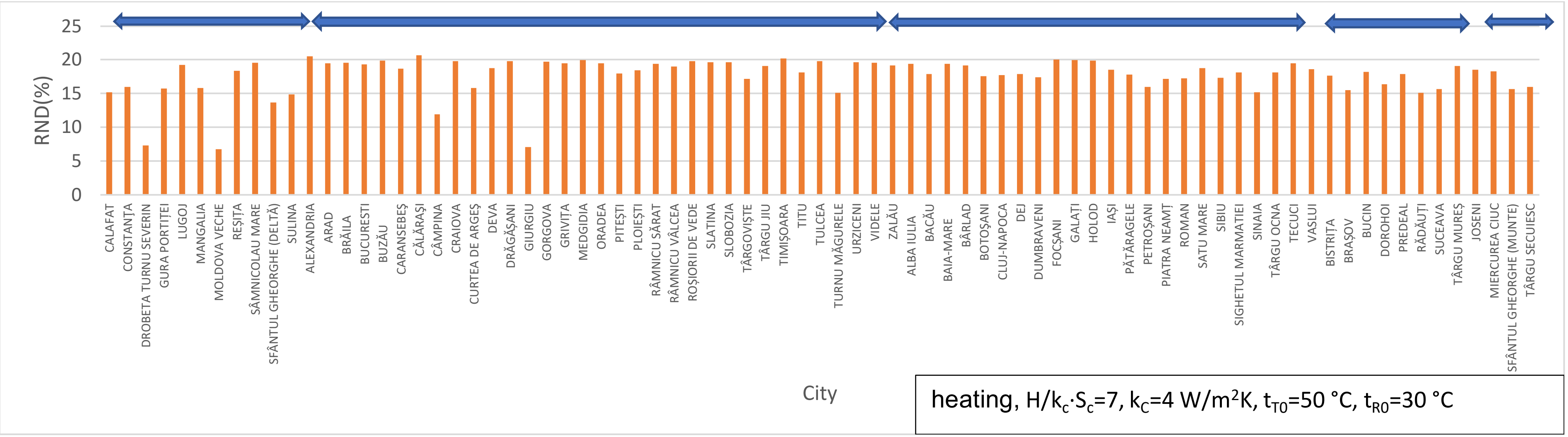

Fig. 40- Efficiency calculated for heating, $H/k_c \cdot S_c=7$, $k_C=4\ W/m^2K$, $t_{T0}=50$ °C, $t_{R0}=30$ °C

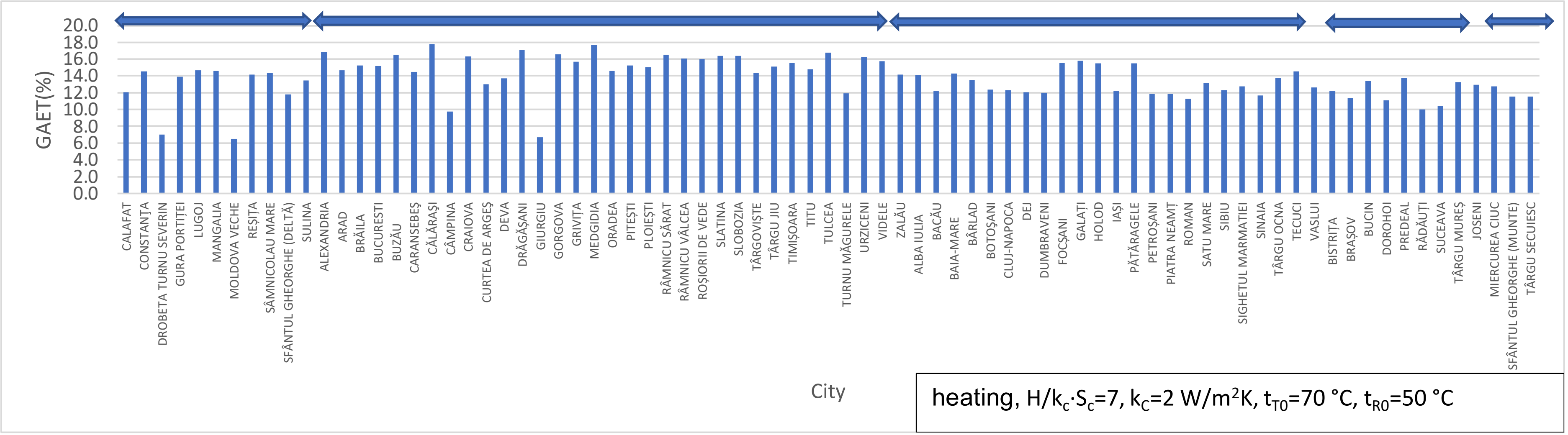

Fig. 41- Degree of coverage calculated for heating, $H/k_c \cdot S_c=7$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

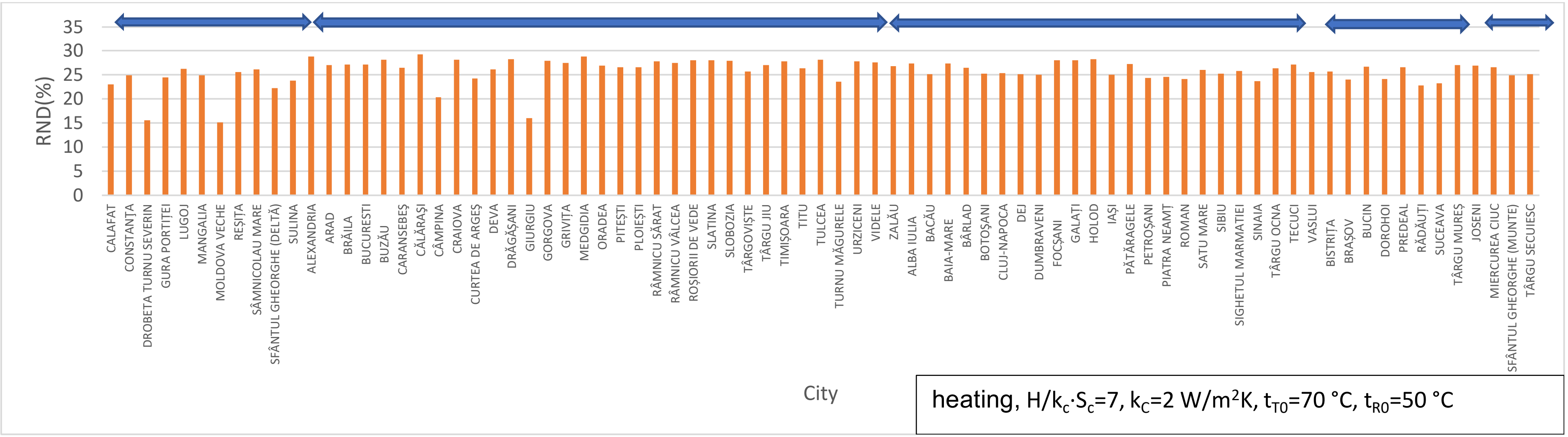

Fig. 42- Efficiency calculated for heating, $H/k_c \cdot S_c=7$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

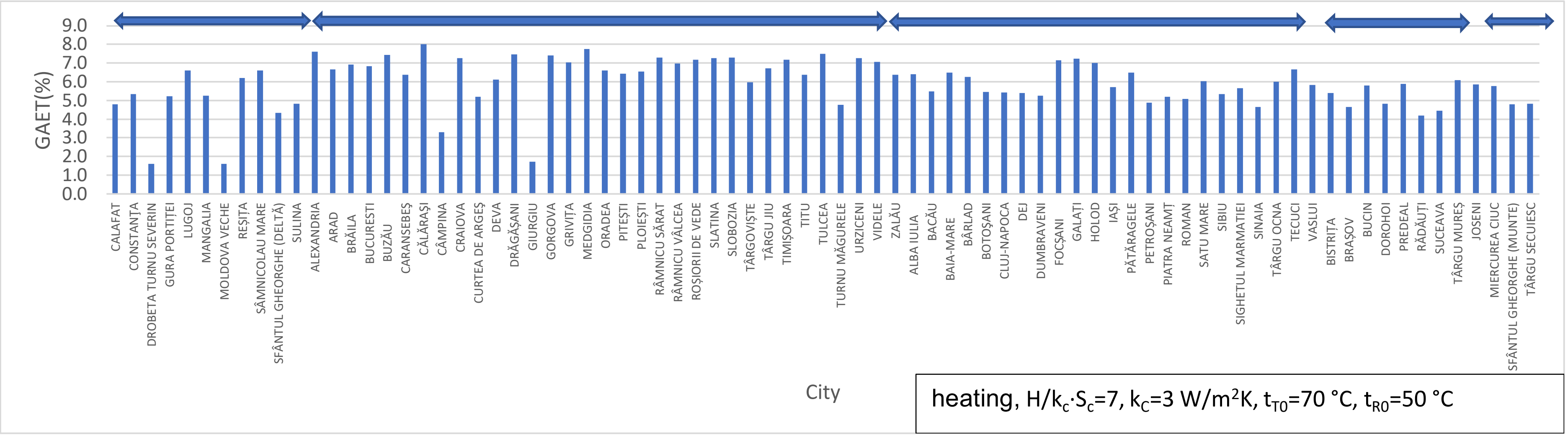

Fig. 43- Degree of coverage calculated for heating, $H/k_c \cdot S_c=7$, $k_C=3$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

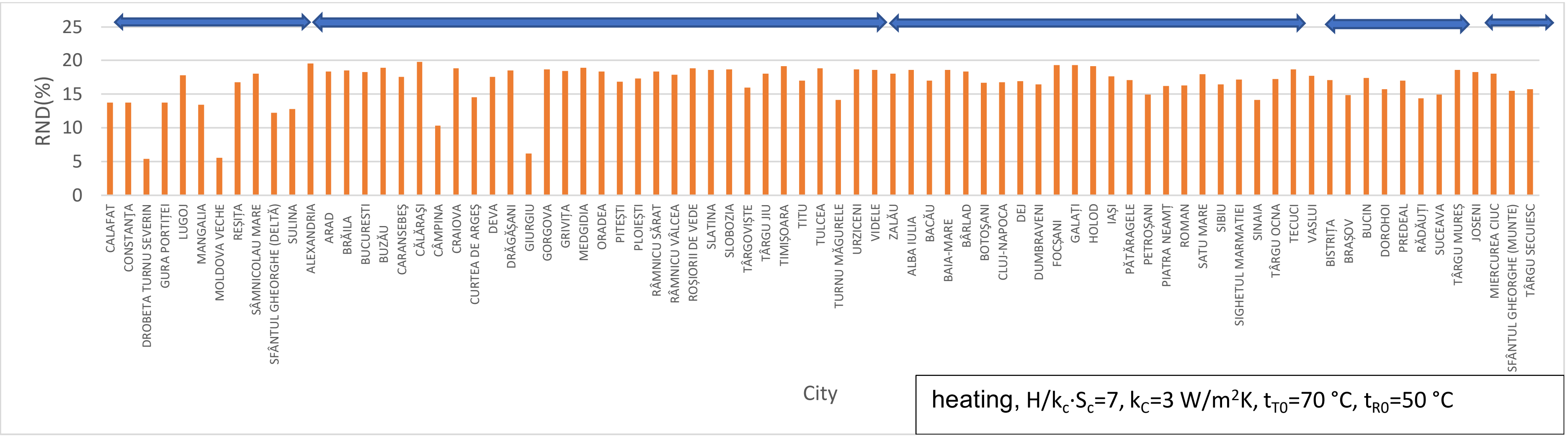

Fig. 44- Efficiency calculated for heating, $H/k_c \cdot S_c=7$, $k_C=3$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

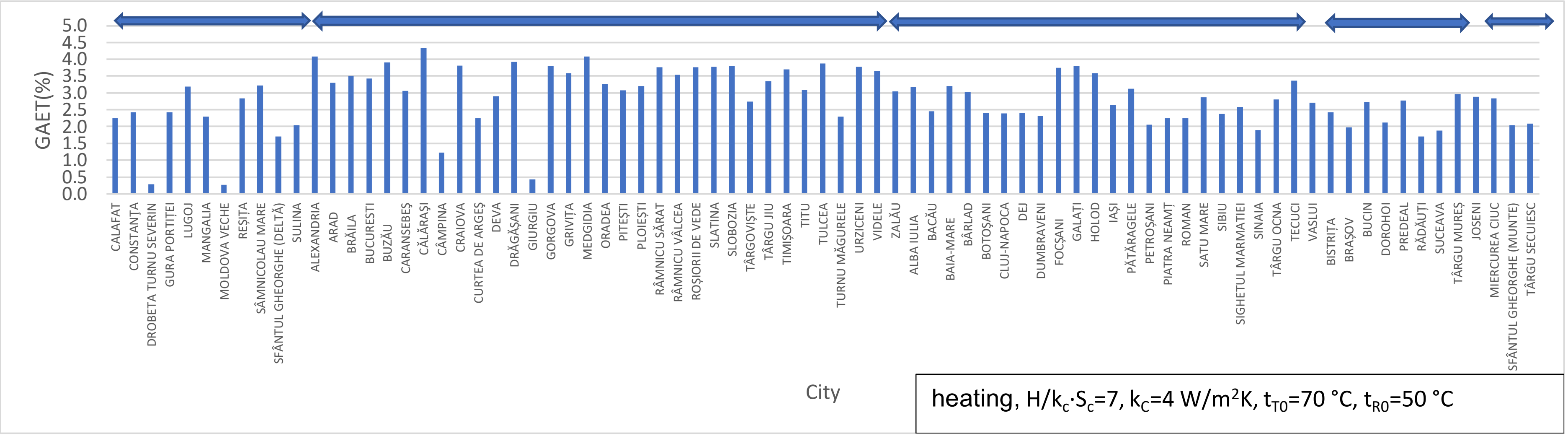

Fig. 45- Degree of coverage calculated for heating, $H/k_c \cdot S_c$=7, k_C=4 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

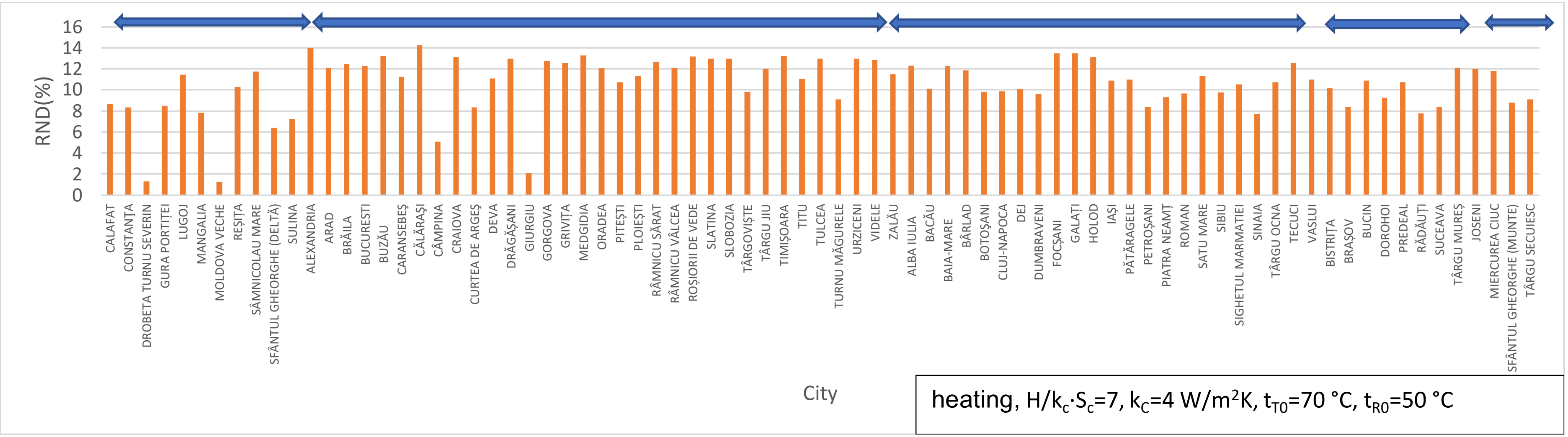

Fig. 46- Efficiency calculated for heating, $H/k_c \cdot S_c$=7, k_C=4 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

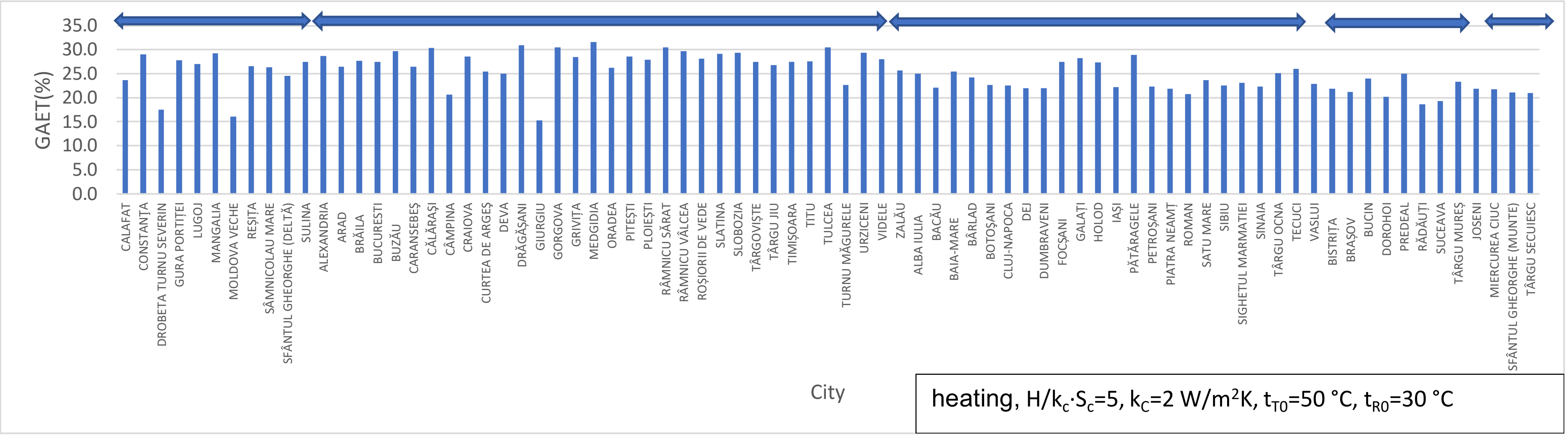

Fig. 47- Degree of coverage calculated for heating, $H/k_c \cdot S_c=5$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

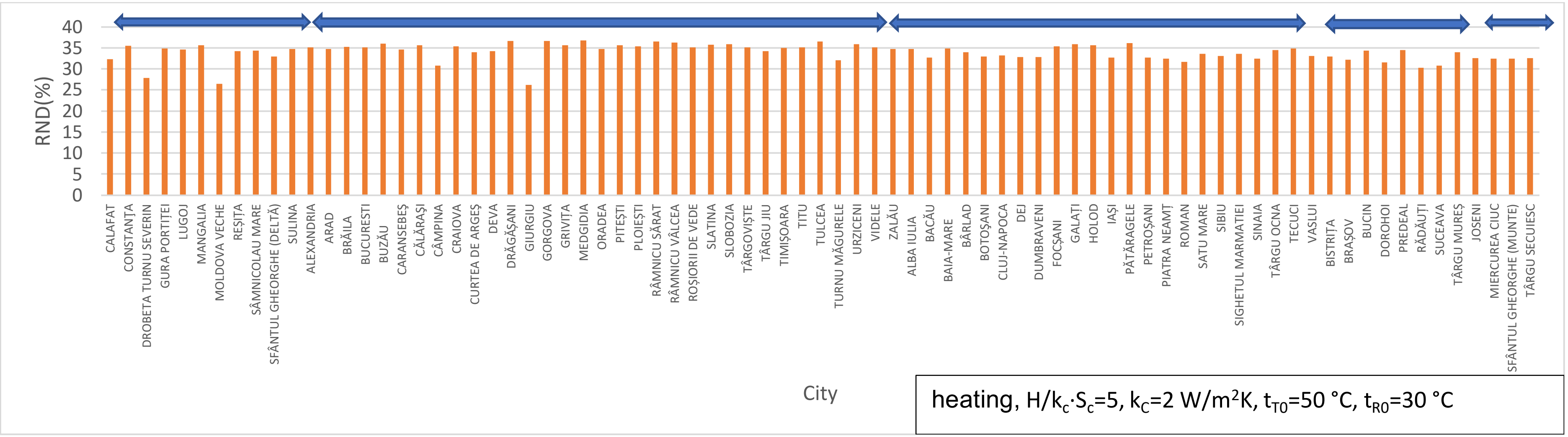

Fig. 48- Efficiency calculated for heating, $H/k_c \cdot S_c=5$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

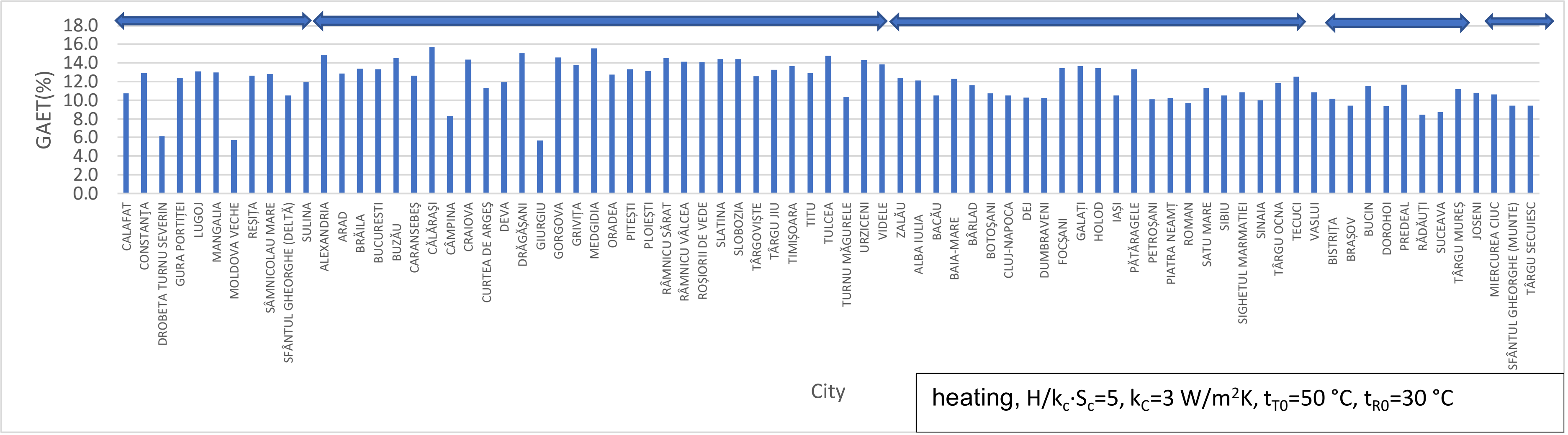

Fig. 49- Degree of coverage calculated for heating, $H/k_c \cdot S_c=5$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

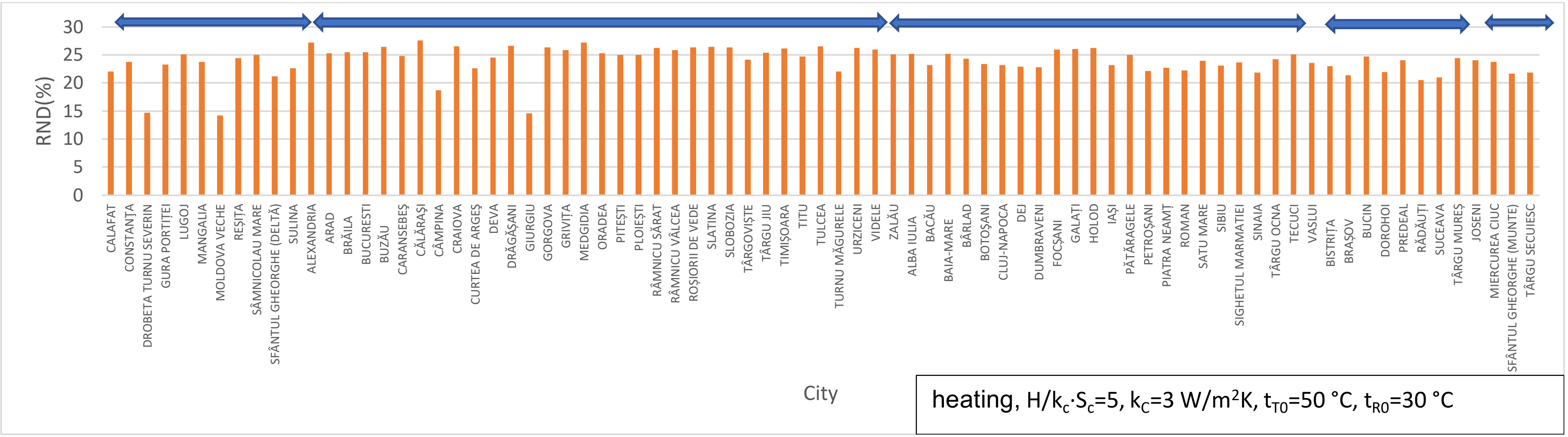

Fig. 50- Efficiency calculated for heating, $H/k_c \cdot S_c=5$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

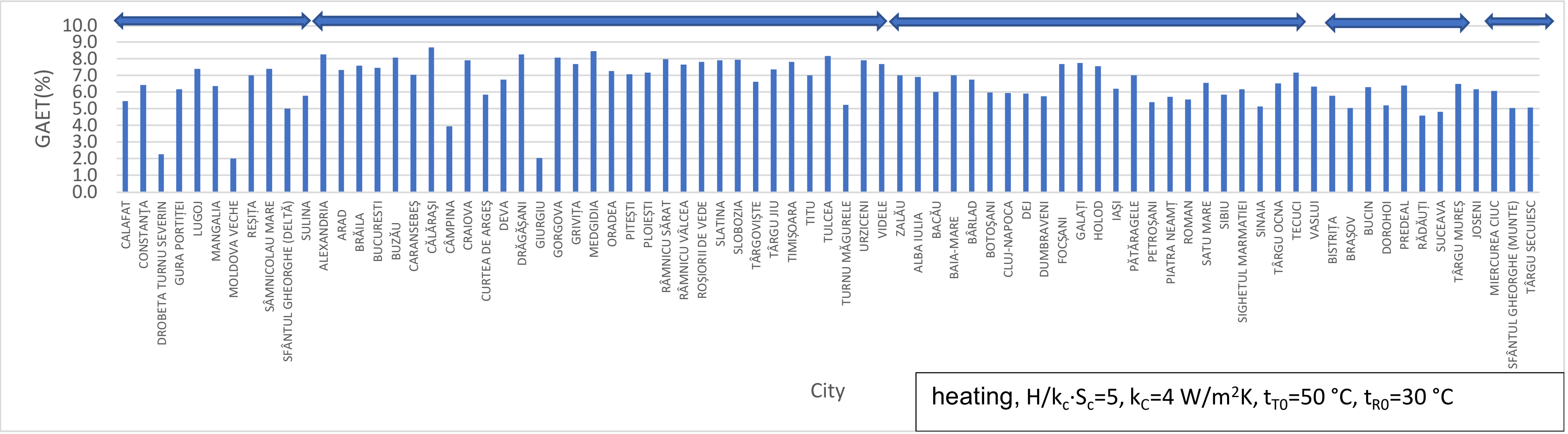

Fig. 51- Degree of coverage calculated for heating, $H/k_c \cdot S_c=5$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

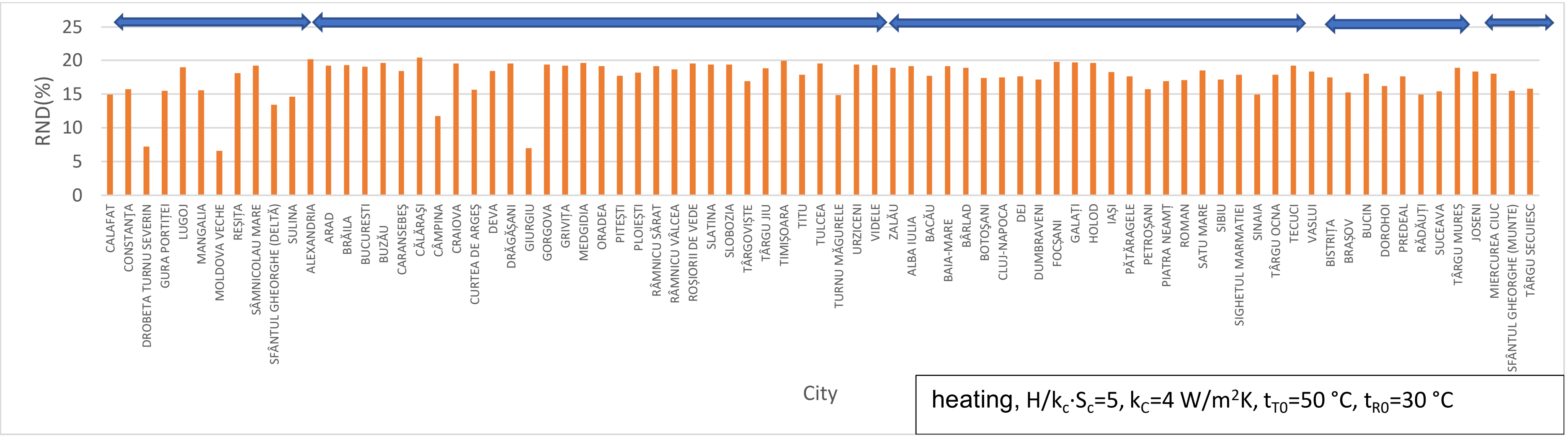

Fig. 52- Efficiency calculated for heating, $H/k_c \cdot S_c=5$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

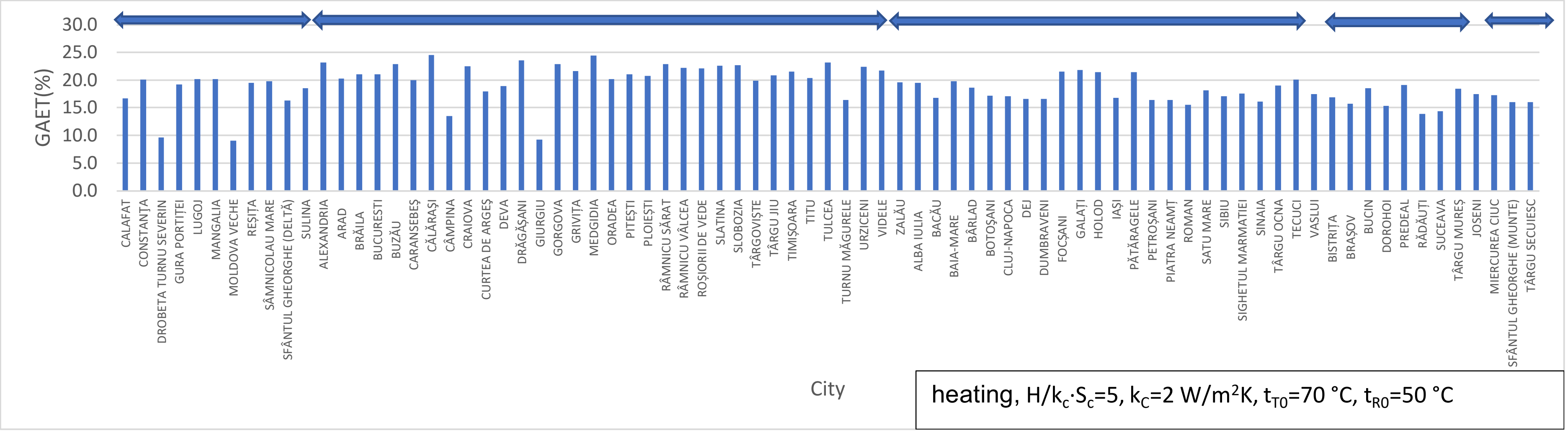

Fig. 53- Degree of coverage calculated for heating, $H/k_c \cdot S_c$=5, k_C=2 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

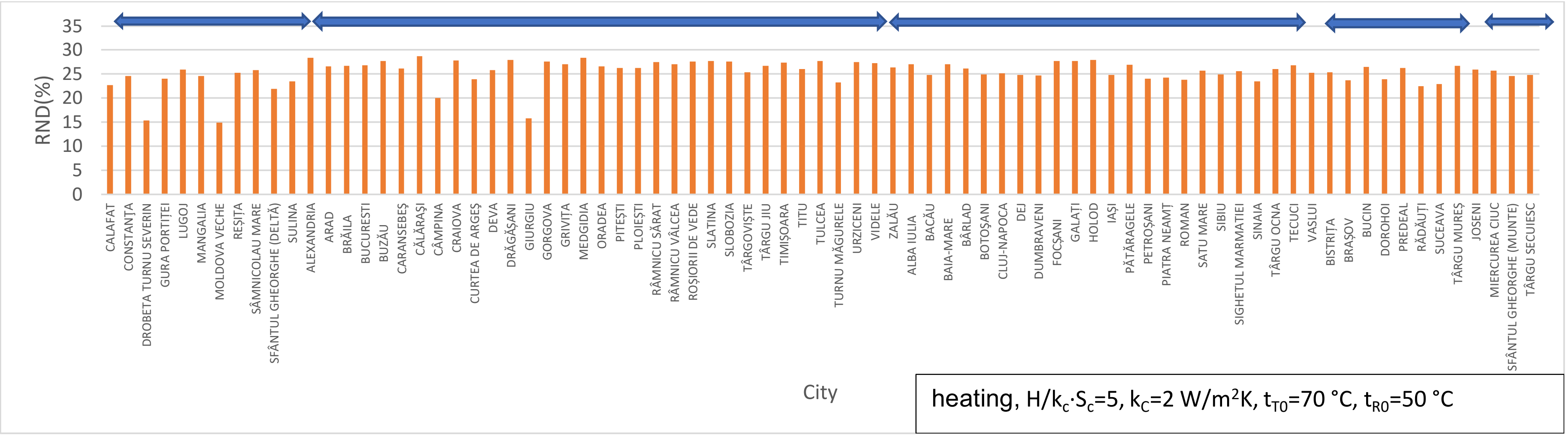

Fig. 54- Efficiency calculated for heating, $H/k_c \cdot S_c$=5, k_C=2 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

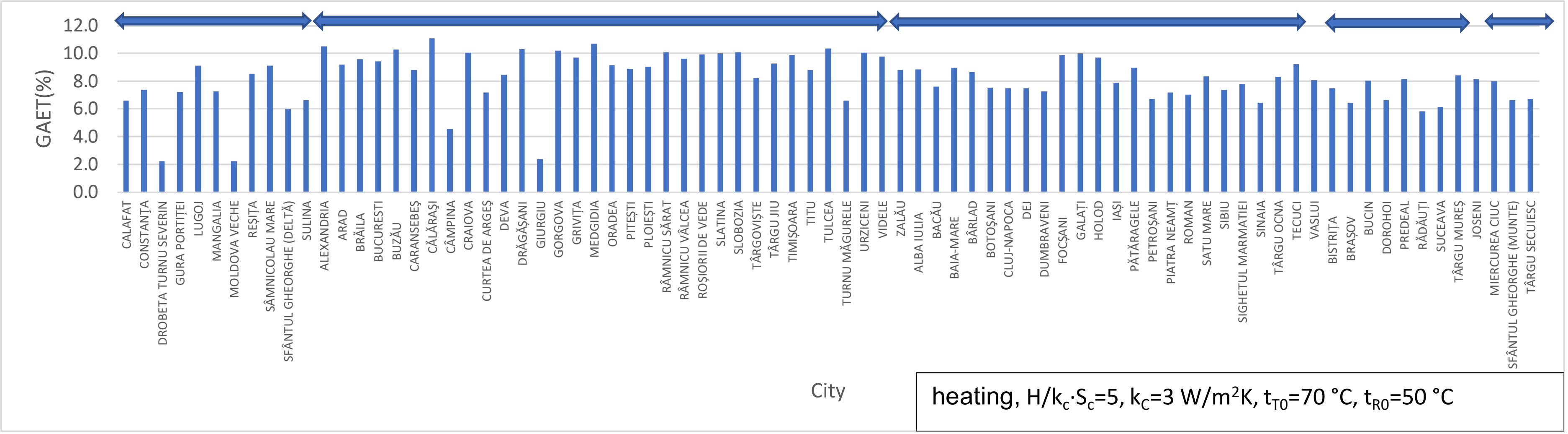

Fig. 55- Degree of coverage calculated for heating, $H/k_c \cdot S_c=5$, $k_C=3$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

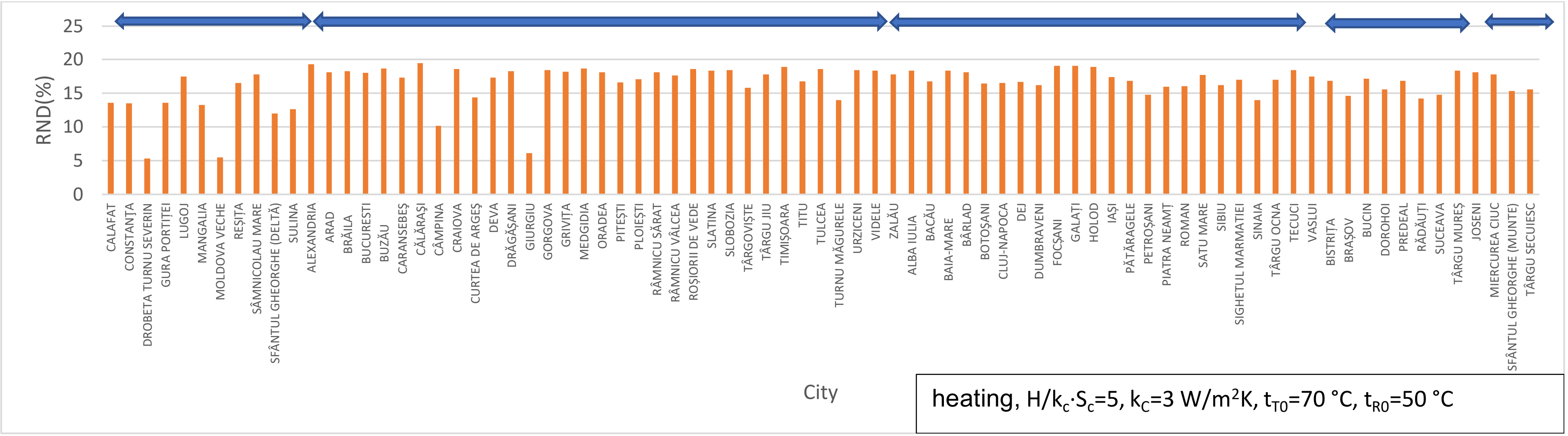

Fig. 56- Efficiency calculated for heating, $H/k_c \cdot S_c=5$, $k_C=3$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

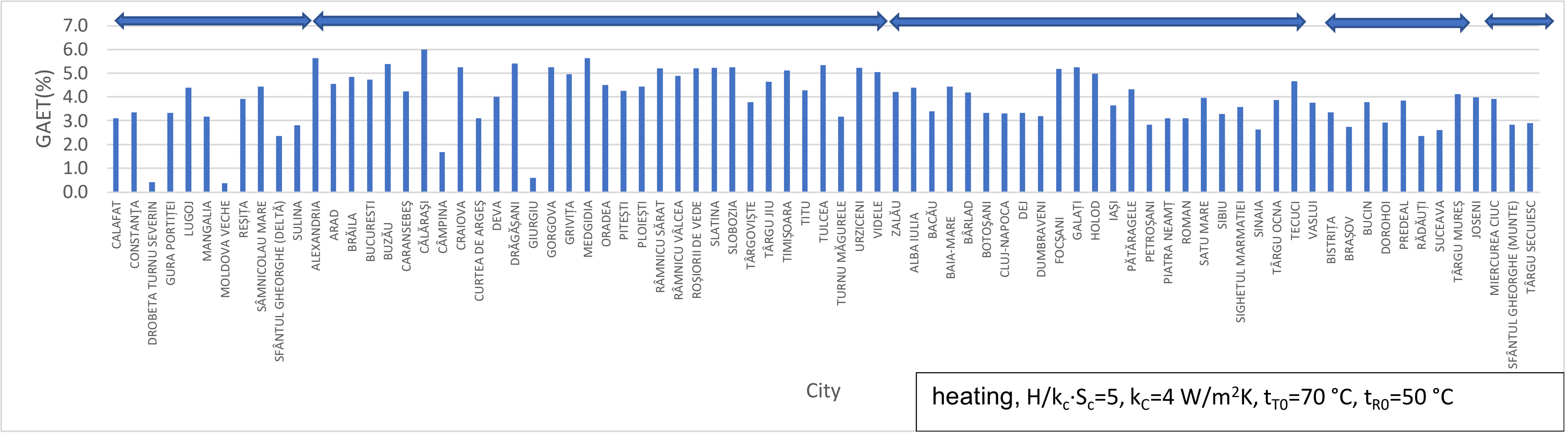

Fig. 57- Degree of coverage calculated for heating, $H/k_c \cdot S_c=5$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

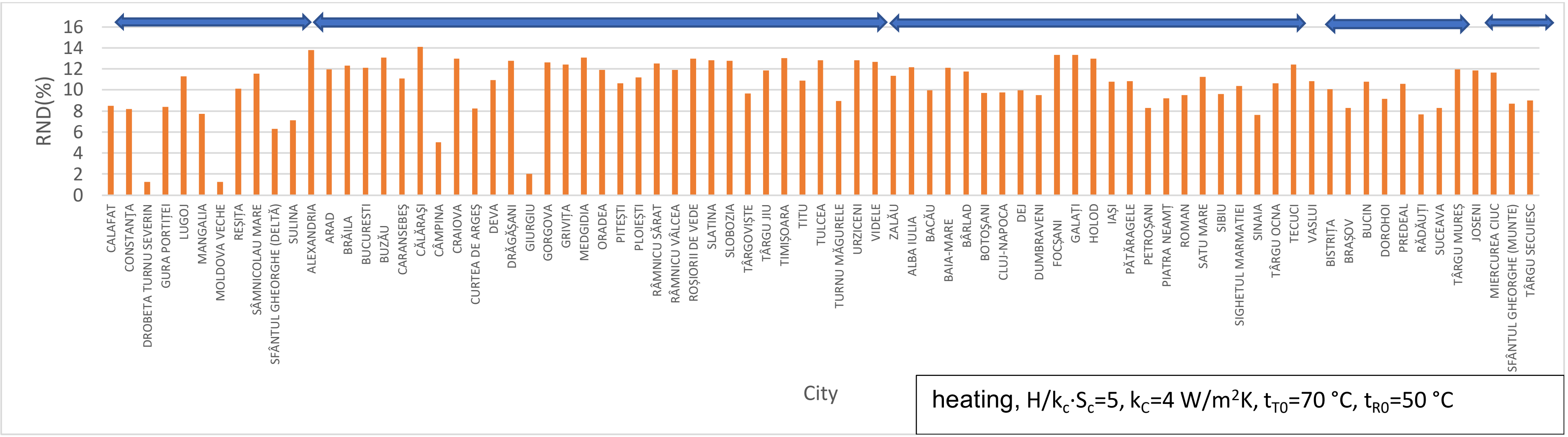

Fig. 58- Efficiency calculated for heating, $H/k_c \cdot S_c=5$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

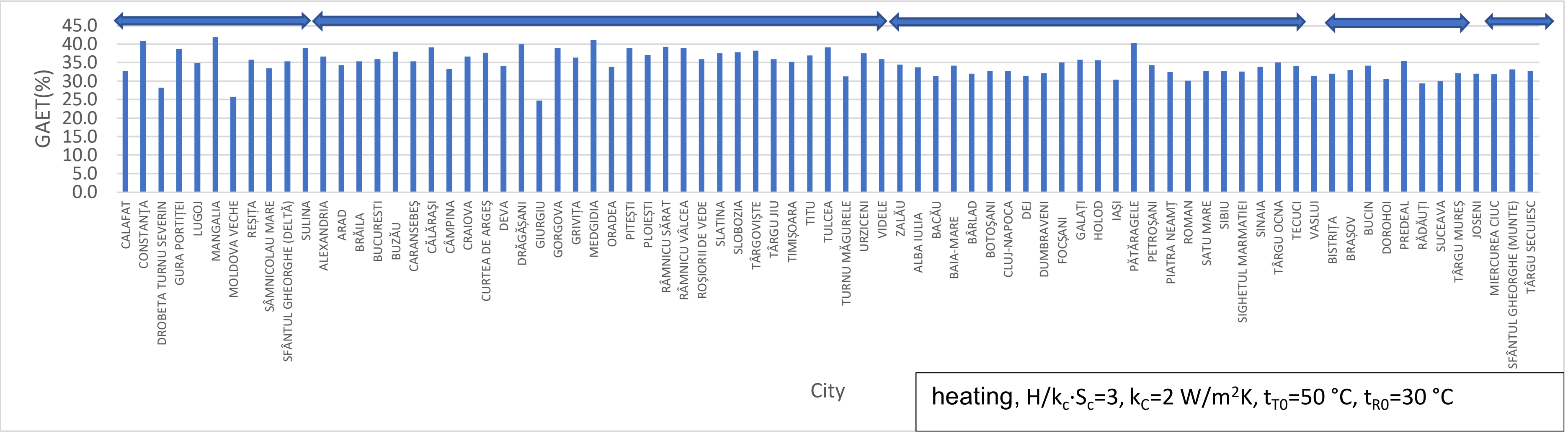

Fig. 59- Degree of coverage calculated for heating, $H/k_c{\cdot}S_c=3$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

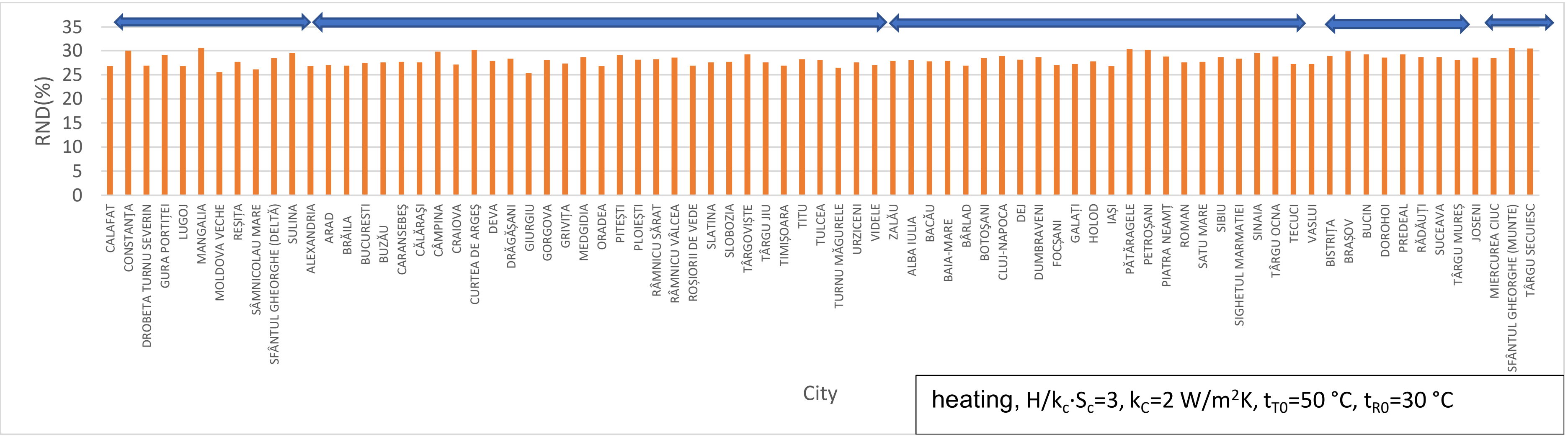

Fig. 60- Efficiency calculated for heating, $H/k_c{\cdot}S_c=3$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

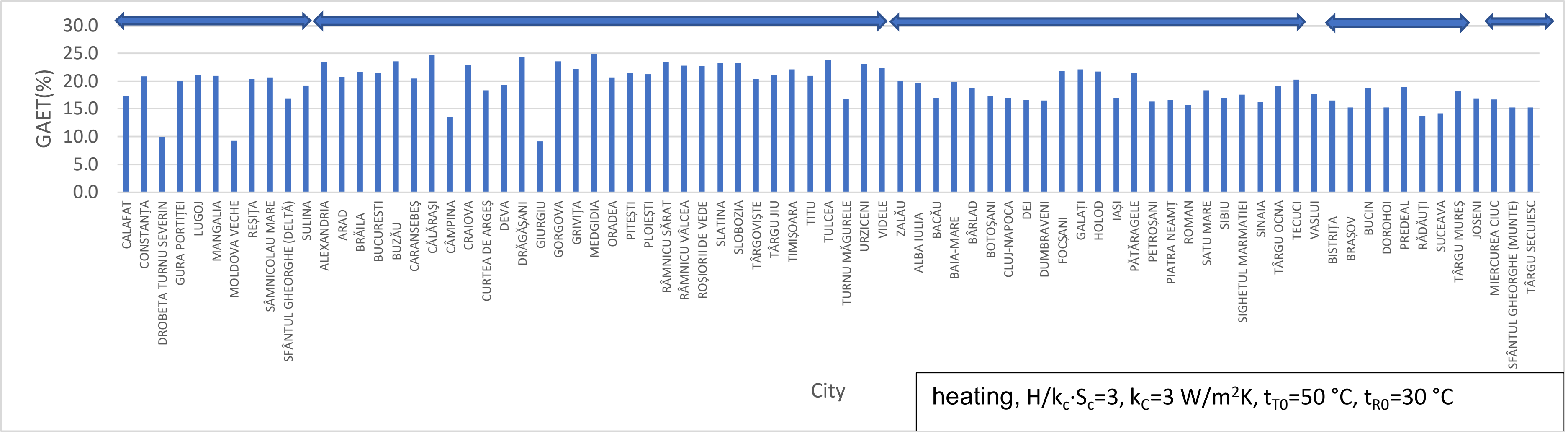

Fig. 61- Degree of coverage calculated for heating, $H/k_c \cdot S_c=3$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

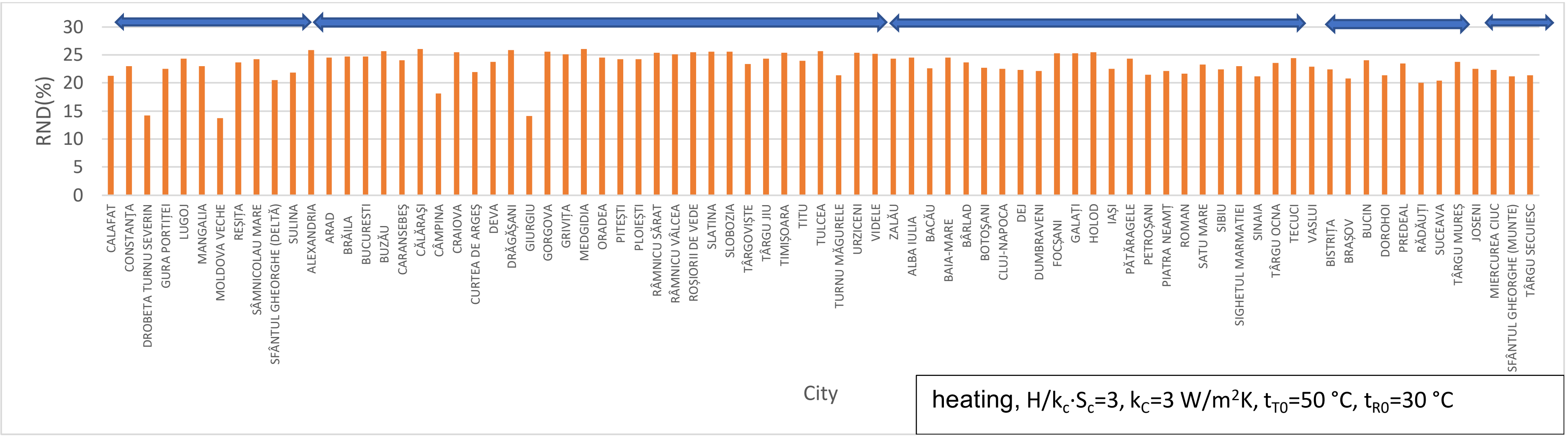

Fig. 62- Efficiency calculated for heating, $H/k_c \cdot S_c=3$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

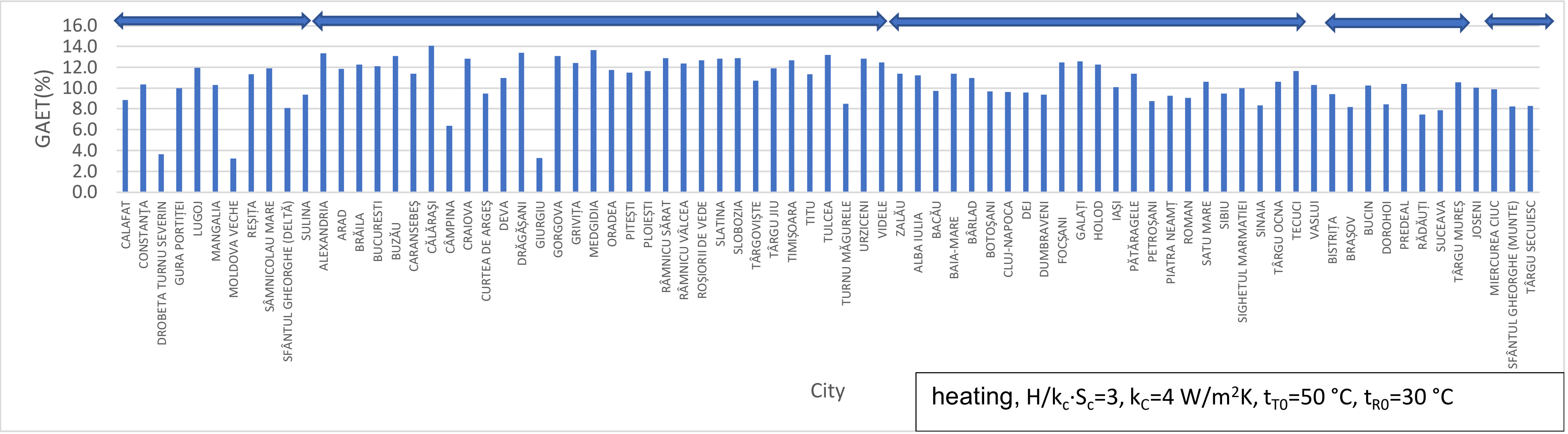

Fig. 63- Degree of coverage calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

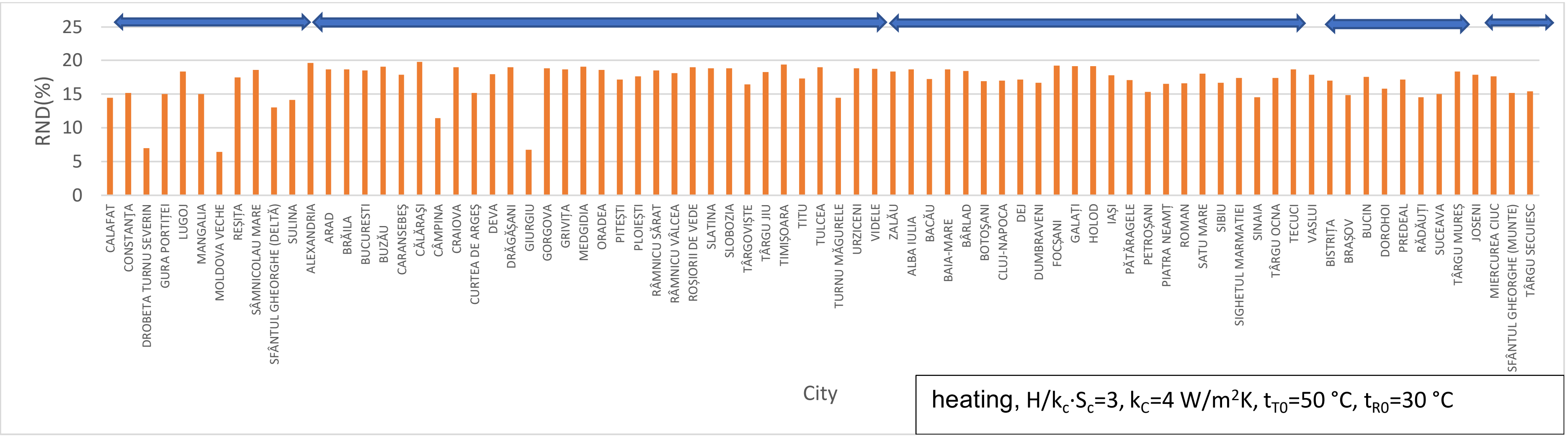

Fig. 64- Efficiency calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

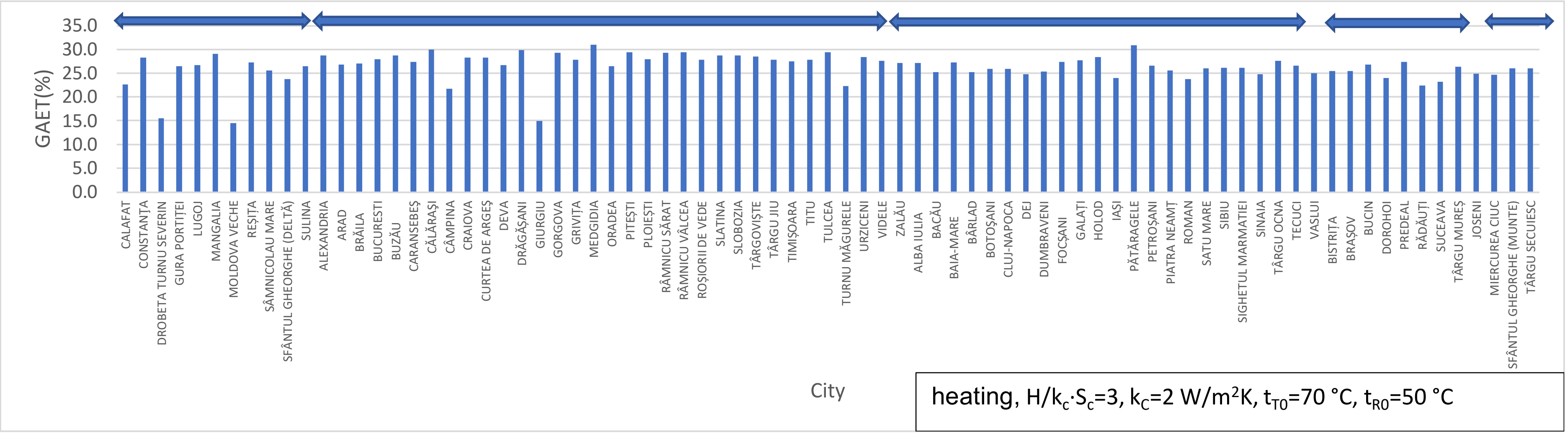

Fig. 65- Degree of coverage calculated for heating, $H/k_c \cdot S_c=3$, $k_C=2$ W/m²K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

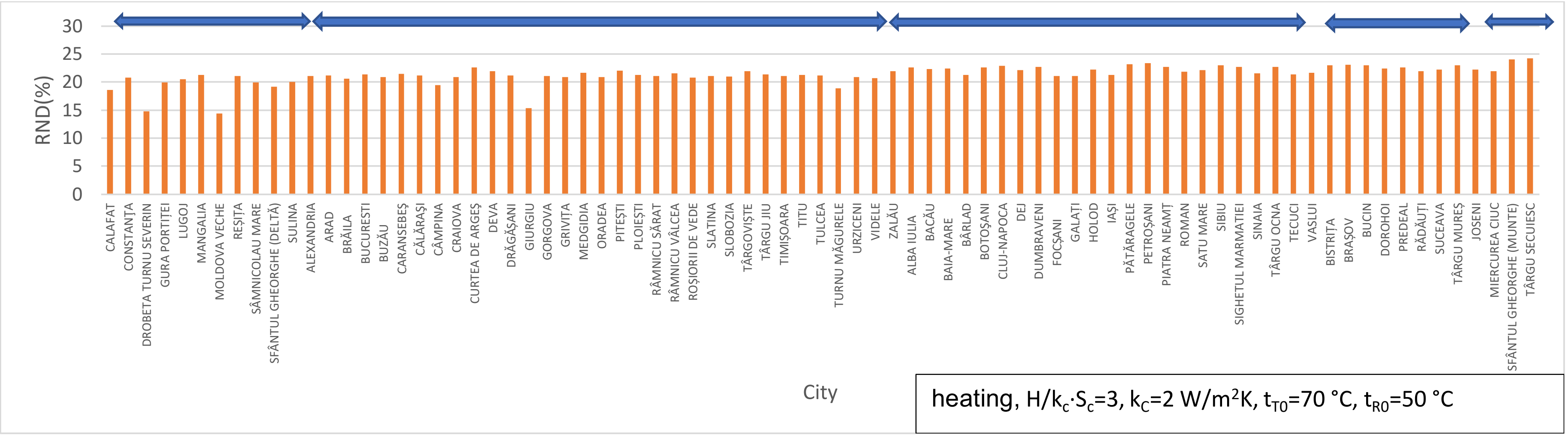

Fig. 66- Efficiency calculated for heating, $H/k_c \cdot S_c=3$, $k_C=2$ W/m²K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

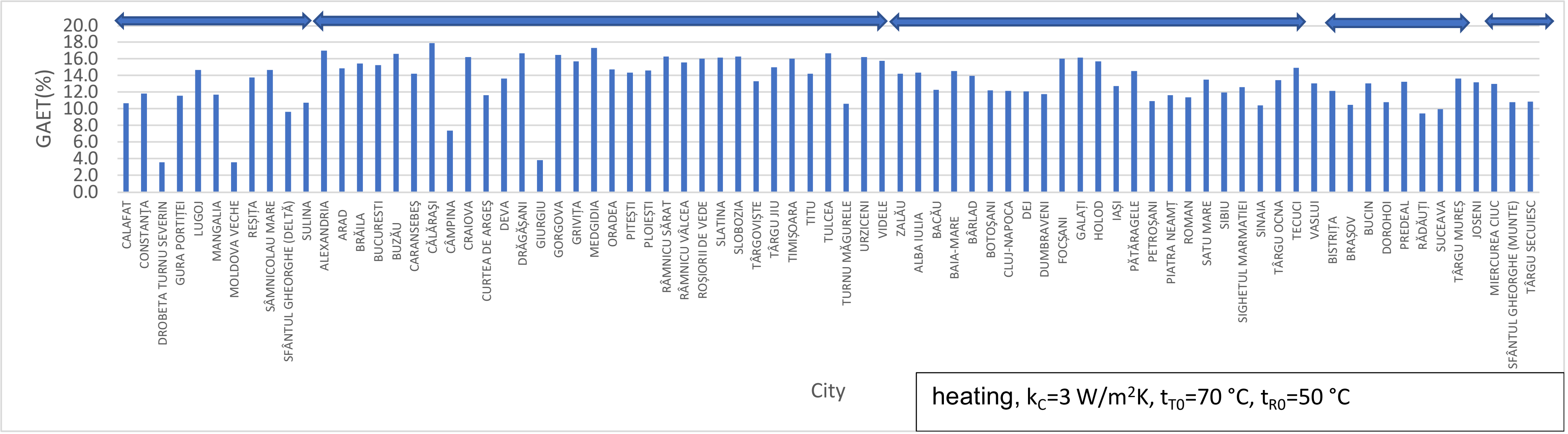

Fig. 67- Degree of coverage calculated for heating, $H/k_c \cdot S_c=3$, k_C=3 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

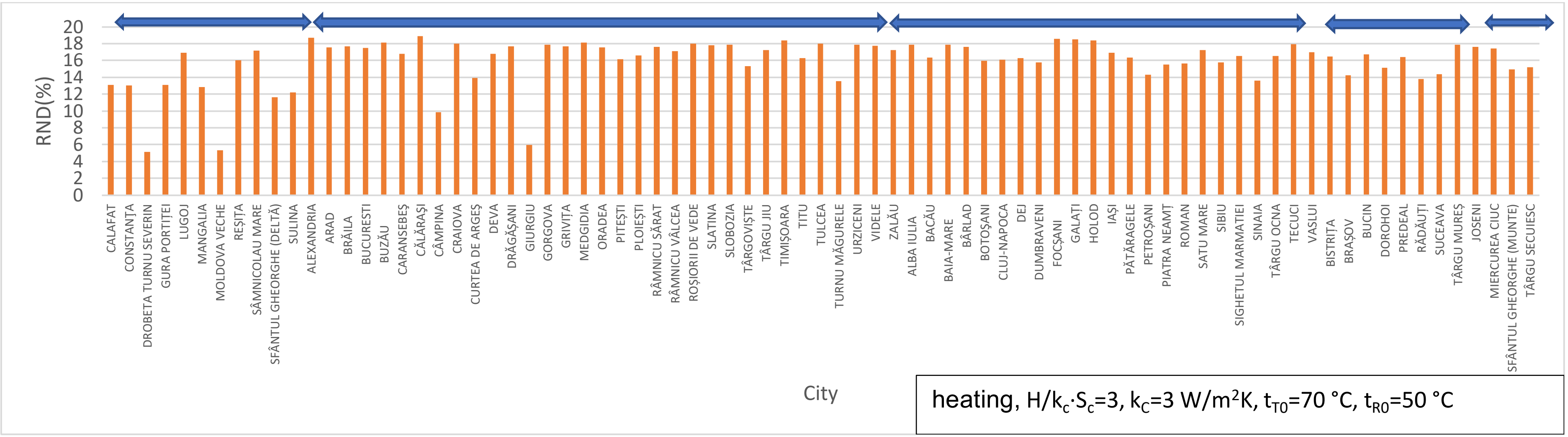

Fig. 68- Efficiency calculated for heating, $H/k_c \cdot S_c=3$, k_C=3 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

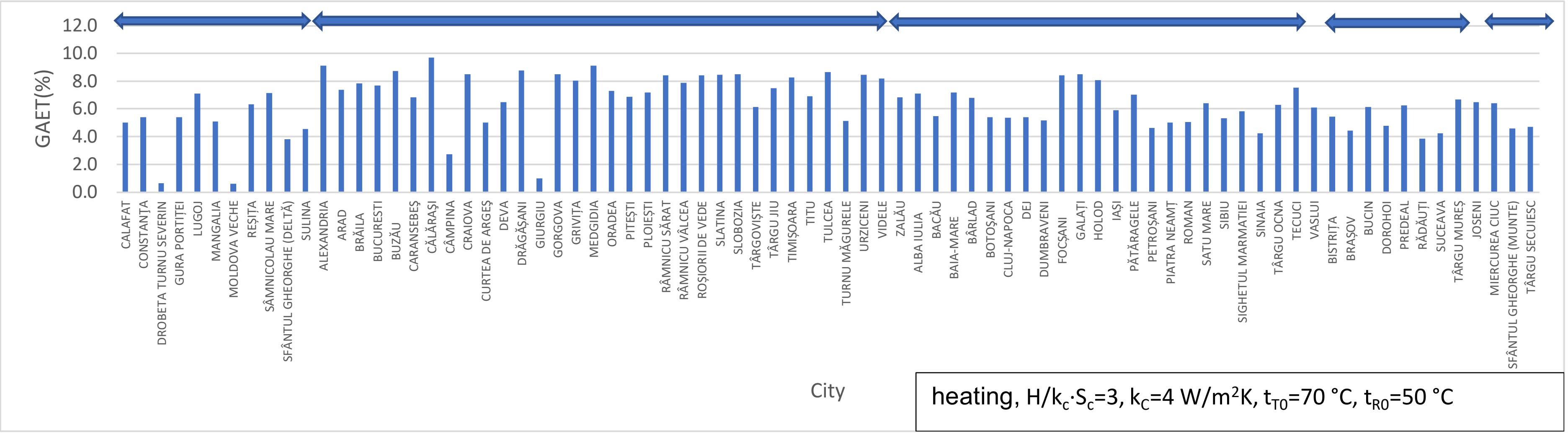

Fig. 69- Degree of coverage calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

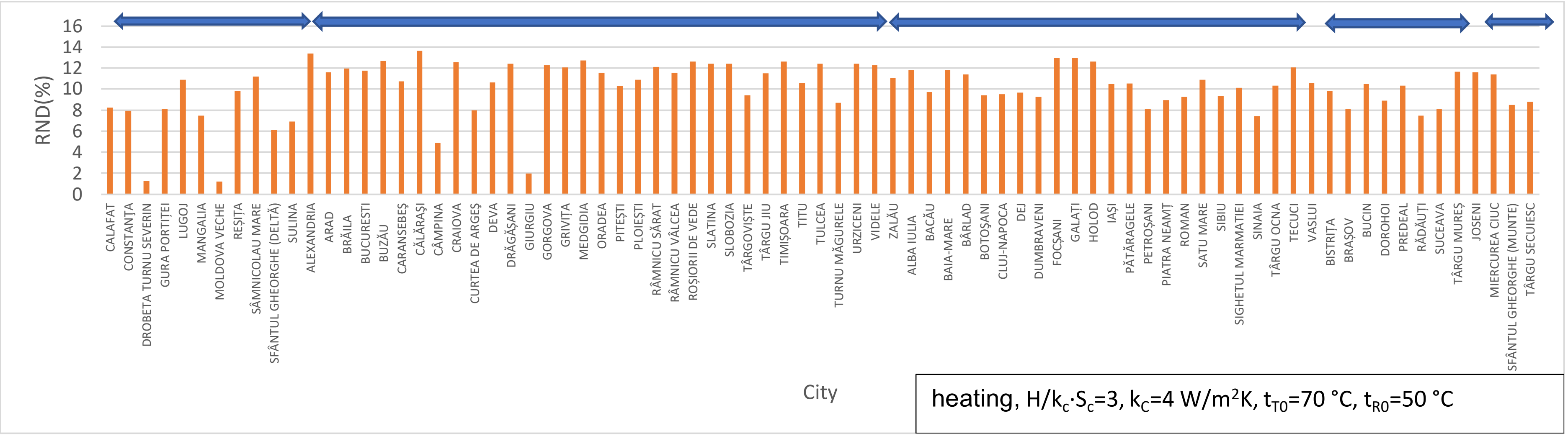

Fig. 70- Efficiency calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

Diagrams obtained for the domestic hot water preparation of each case (depending on the report $H/(k_c \cdot S_c)$, variation of k_C, variation of supply temperatures) are as follows:

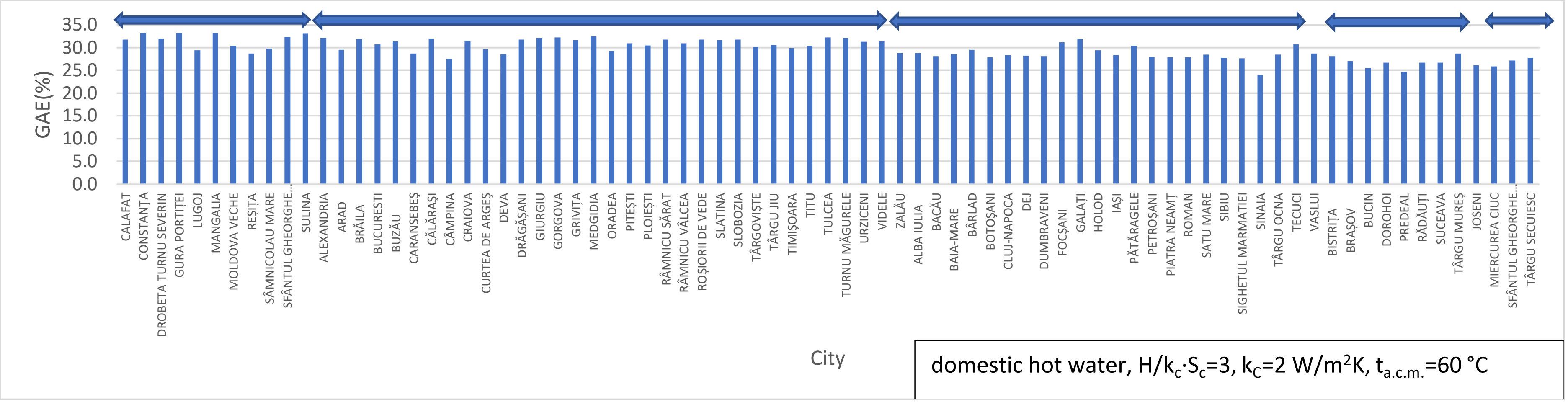

Fig. 71- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=60$ °C

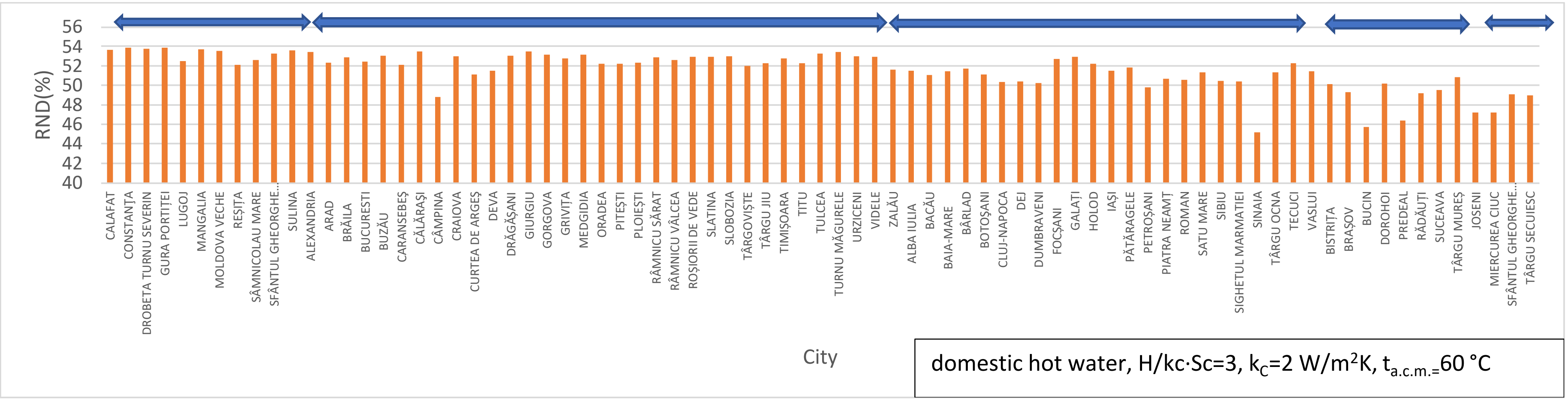

Fig. 72- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=3$, $k_C=2$ W/m^{2}K, $t_{a.c.m.=}60$ °C

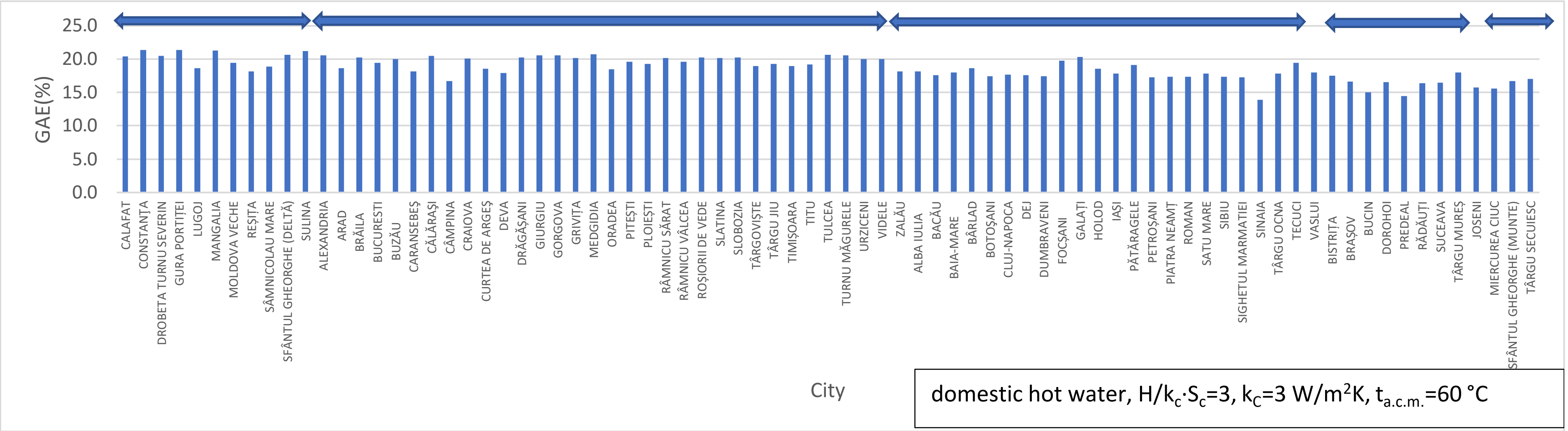

Fig. 73- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=60$ °C

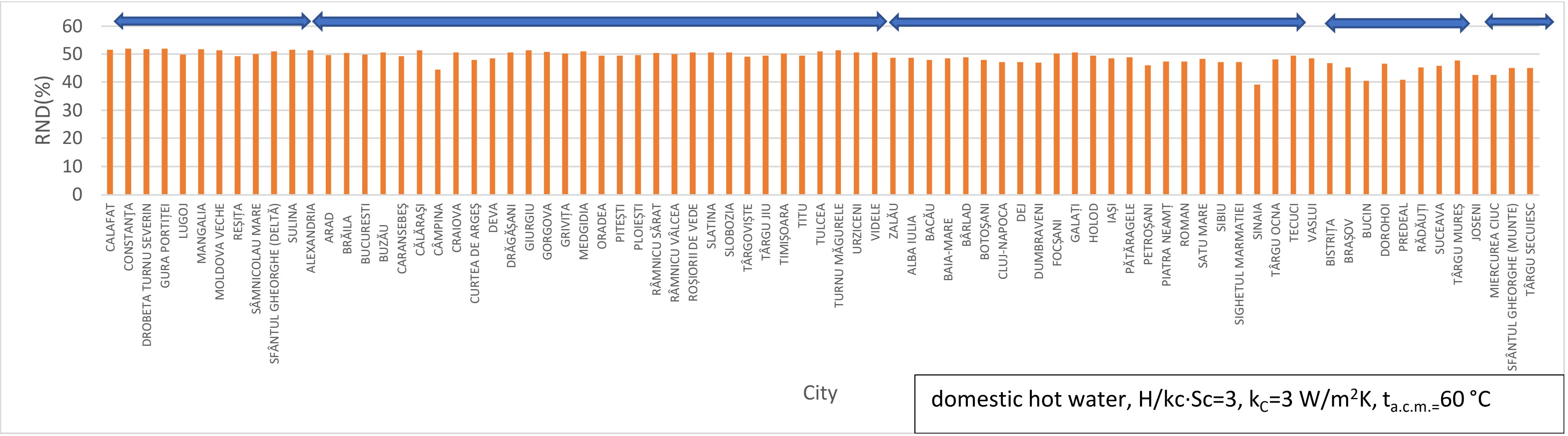

Fig. 74- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=3$, $k_C=3$ W/m^{2}K, $t_{a.c.m.=}60$ °C

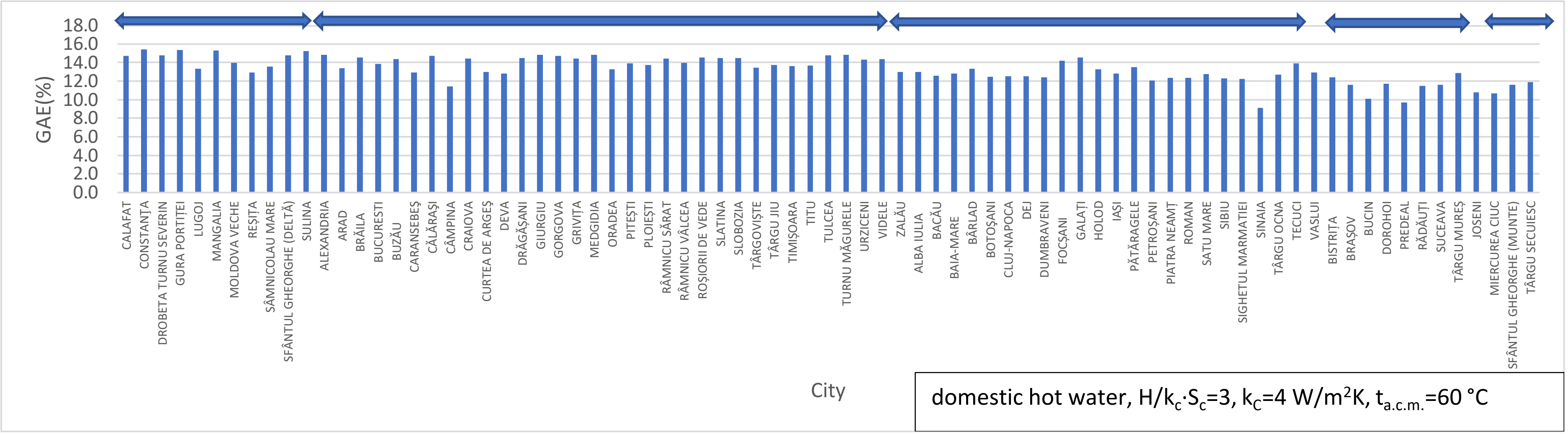

Fig. 75- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$, $k_C=4$ W/m²K, $t_{a.c.m.}=60$ °C

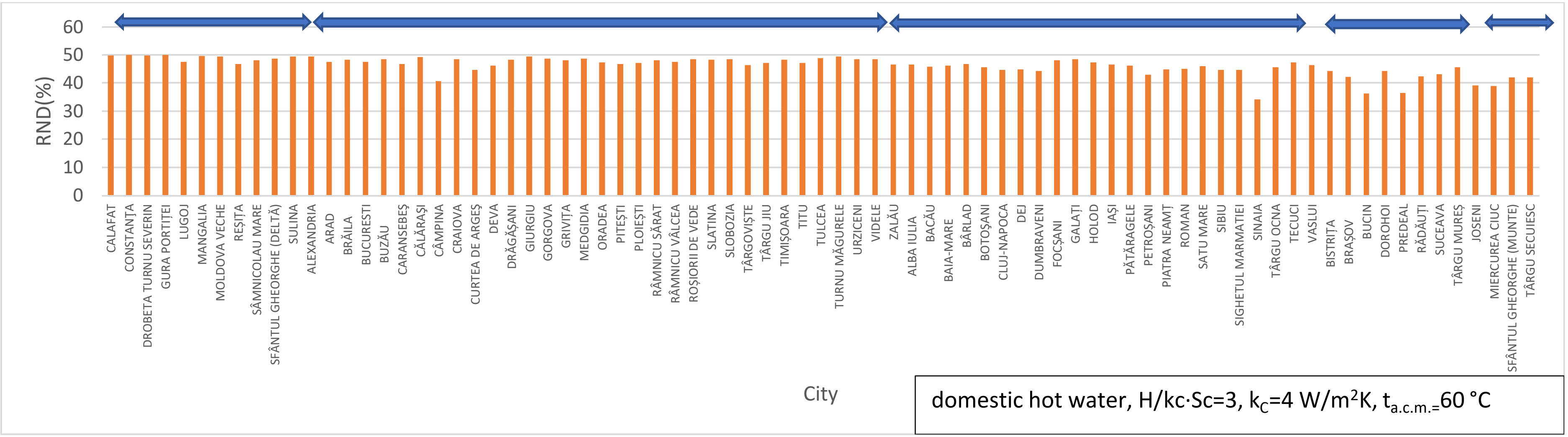

Fig. 76- Efficiency calculated for domestic hot water, H/kc·Sc=3, $k_C=4$ W/m²K, $t_{a.c.m.=}60$ °C

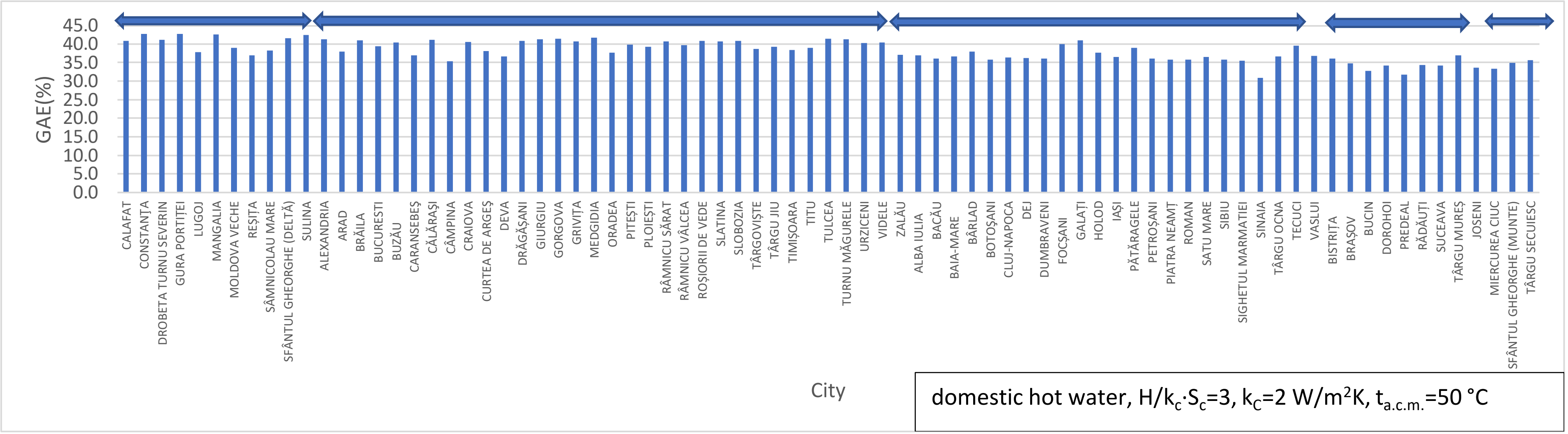

Fig. 77- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=50$ °C

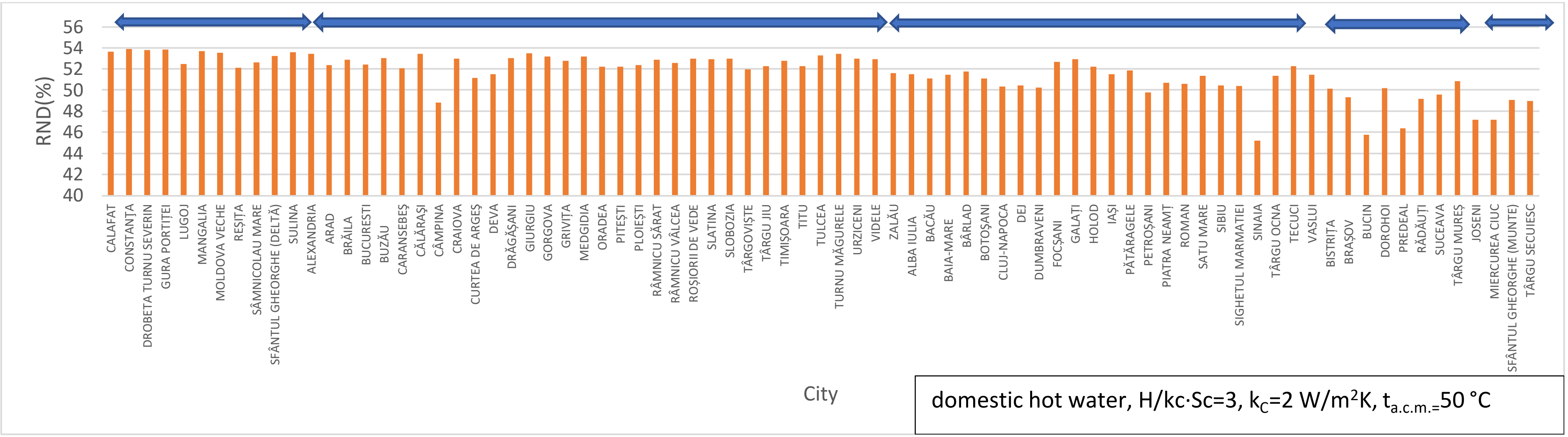

Fig. 78- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=3$, $k_C=2$ W/m^{2}K, $t_{a.c.m.=}50$ °C

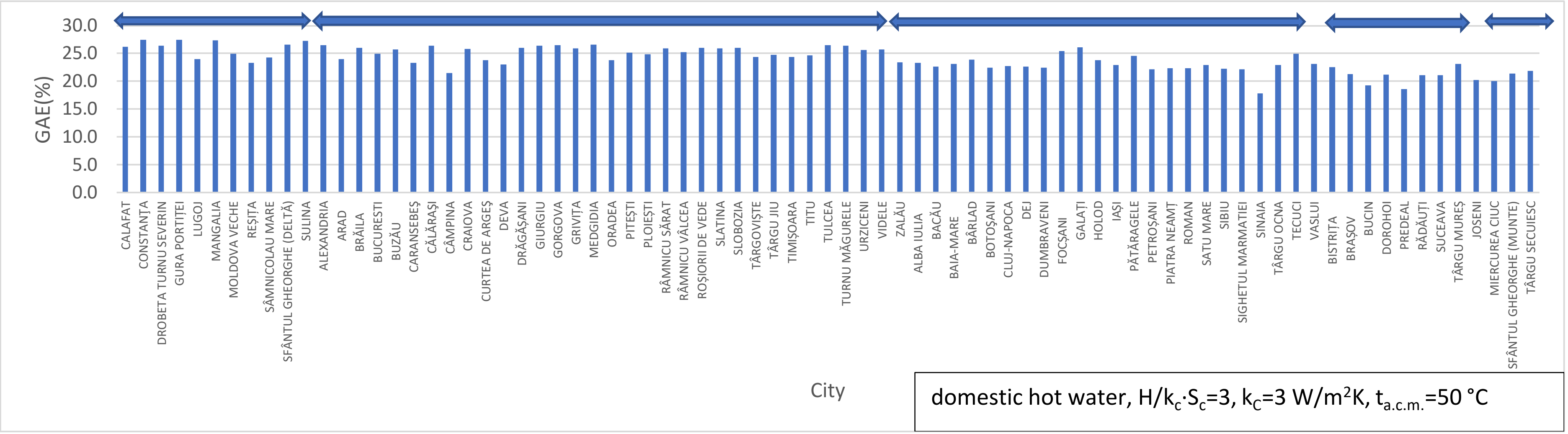

Fig. 79- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=50$ °C

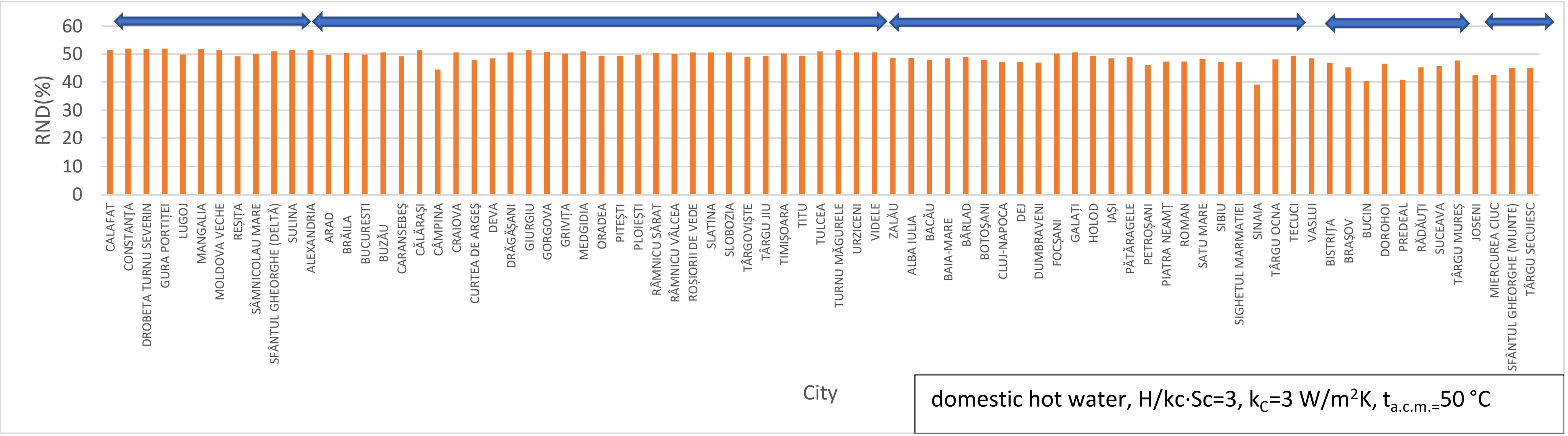

Fig. 80- Efficiency calculated for domestic hot water, H/kc·Sc=3, $k_C=3$ W/m^{2}K, $t_{a.c.m.=}50$ °C

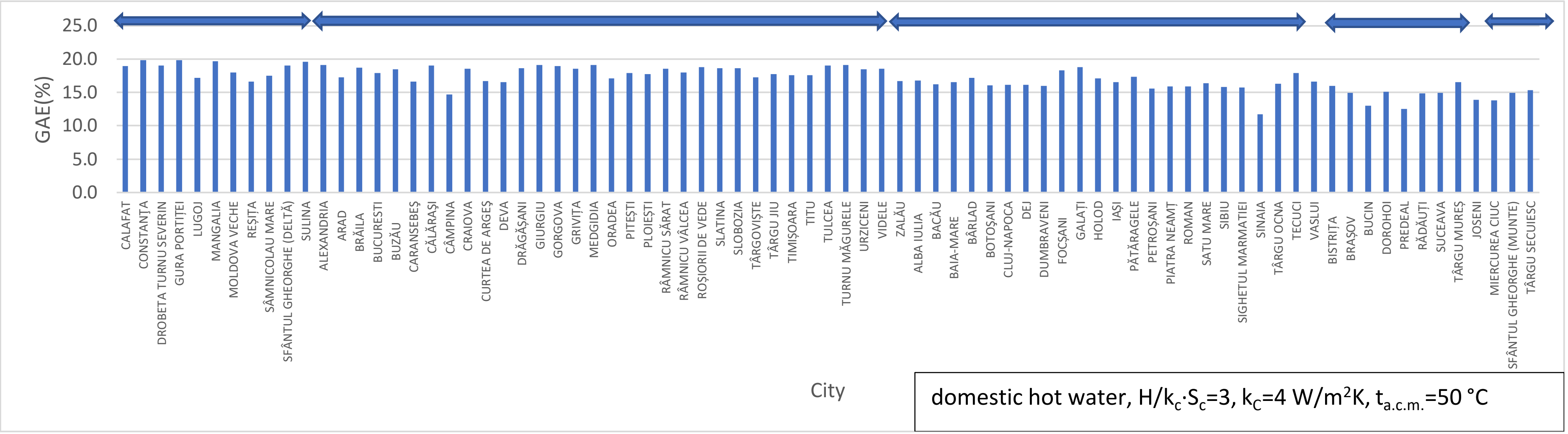

Fig. 81- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{a.c.m.}=50$ °C

Fig. 82- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=3$, $k_C=4$ W/m^{2}K, $t_{a.c.m.=}50$ °C

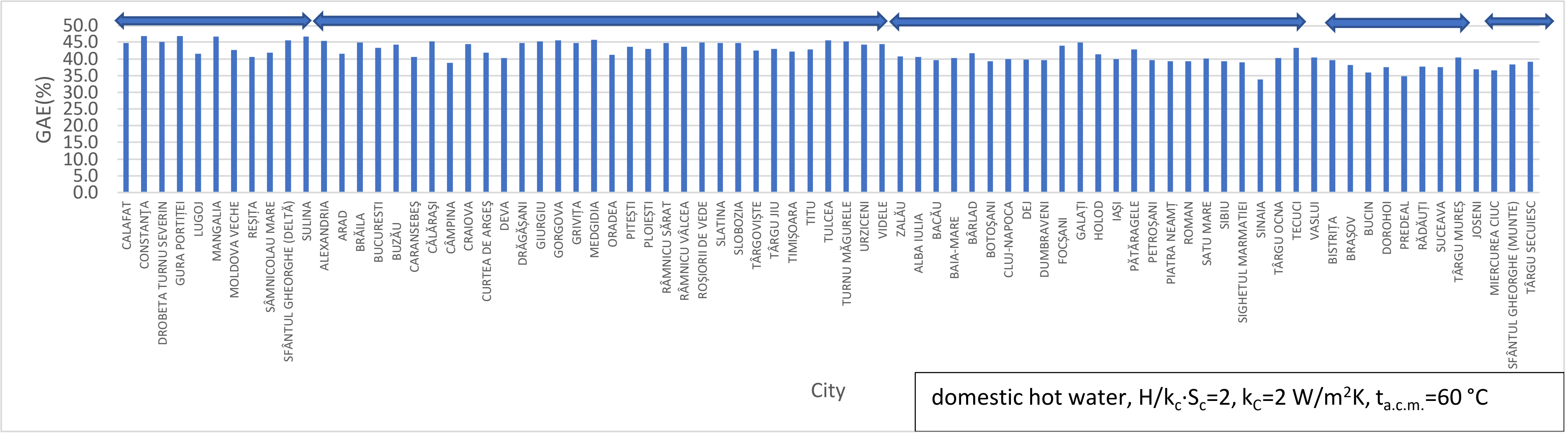

Fig. 83- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=2$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=60$ °C

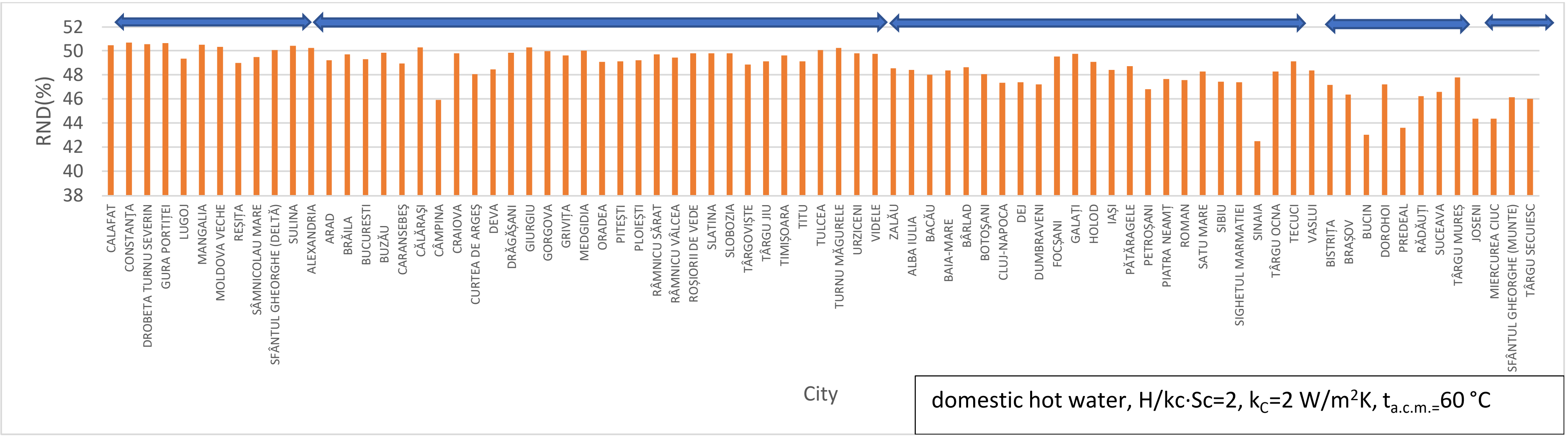

Fig. 84- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=2$, $k_C=2$ W/m^{2}K, $t_{a.c.m.=}60$ °C

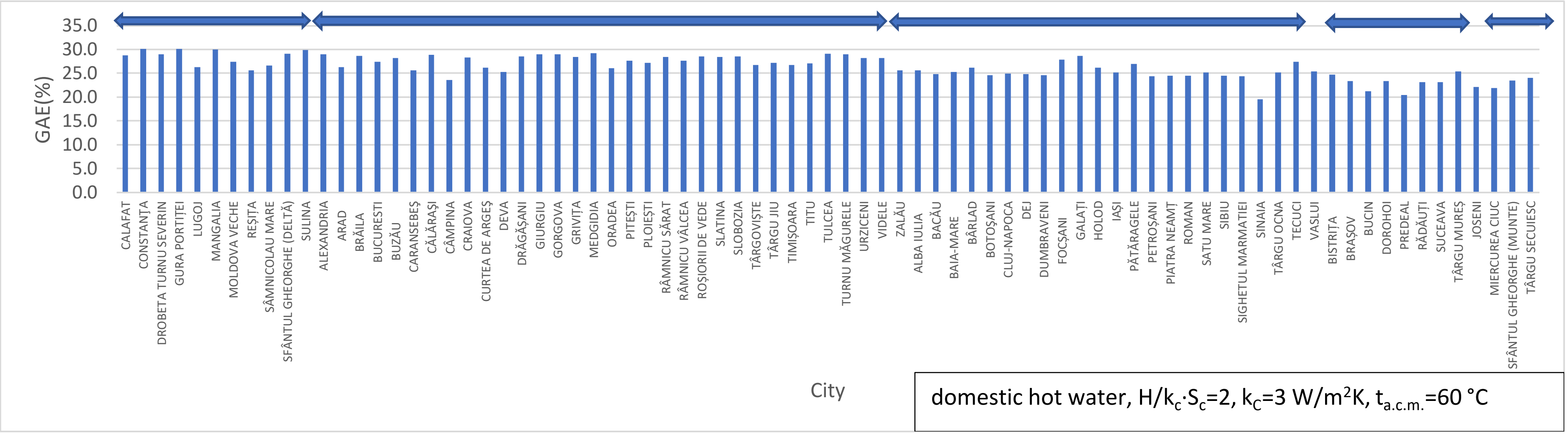

Fig. 85- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=2$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=60$ °C

Fig. 86- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=2$, $k_C=3$ W/m^{2}K, $t_{a.c.m.=}60$ °C

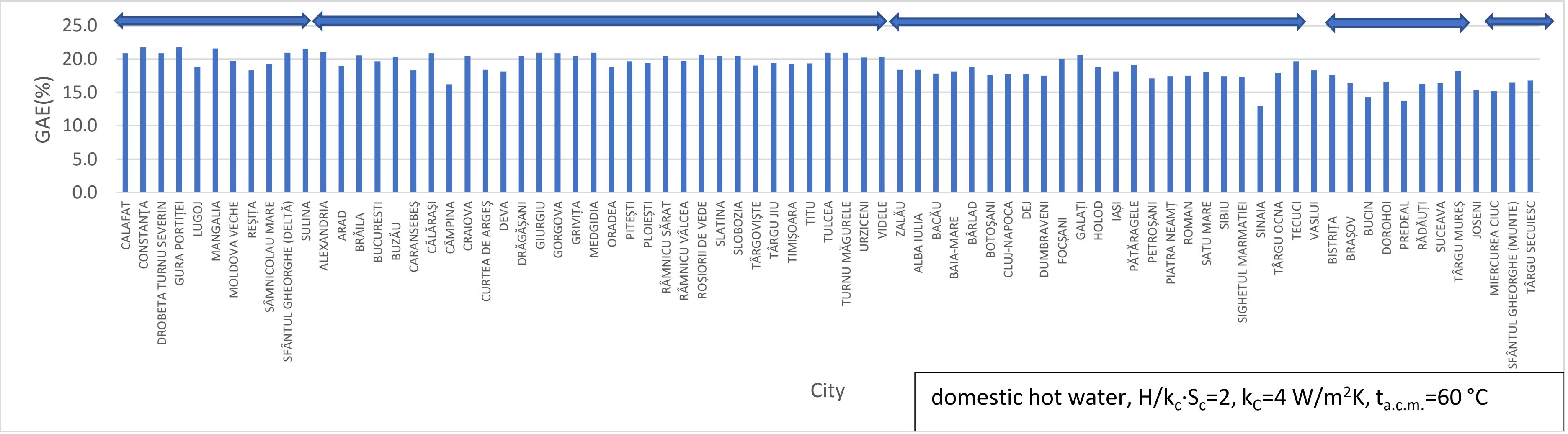

Fig. 87- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=2$, $k_C=4$ W/m^{2}K, $t_{a.c.m.}=60$ °C

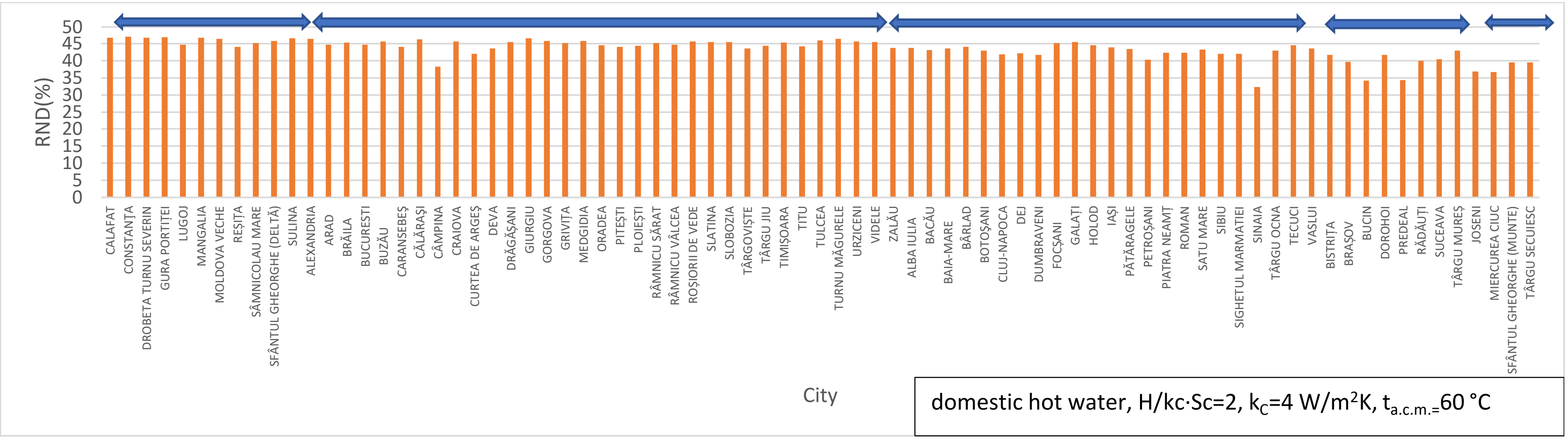

Fig. 88- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=2$, $k_C=4$ W/m^{2}K, $t_{a.c.m.=}60$ °C

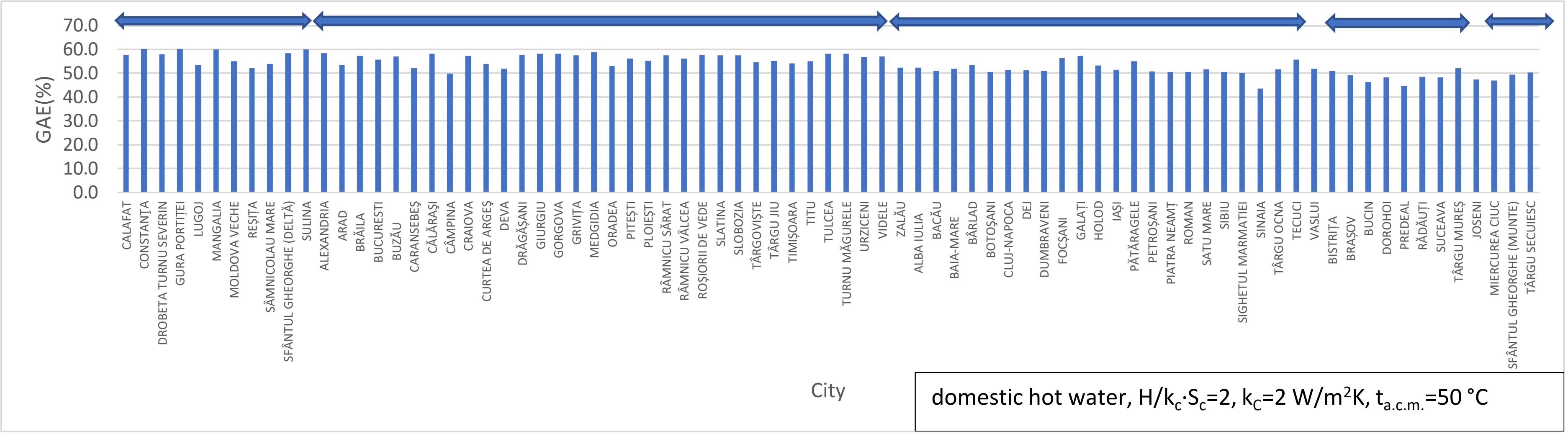

Fig. 89- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=2$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=50$ °C

Fig. 90- Efficiency calculated for domestic hot water, H/kc·Sc=2, $k_C=2$ W/m^{2}K, $t_{a.c.m.=}50$ °C

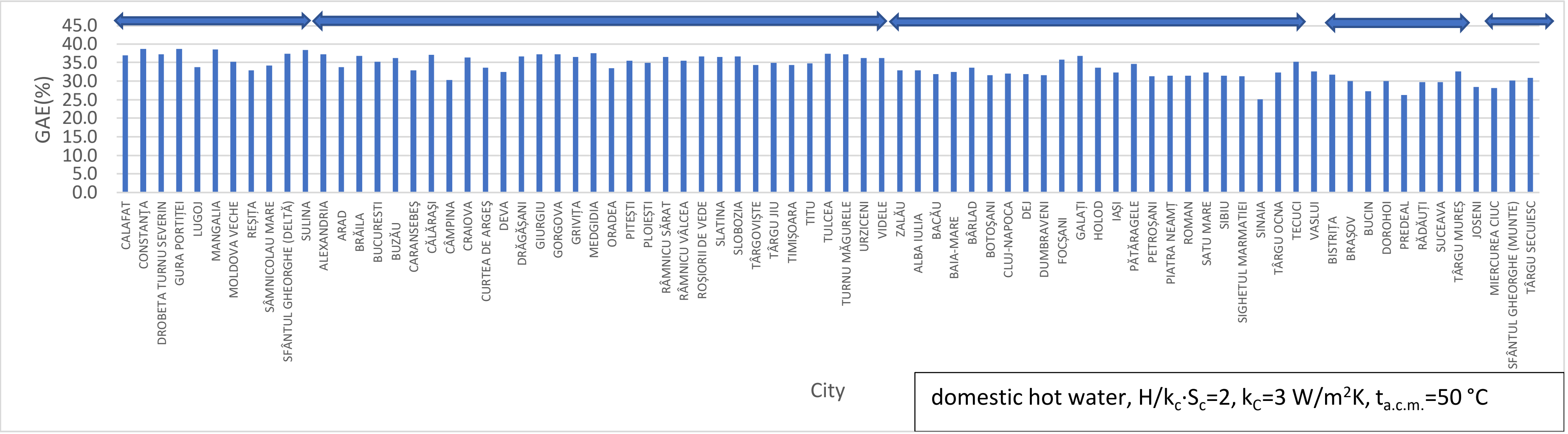

Fig. 91- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=2$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=50$ °C

Fig. 92- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=2$, $k_C=3$ W/m^{2}K, $t_{a.c.m.=}50$ °C

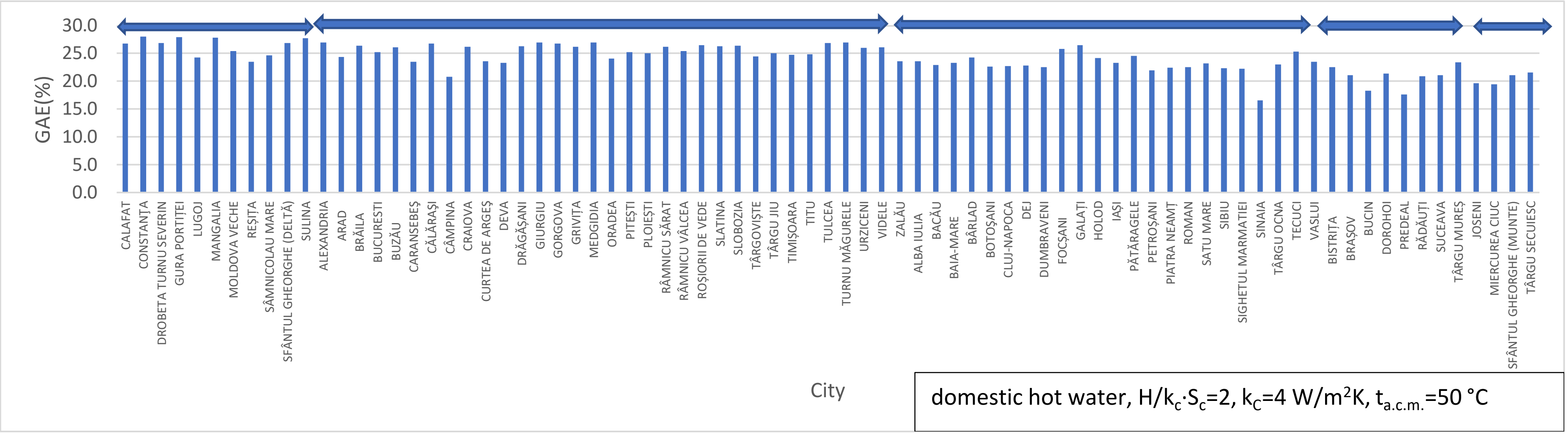

Fig. 93- Degree of coverage calculated for domestic hot water preparation, $H/k_c{\cdot}S_c=2$, $k_C=4$ W/m^{2}K, $t_{a.c.m.}=50$ °C

Fig. 94- Efficiency calculated for domestic hot water, $H/kc{\cdot}Sc=2$, $k_C=4$ W/m^{2}K, $t_{a.c.m.=}50$ °C

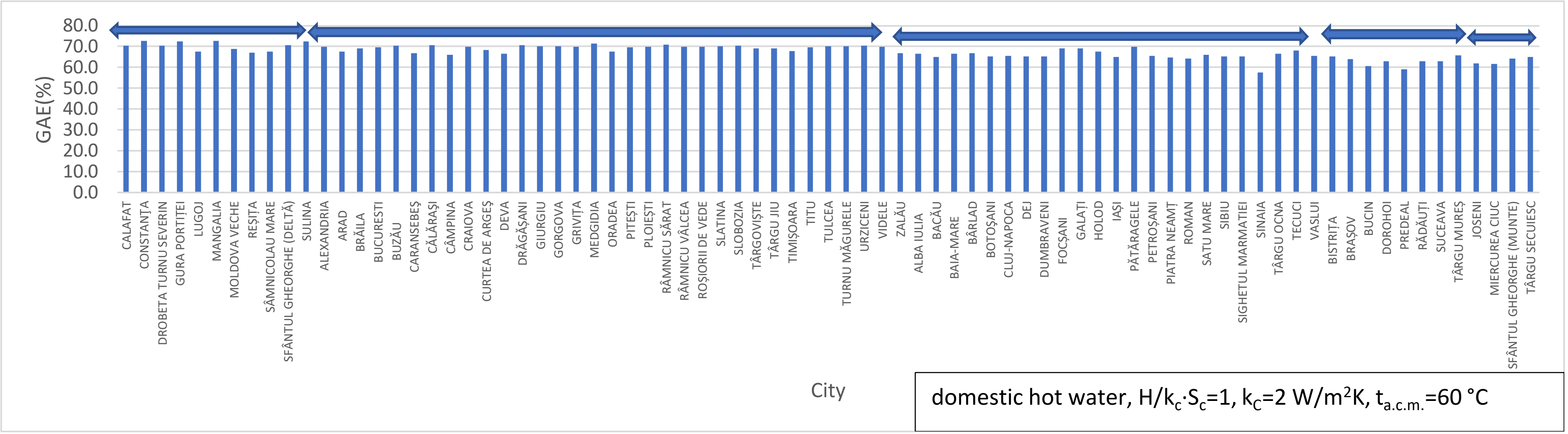

Fig. 95- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=1$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=60$ °C

Fig. 96- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=1$, $k_C=2$ W/m^{2}K, $t_{a.c.m.=}60$ °C

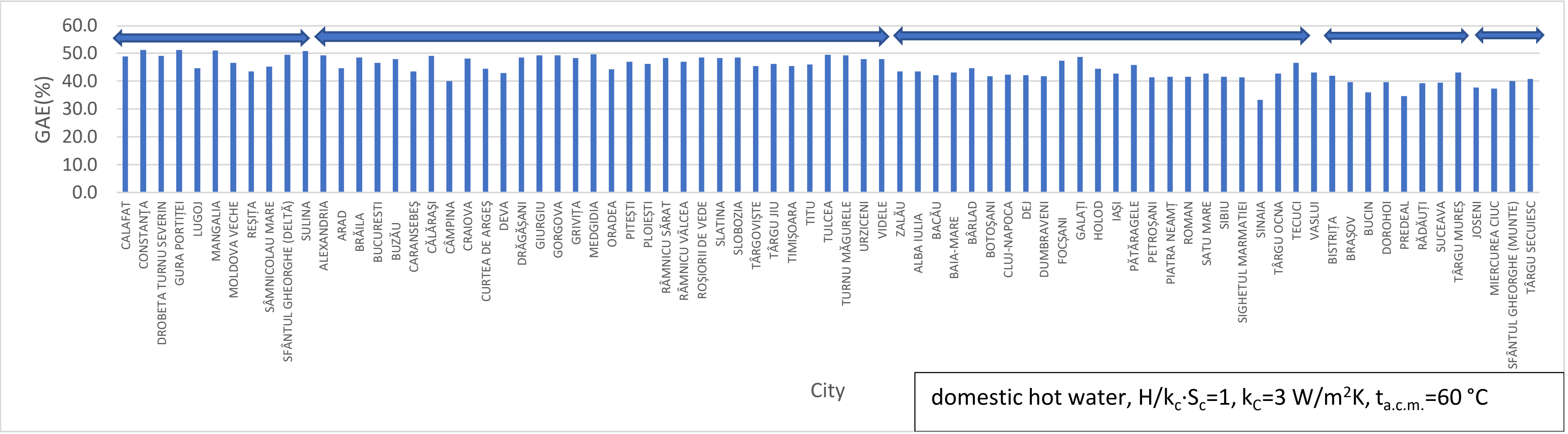

Fig. 97- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=1$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=60$ °C

Fig. 98- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=1$, $k_C=3$ W/m^{2}K, $t_{a.c.m.=}60$ °C

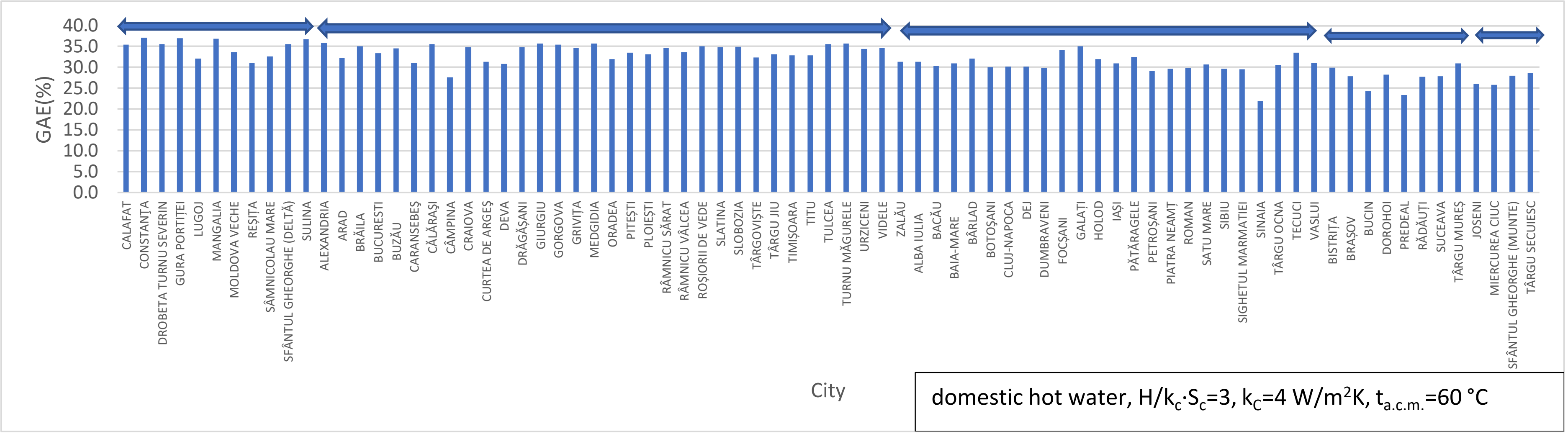

Fig. 99- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{a.c.m.}=60$ °C

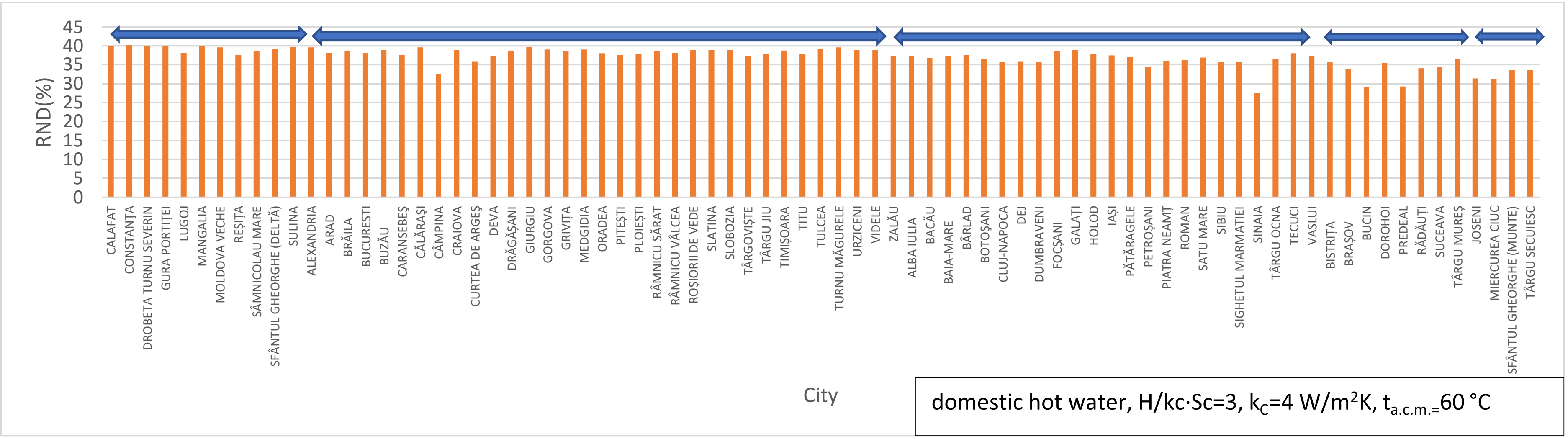

Fig. 100- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=3$, $k_C=4$ W/m^{2}K, $t_{a.c.m.=}60$ °C

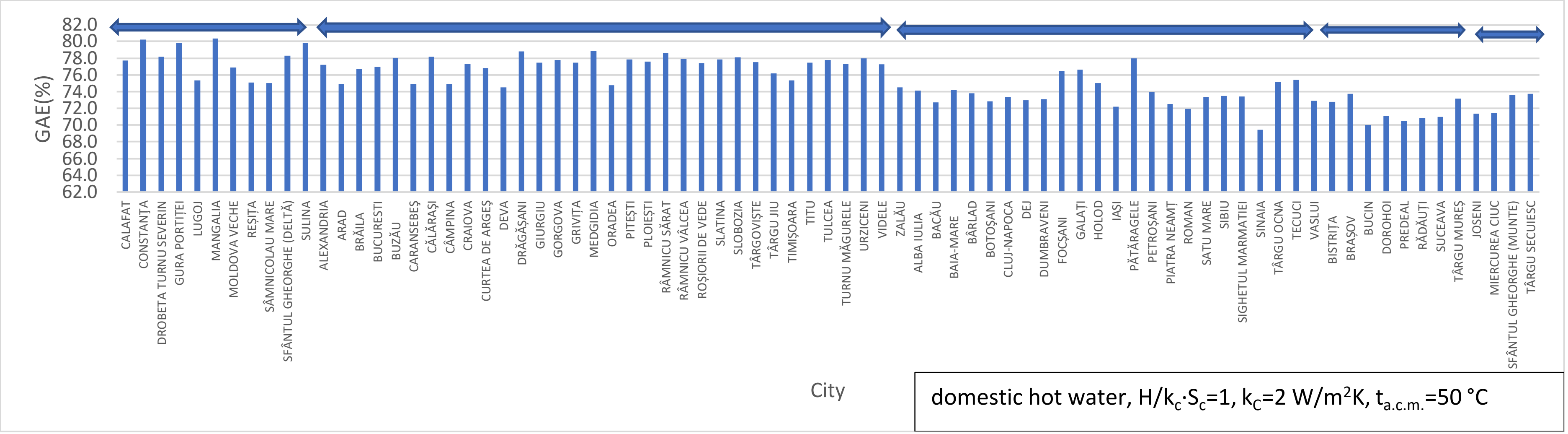

Fig. 101- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=1$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=50$ °C

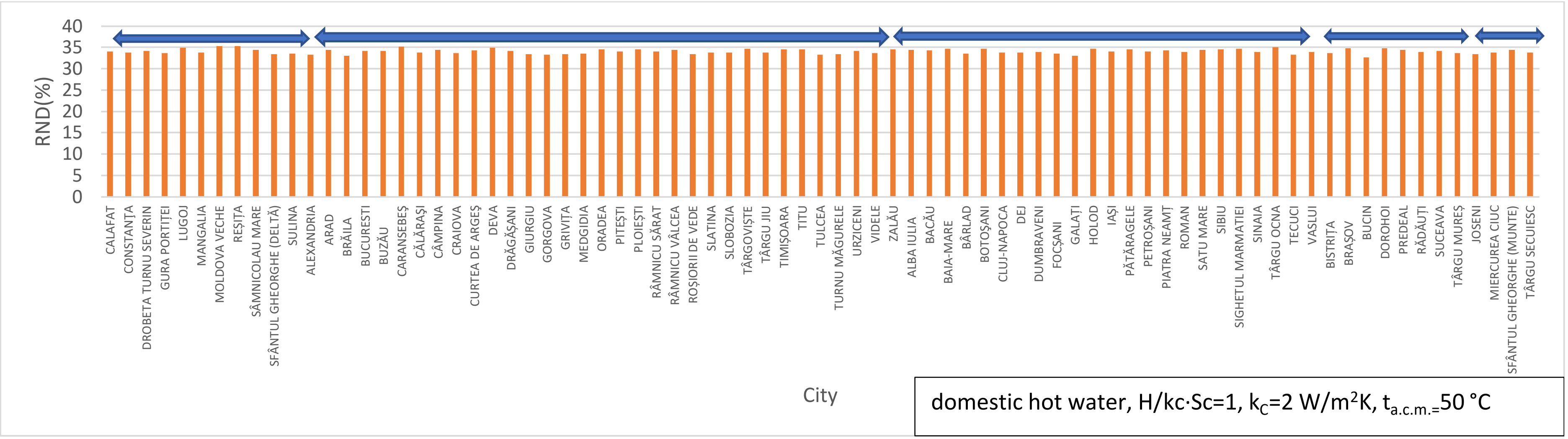

Fig. 102- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=1$, $k_C=2$ W/m^{2}K, $t_{a.c.m.=}50$ °C

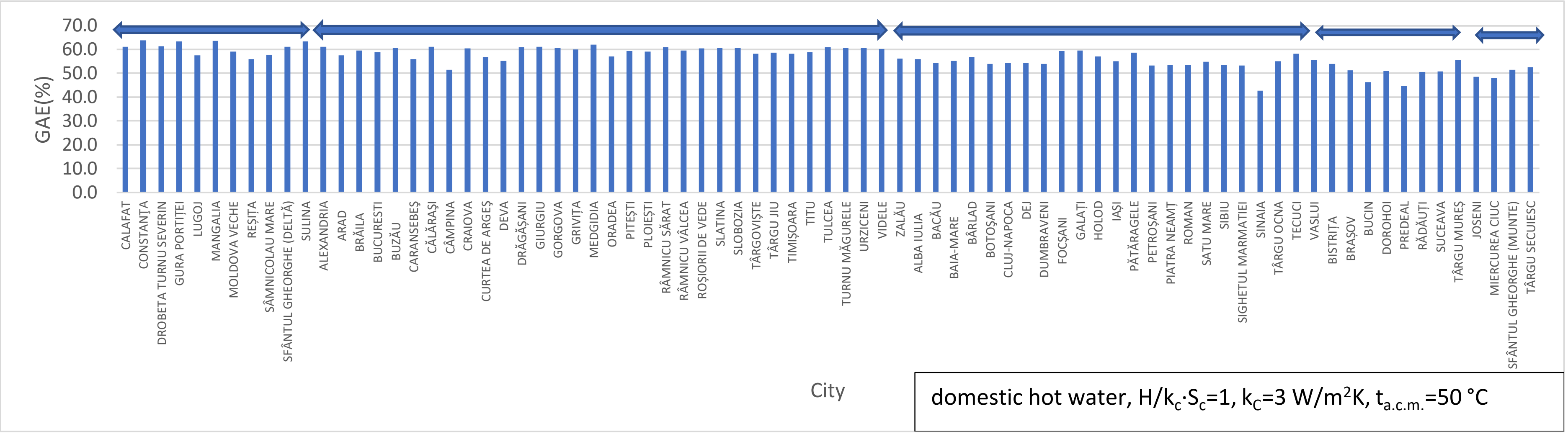

Fig. 103- Degree of coverage calculated for domestic hot water preparation, $H/k_c{\cdot}S_c=1$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=50$ °C

Fig. 104- Efficiency calculated for domestic hot water, $H/kc{\cdot}Sc=1$, $k_C=3$ W/m^{2}K, $t_{a.c.m.=}50$ °C

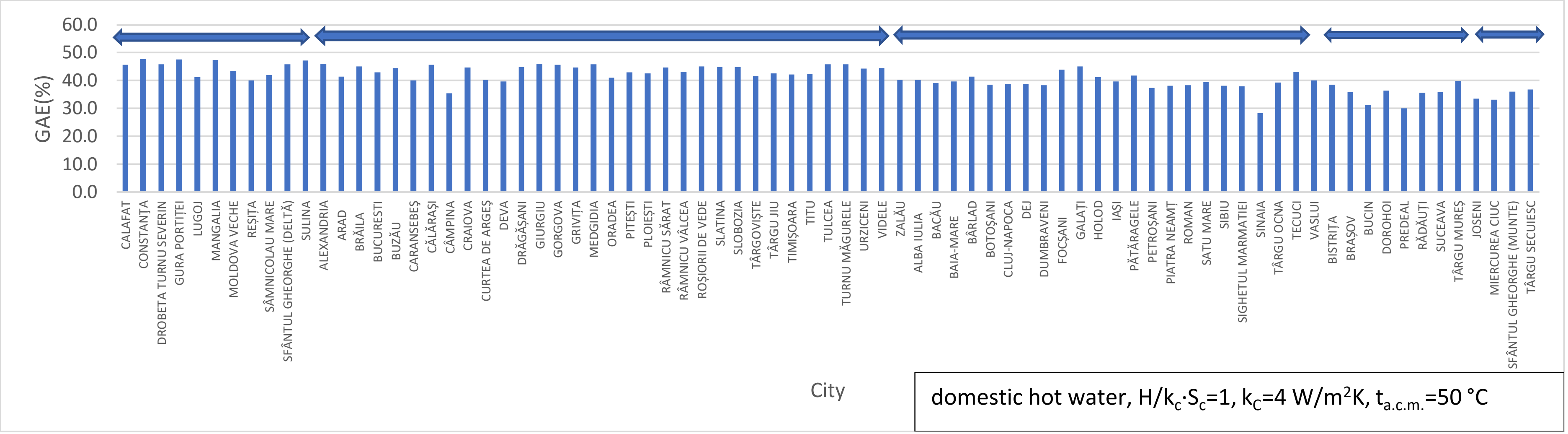

Fig. 105- Degree of coverage calculated for domestic hot water preparation, $H/k_c \cdot S_c=1$, $k_C=4$ W/m^{2}K, $t_{a.c.m.}=50$ °C

Fig. 106- Efficiency calculated for domestic hot water, $H/kc \cdot Sc=1$, $k_C=4$ W/m^{2}K, $t_{a.c.m.=}50$ °

3.4 Energy performance of systems using renewable sources using an innovative calculation method

In the next study, it was desired to achieve a qualitative improvement of the current calculation methodology of the improved MC001 version of 2018 (proposal) for the preparation of heating medium. The following steps were proposed:

a. A heat calculation requirement for heating is established and divided by the thermal difference, and the H-result of the house:

$$H = \varphi_0 / (t_{h0}-t_e); \quad (36)$$

b. Determine the type of solar collectors by setting the value of k_c;

c. Set the value of the ratio $H / (k_c \cdot S_c)$;

d. The value of the scraping surface S_c is accordingly established;

h. Set the city of calculation with the values;

i. Monthly heating demand for heating in each of the heating season months (in kWh); these months are defined by (temperature <12 ^oC):

$$Q_k = H \cdot (t_{i0} - t_{eml}) \cdot Nz_k \cdot 0{,}024 \quad (37)$$

j. Set the incident solar energy in each of the heating season months (in kWh):

$$Esi_k = f_{cap} \cdot Io_k \cdot Sc \cdot Nz_k \cdot 0{,}024 \quad (38)$$

k. Set the duration (in hours) of daily sunshine hours for each month of the heating season (approximately 5 hours / day);

l. Determine the average incidence of incident solar radiation for each month of the heating season;

m. Establish the average monthly solar energy capture yield using the relationship (15) of the Mc001 Solar System Methodology proposal;

n. Determine the solar energy captured by applying the capture efficiency to the incident monthly solar energy on the capture surface:

$$Esc_k = \eta_{BC} \cdot Esi_k \quad (39)$$

o. Set monthly coverage by reporting monthly solar energy to the consumer's energy needs:

$$Gae_k = \frac{Esc_k}{Q_k} \quad (40)$$

p. Determine the coverage over the entire cold season as a weighted average coverage of monthly coverage rates with monthly energy requirements or formula:

$$Gae_{an} = \frac{\sum_k Esc_k}{\sum_k Q_k} \quad (41)$$

To calculate the incident solar radiation for each month of the heating season, we have estimated the sunshine times as follows:

a. The maximum day length of each N_{ozm} heating month was determined;

b. The hours required for the sun to reach the surface of the solar panel, N_{osc};

c. Approximate hours of covered sky, N_{oca};

d. The number of hours of daily sunshine has been calculated:

$$N_{oz} = N_{ozm} - N_{osc} - N_{oca} \quad (42)$$

e. The result was compared with the minimum number of hours of sunshine according to NP 057-02.

Thus, the following estimates were made:

Table 2

LUNA	IAN	FEB	MAR	APR	MAI	IUN	IULIE	AUG	SEPT	OCT	NOV	DEC
Nozm	10	11	12	13	14	15	14	13	12	11	10	9
Nosc	3	3	3	2	2	2	2	2	3	3	3	3
Noca	2	2	2	2	1	1	1	2	2	2	2	2
Noz	5	6	8	9	10	12	10	9	8	6	5	3

These intensities calculated using Table 2 and Formula (43) can estimate the hourly values for solar plant efficiency. Calculating these solar intensities and introducing them into the bp calculation formula (relationship 14) determines corrected values of the degree of coverage and solar efficiency.

$$I = f_{cap} \cdot I_0 \cdot 24 / N_{oz} \quad (43)$$

Introducing the calculation of sunshine hours by a 24 / N_{oz} (f_s) ratio in determination I leads to the actual solar system yield, which estimates the efficiency of the solar plant for actual operating hours. Estimating the coverage and efficiency of the solar system by replacing only the batch of this modified I is improved. Thus, in the improved methodology proposal a fs factor is used to include the sunrise period (relationship 44).

$$\beta_{ref} = \frac{t_{i0-}t_e}{I \bullet fs} \quad (44)$$

The parameter values used in this calculation were as follows:

a. The H / ($k_c \cdot S_c$) ratio = 5;

b. The geometric correction factor of the captured heat flux, F '= 0.9;

c. Global heat transfer coefficient of solar collectors, k_C = 3 W / m^{2}K;

d. Shock absorber coefficient of absorption, α = 0.9;

e. The coefficient of transparency of the collector glazing element, τ = 0.85;

f. Angle of inclination from the horizontal plane of the collectors, φ_i = 45 °;

g. Deviation angle of the orientation of the capture surface to the South, $\varphi_a = 0$ ° (South);

h. Heat exchanger surface in the solar loop, $S_S = 0.1 \cdot S_C$;

i. Storage tank volume, $V_a = V / S_C = 50$ l / m^2;

j. The global heat transfer coefficient of the heat exchanger in the solar loop, $k_S =$ 600 W / m^{2}K;

k. The flow rate of the heat transfer medium into the solar loop, $G_C = 50$ l / m^{2}h;

l. Surface of the consumer central heating system, S_{INC}-corresponding to 80 apartments;

m. Nominal heat sink temperatures at plant sizing, $t_{T0} = 50$ ° C $t_{R0} = 30$ ° C;

n. Solar radiation intensities, monthly averages, for a horizontal capture area, I_O, for all months of the year, according to the Mc001 methodology of 2006;

o Average monthly average temperatures for all months of the year, according to SR 4839/2014;

Representative of the same residential building with 80 apartments, which has a heat requirement for Constanta city of 512 MWh, has been chosen as representative. It is the same building with a $H_{inc} = 16000$ W / K, maintained constantly for all cities of the study described in 3.1.

If b_{ref} is calculated according to the methodology in force, using the new simplified calculation method, the same values as those obtained in Chapter 3.2 are obtained.

Using the values corrected for I that are involved in the calculation of b_{ref} (according to Table 2 and Relationship 43), we determine coverage rates and monthly returns for the city of Constanta.

The values of the captured energy, the energy consumed by the classical source and the solar incident energy for the city of Constanta were also calculated.

In addition, the heating energy yield for heating (serving the described consumer) was also calculated for the heating hours estimated in Table 2 (Figure 109). In calculating this yield, it was replaced with that calculated by the formula 43 and the operating time of the plant (number of hours per month) was reduced to the actual number of hours of operation estimated in Table 2. This effective production yield during sunlight hours does not depend on the consumer's needs.

To extend the study, coverage rates and annual yields were obtained by introducing a variation of $k_c = 2 \div 4$ W / m^{2}K of the ratio $H / (k_c \cdot S_c) = 7$, 5 and 3 and the setting temperatures $t_{T0} = 50$ ° C, $t_{R0} = 30$ ° C and $t_{T0} = 70$ ° C, $t_{R0} = 50$ ° C, for each climatic zone, represented by the following cities: Constanta (zone 1), Bucharest (zone 2) area 3), Predeal (area 4), Targul Secuiesc (zone 5).

The difference between this calculation and the calculation in Chapter 3.2.2 would have been invalid if there had been no change in the b_{ref} calculation (formula 44), because the same H (building transmittance) was maintained constant. Values obtained by using an approximate I for a certain number of hours of sunshine only in the calculations estimate better the actual operation of these solar installations. The results presented using this improved calculation method are shown in Figures 110-115. A comparison was also made with the values obtained using the previous MC001 proposal in Figures 116-121.

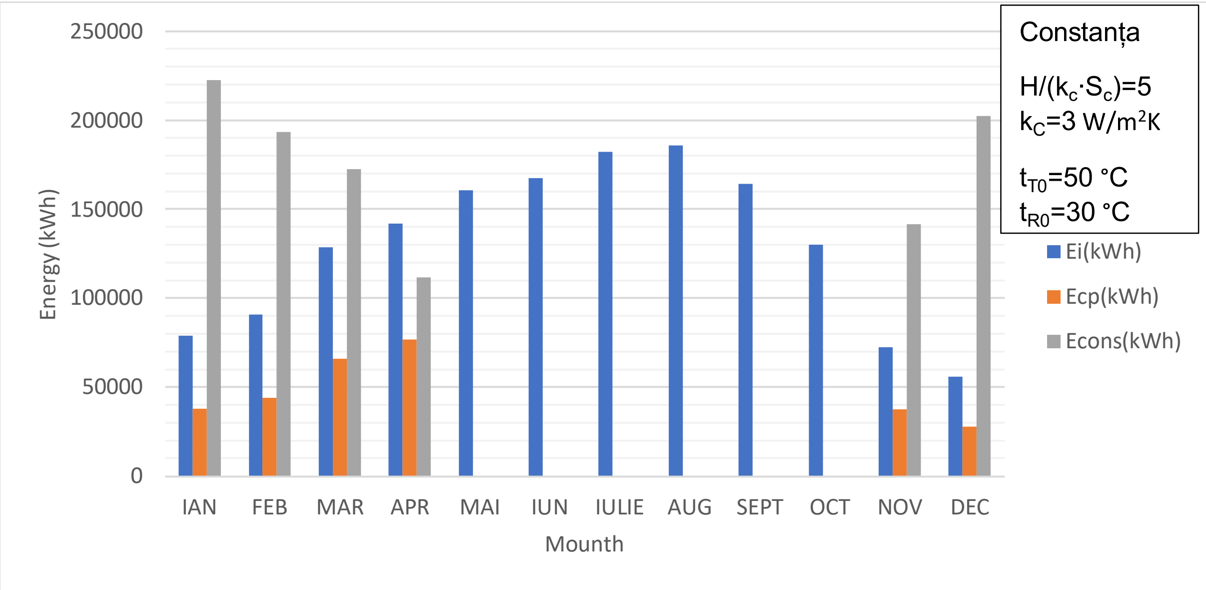

Fig. 107- Monthly heating energy calculated for Constanta using a new calculation methodology

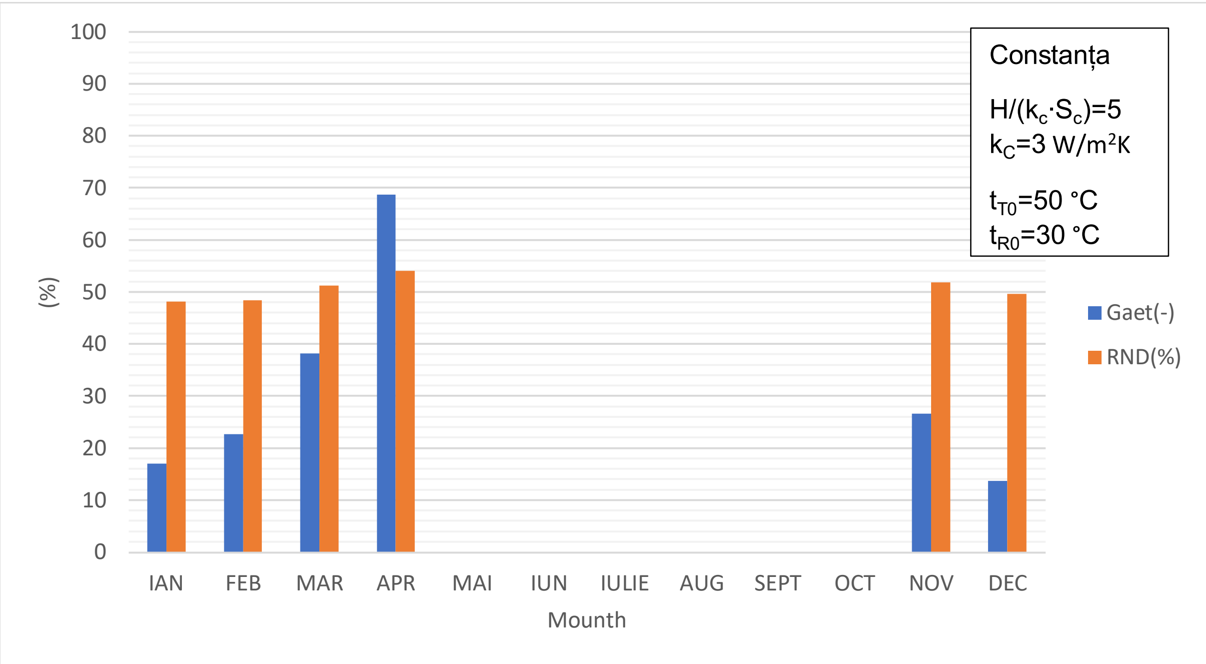

Fig. 108- Heating efficiency and coverage, calculated for the city of Constanta using a new calculation methodology

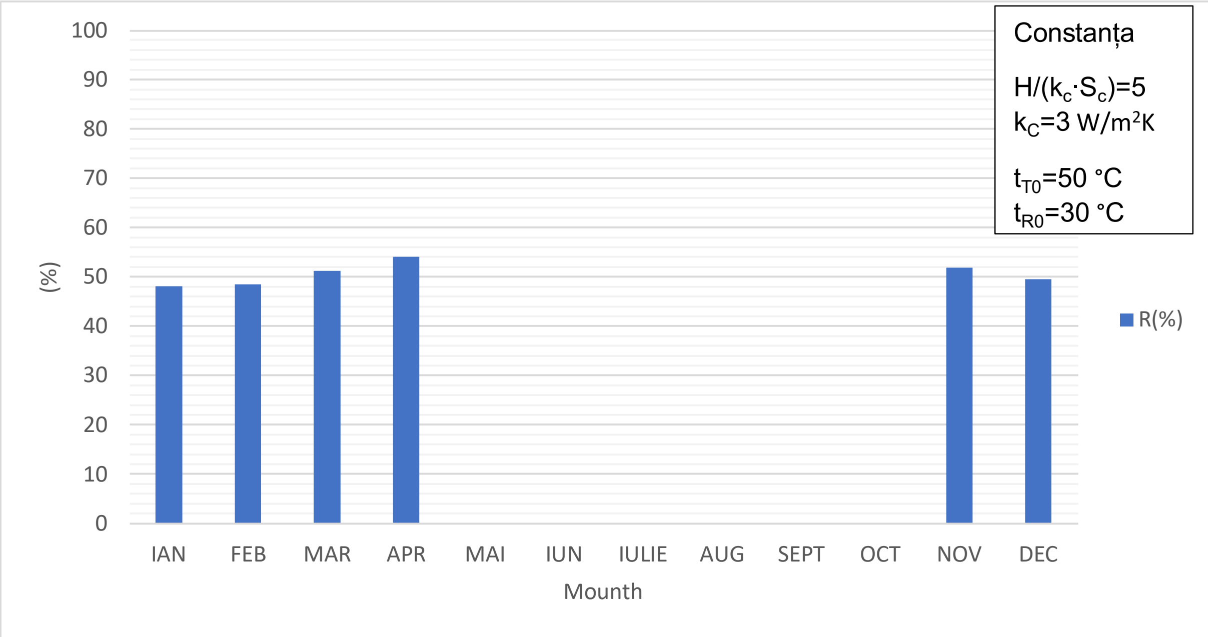

Fig. 109- Heating efficiency, calculated for the city of Constanta using a new calculation methodology

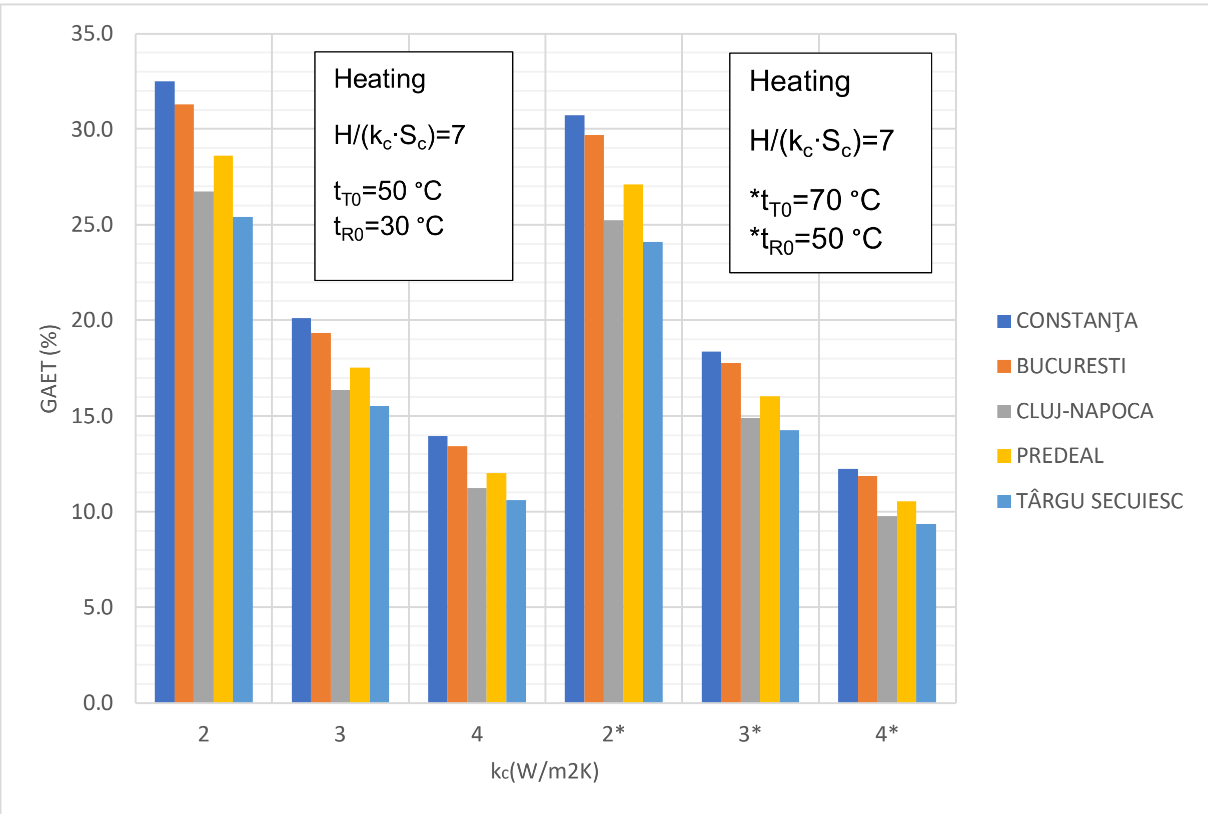

Fig. 110- Degree of coverage calculated for heating, $H/k_c{\cdot}S_c$=7, using a new calculation methodology

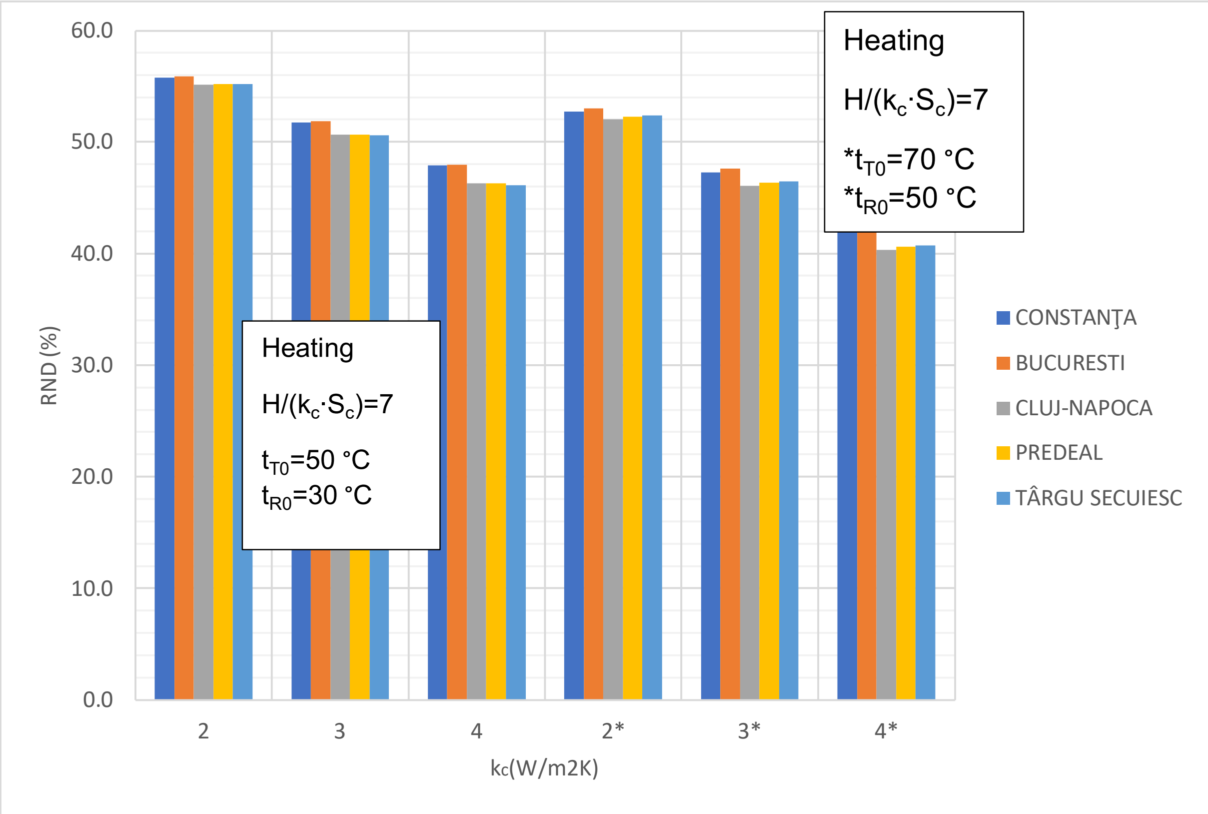

Fig. 111- Efficiency calculated for heating, $H/k_c{\cdot}S_c$=7, using a new calculation methodology

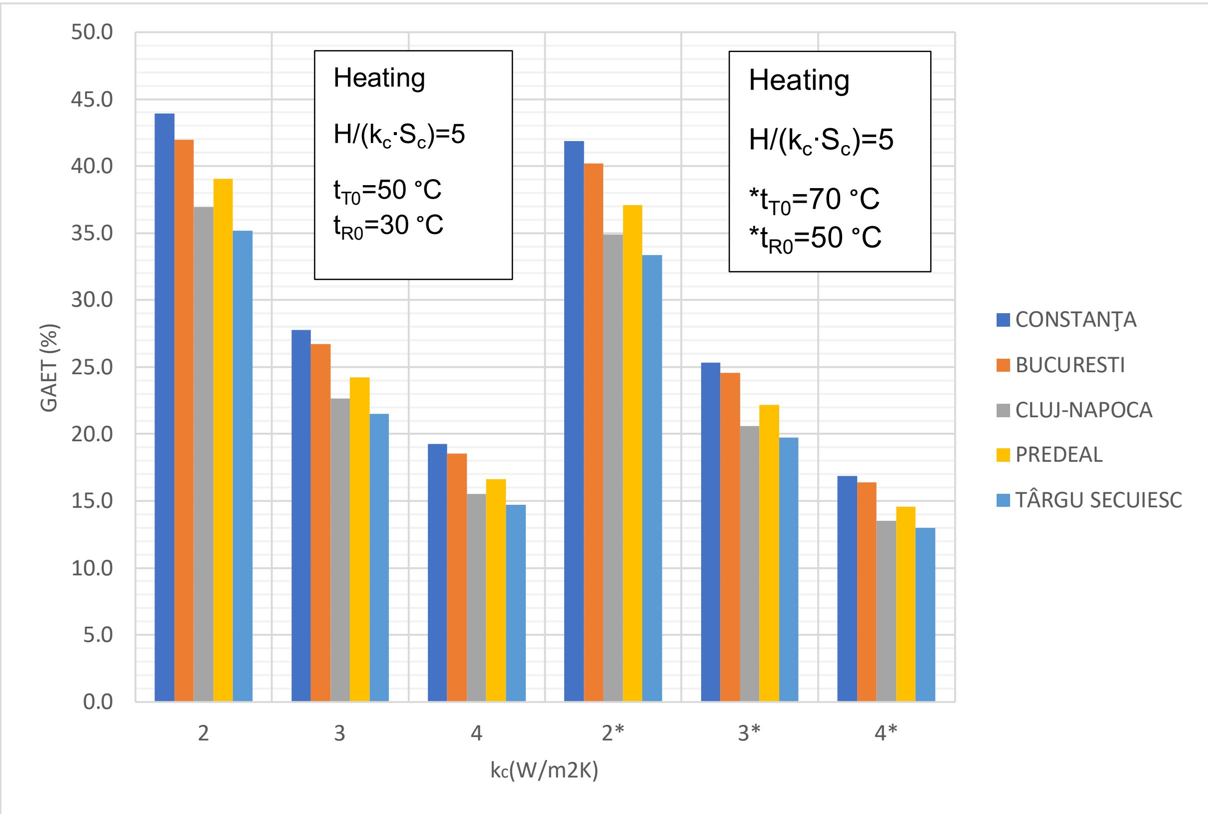

Fig. 112- Degree of coverage calculated for heating, $H/k_c{\cdot}S_c$=5, using a new calculation methodology

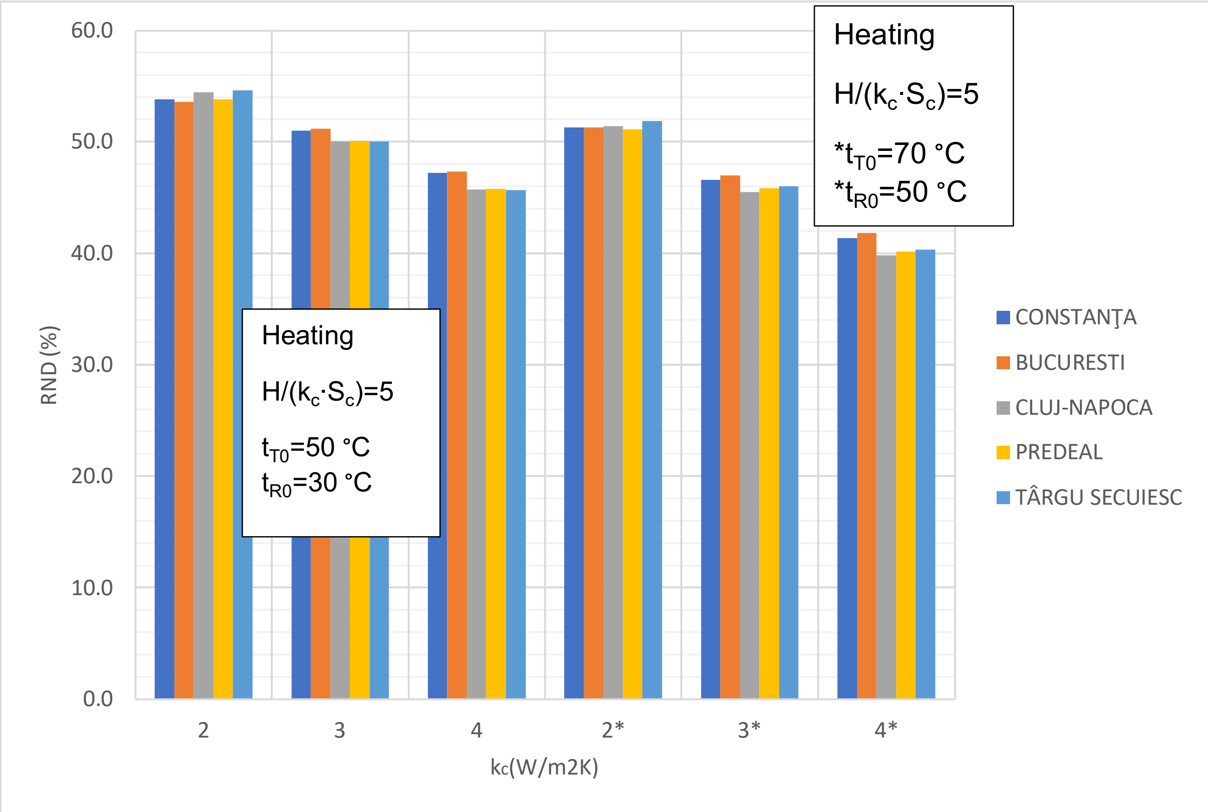

Fig. 113- Efficiency calculated for heating, $H/k_c{\cdot}S_c$=5, using a new calculation methodology

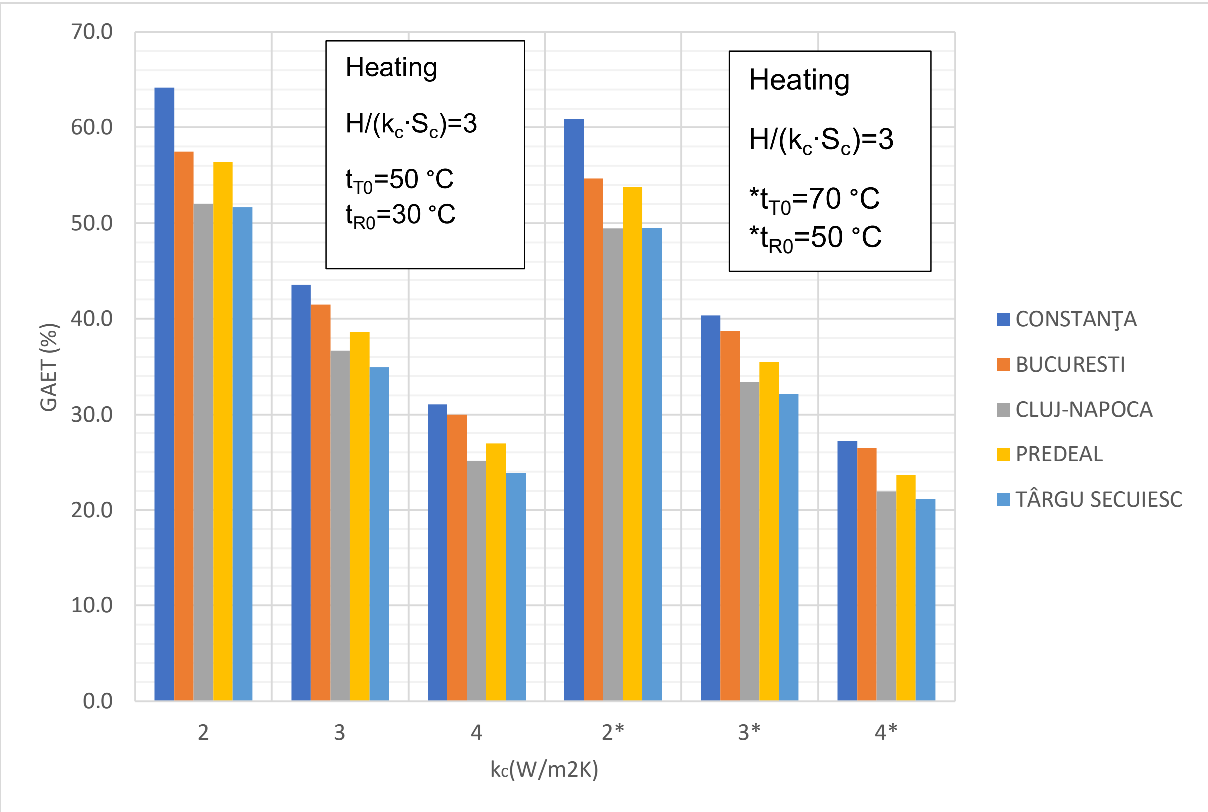

Fig. 114- Degree of coverage calculated for heating, $H/k_c{\cdot}S_c$=3, using a new calculation methodology

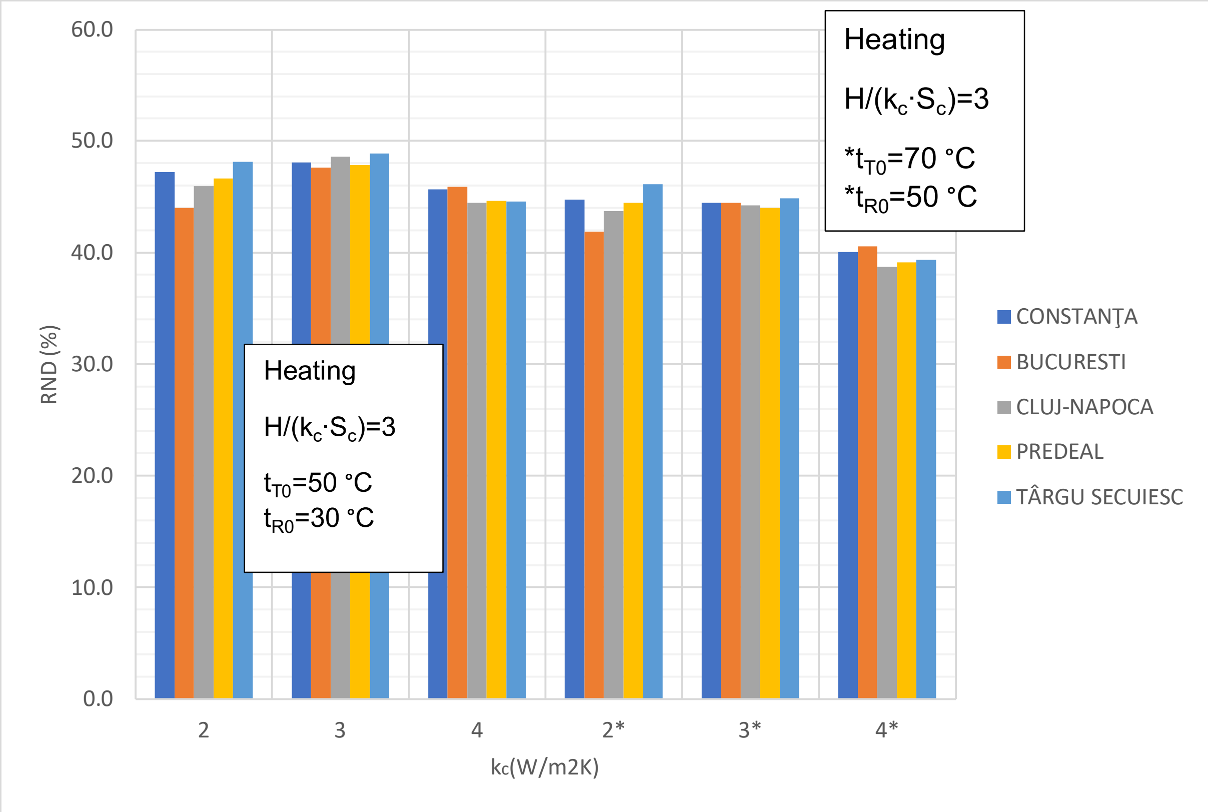

Fig. 115- Efficiency calculated for heating, $H/k_c \cdot S_c=3$, using a new calculation methodology

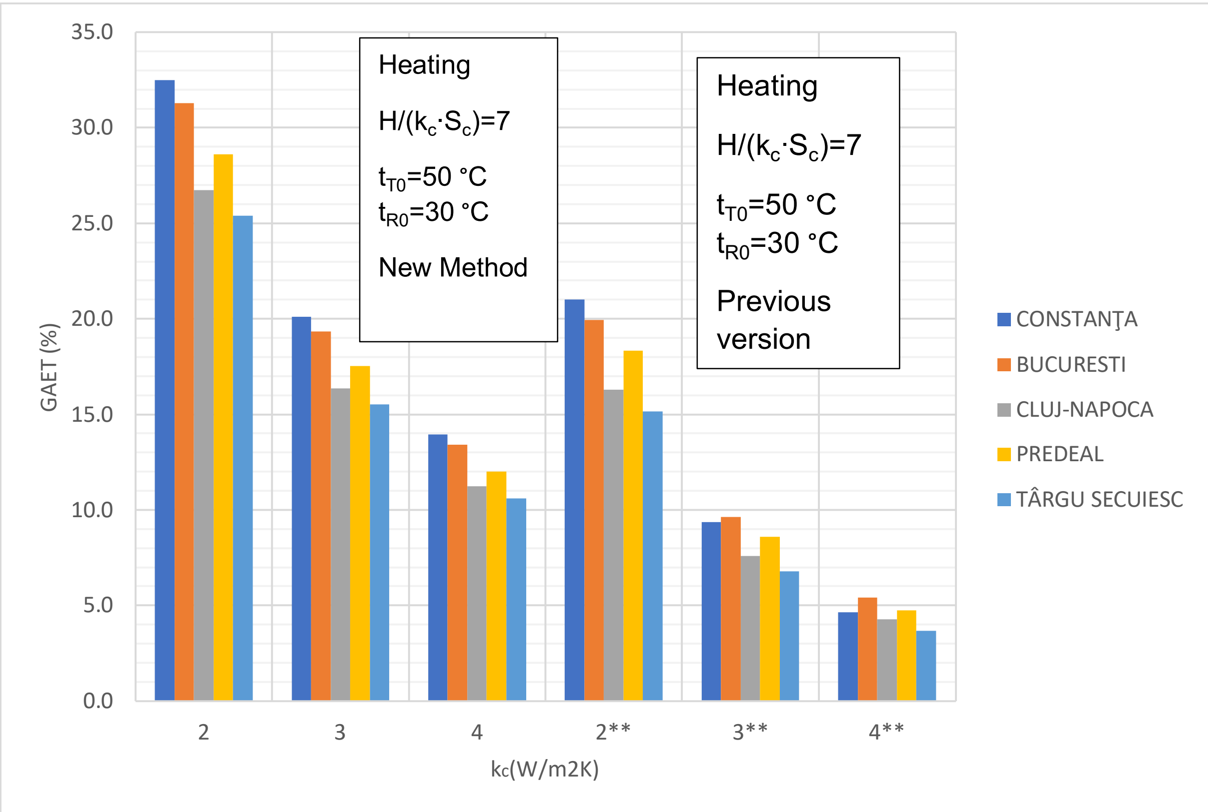

Fig. 116- Comparison of calculated coverage for heating, $H/k_c \cdot S_c=7$, using a new calculation methodology and former MC001 methodology (previous version)

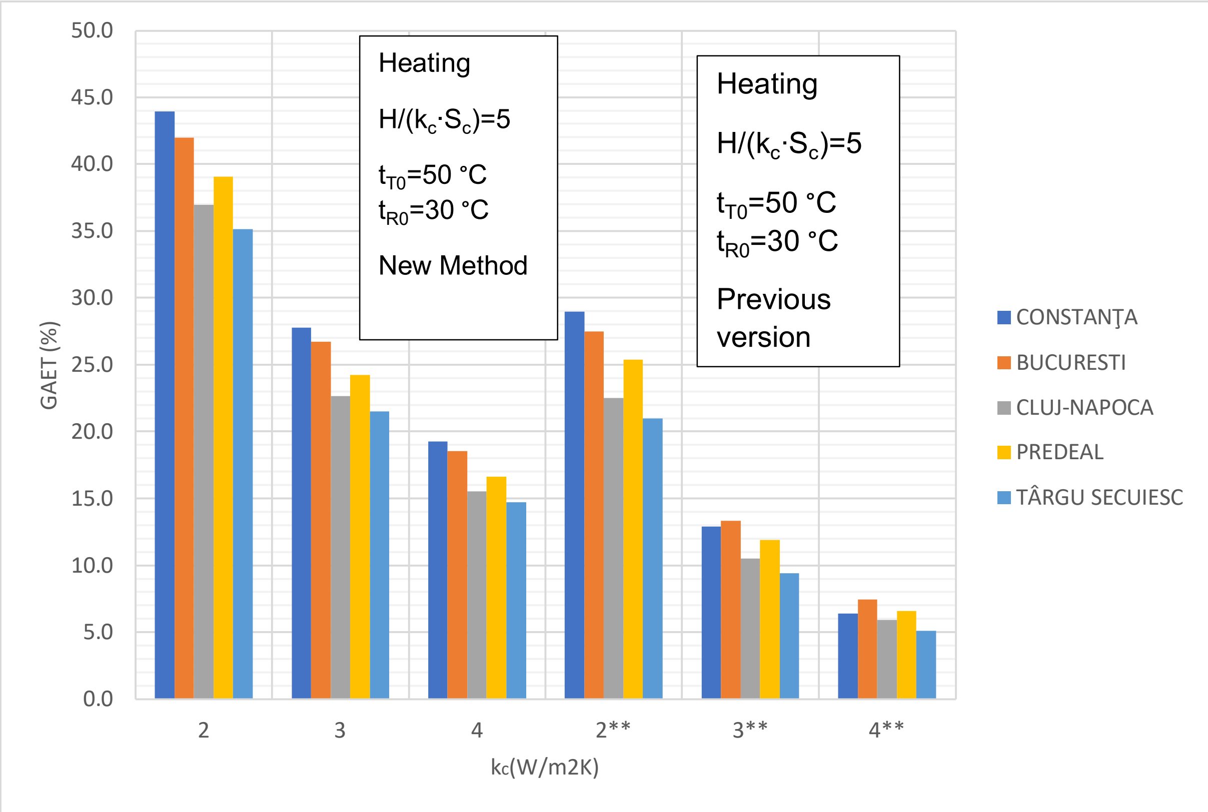

Fig. 117- Comparison of calculated coverage for heating, H/kc·Sc=5, using a new calculation methodology and former MC001 methodology (previous version)

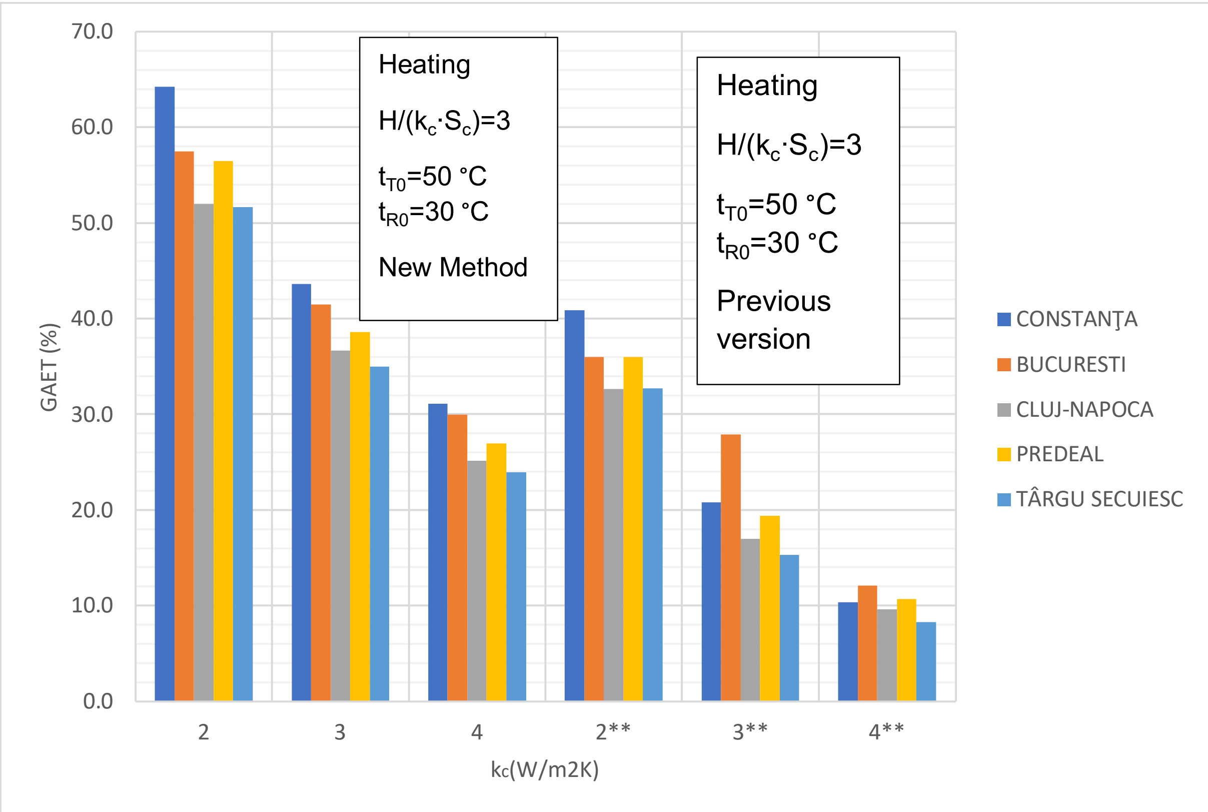

Fig. 118- Comparison of calculated coverage for heating, H/kc·Sc=3, using a new calculation methodology and former MC001 methodology (previous version)

4. ECONOMIC EVALUATION - CASE STUDY

Following the study of paragraph 3, an economic analysis adapted to the investment in solar panels was carried out, based on some of the formulas of the MC001 calculation methodology presented in point 2.2 for the same 80-apartment residential building (described under 3.1) for which the energy analysis was done.

Thus, on the basis of a methodology addressed to all investments in the system leading to energy recovery, a calculation model has been customized exclusively for investments in thermal solar panels.

The economic calculation determined an initial investment cost that depends nonlinear on the capture surface (panels of 2.5 m^2 were chosen). Due to the fact that the price per piece of a solar panel depends on the number of panels purchased, the real situation is simulated by a price reduction based on the capture area shown in Figure 119. Thus, the calculation relation between the unit cost of a panel solar and the number of solar panels purchased (represented by the capture surface). This relationship was introduced in determining the initial cost of investment, starting from the cost per piece when purchasing a single piece of solar panel.

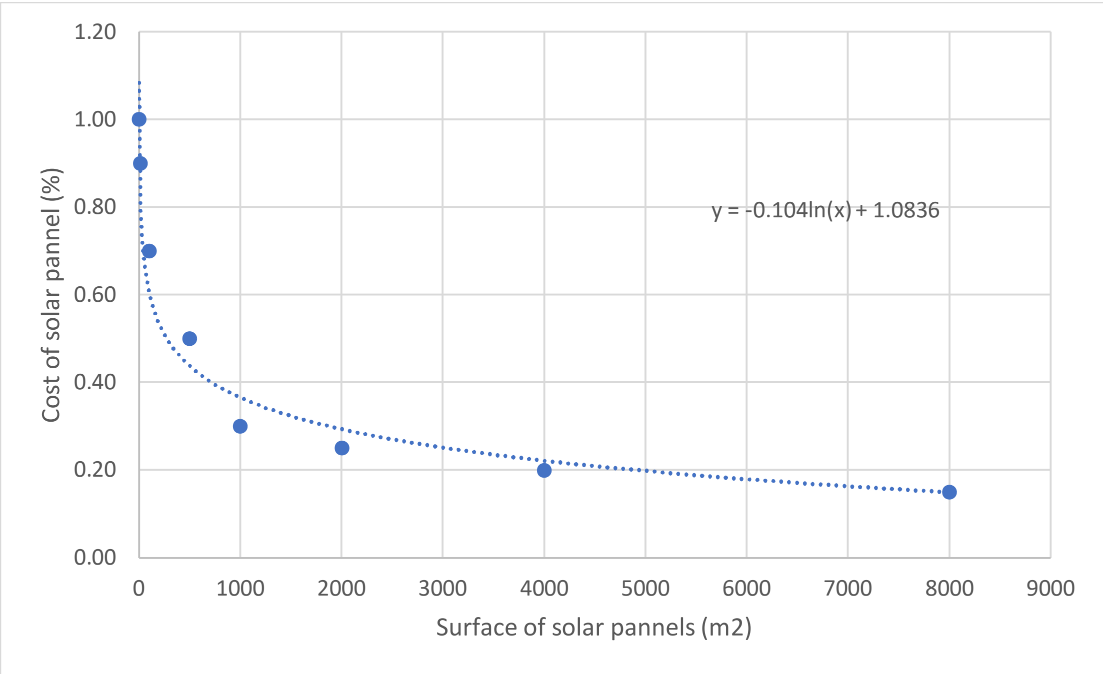

Fig. 119 - The dependence of the unit price of a solar panel on the number of purchased panels

The initial investment costs per piece from which they went for the three types of panels corresponding to k_c = 2, 3 and 4 were as follows: 3000, 2000 and 1500 euro (corresponding to the purchase of a single product). These include both the cost of the solar panel and the panel mounting work (which is fixed, representing 800 euros for each panel and included in the total sum presented above). The selected prices are average prices chosen for the Romanian market at the time of initiation of the study.

The estimated lifetime of the solar plant is 20 years.

Maintenance and maintenance costs were neglected in this calculation, being insignificant in relation to the value of the investment.

This investment cost was updated with the inflation rate of 7% and the 7% thermal energy growth rate. This has resulted in the Net Updated Value of the Investment.

In order to calculate the price per MWh, the last charging plan of RADET was used (Figure 120). The conversion into euro was made at the BNR exchange rate and thus a price of EUR 126,9121875 for 1 MWh was obtained. This tarif was multiplied by the annual amount of usable energy produced by the solar system and the annual value of the heat economy was obtained.

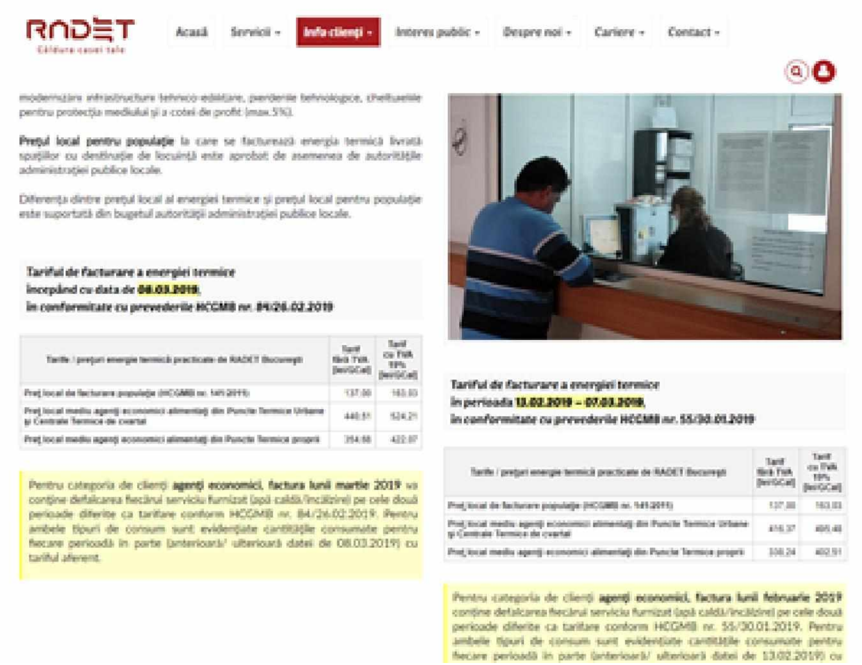

Fig. 120 - Updated Gcal Cost for Year 2019 Used in Calculations

The recovery time and the specific cost for each case were calculated for the 79 cities in 3.3. These were plotted in Annex 1. The recovery time exceeding the lifetime of the investment was specified because it was intended to show the difference between the different cases that are unfavorable to the investment.

The values obtained do not include a possible subsidy offered by the Romanian state or the European Union. If a grant is applied, we can approximate that the recovery time is reduced by the amount (in percent) of the grant. Thus, in the case of a 50% subsidy, the recovery times of the investment are reduced by half.

A detailed analysis was made for each year (Figure 121 and 122) for the city of Bucharest in the case: $H/k_c \cdot S_c=3$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C.

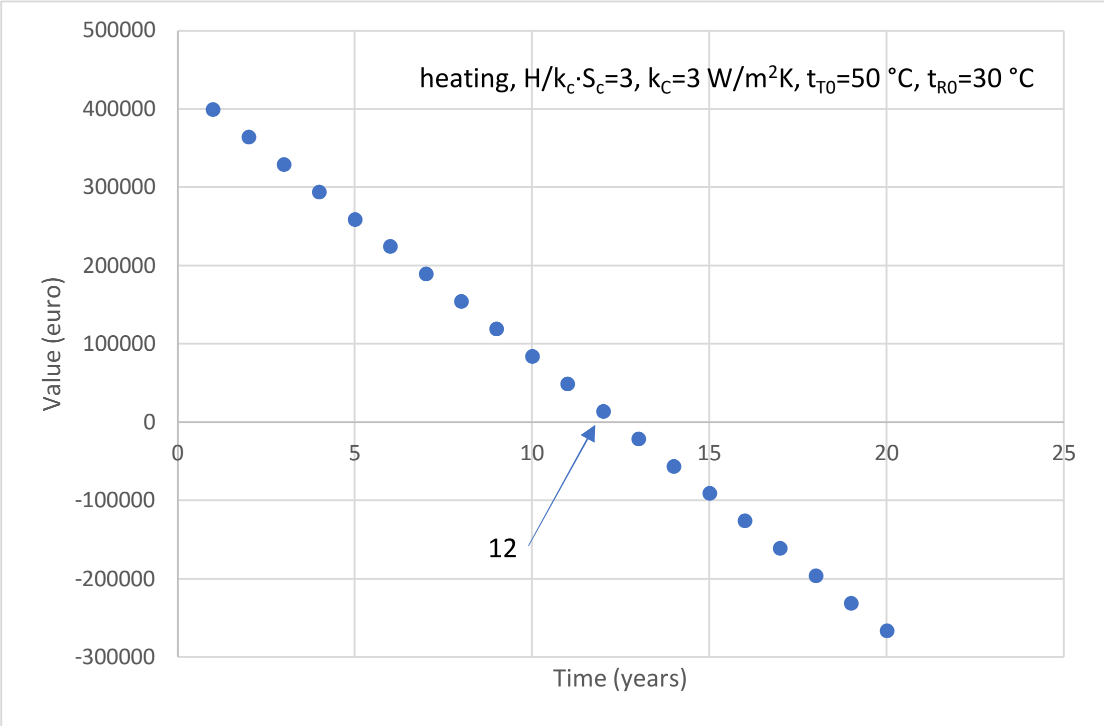

Fig. 121- Recovery time calculated for heating,

$H/(k_c \cdot S_c)=3$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

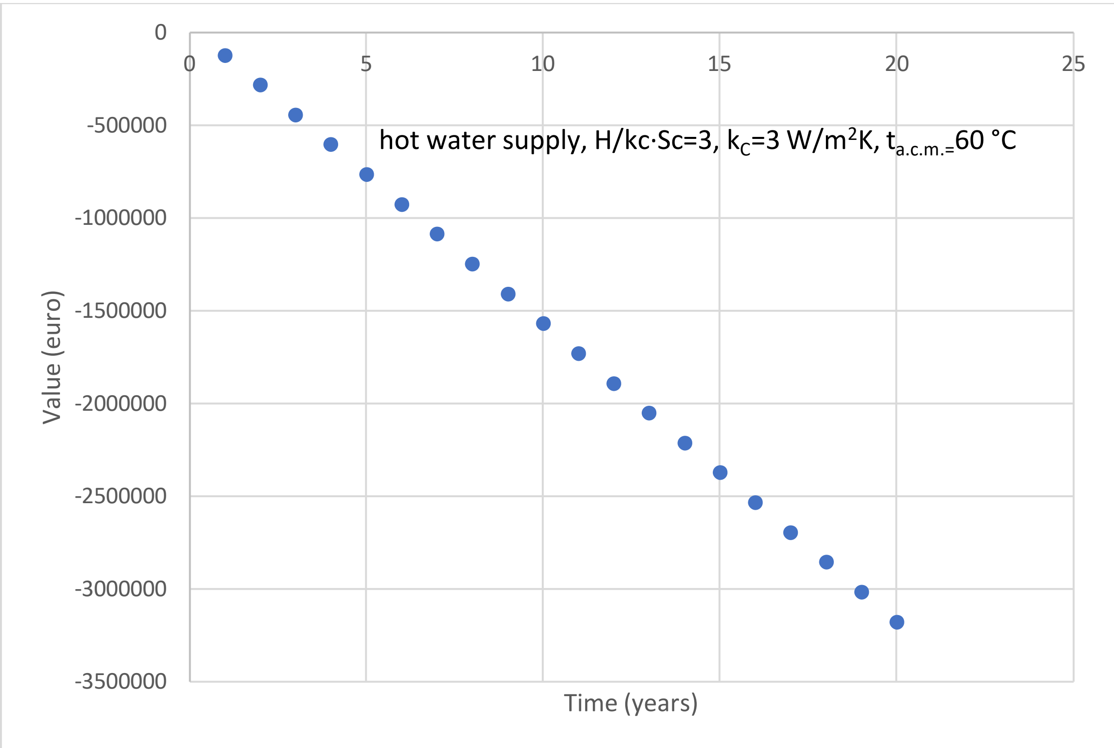

Fig. 122- Calculated recovery time for domestic hot water preparation,

$H/(k_c \cdot S_c)=3$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=60$ °C

Diagrams obtained for this case ($H/(k_c \cdot S_c)=3$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$°C) for all 79 cities are the following:

Fig. 123- Recovery time calculated for heating, $H/(k_c \cdot S_c)$=3, k_C=3 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

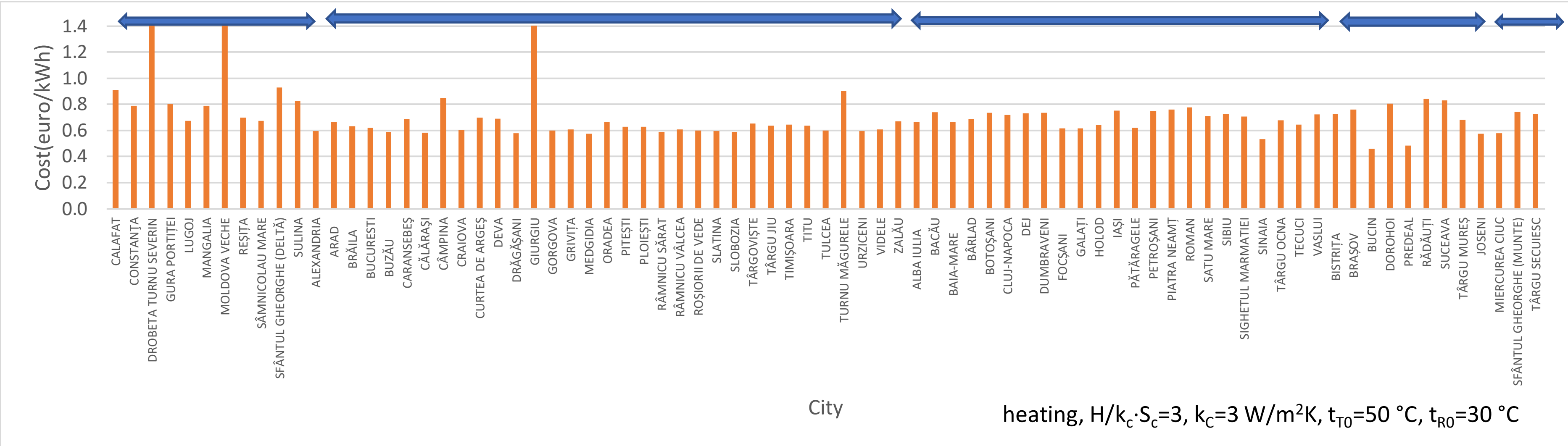

Fig. 124- Specific investment cost calculated for heating, $H/(k_c \cdot S_c)$=3, k_C=3 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

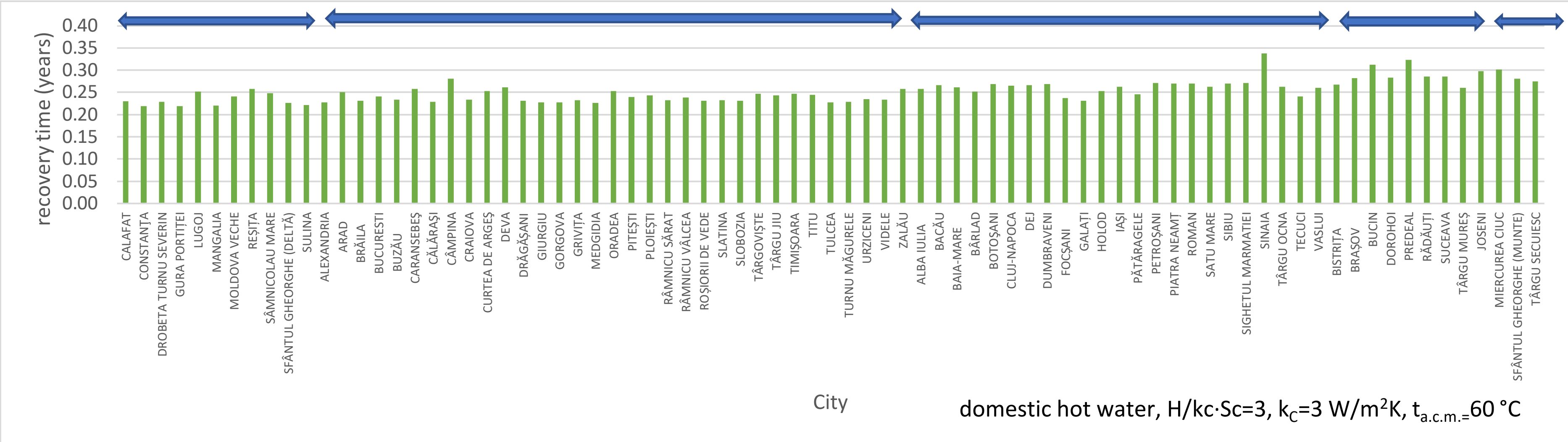

Fig. 125- Calculated recovery time for domestic hot water preparation, H/(kc·Sc)=3, k_C=3 W/m^{2}K, $t_{a.c.m.}$=60 °C

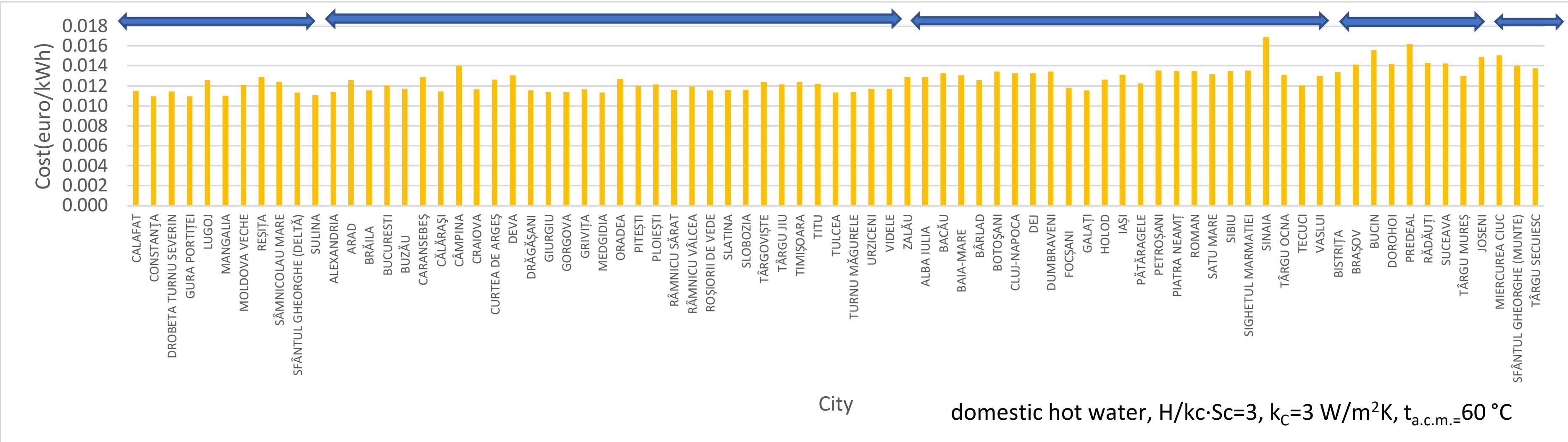

Fig. 126- Specific investment cost calculated for domestic hot water, H/(kc·Sc)=3, k_C=3 W/m^{2}K, $t_{a.c.m.}$=60 °C

4. CONCLUSIONS

The first study presented in this research report identified the set of parameters that need to be controlled to achieve energy outcomes that express the performance of solar collectors in terms of home heating and domestic hot water preparation. These are:

• k_C - the global heat transfer coefficient of the solar collectors, W / m^{2}K;

• H / (kc·Sc) - dimensional ratio of building transmittance to capture surface indicators;

• T_{T0} / T_{R0} or T_{ac} - Temperature control temperatures, ° C.

For the five reference cities selected in point 3.1, it is shown that solar panels can provide heat production for a residential consumer. Monthly values show that a panel with a heat transfer coefficient of 3 W / m^{2}K has problems in providing a heating input for January and February of the year for all 5 studied cities. The situation is similar in the case of domestic hot water preparation, it is recommended in these months to use another complementary system that can provide the thermal demand. For cities in areas 4 and 5, this panel type cannot provide heating for heating in November-February of the year.

Coverage rates for spring and autumn heating are satisfactory, reaching values of 20-50%. However, for the winter period, it is not recommended to use this configuration, mainly due to the use of a worse solar panel.

In the case of domestic hot water, there is a higher monthly efficiency of these panels because they operate during the summer when the solar intensities are at their maximum.

There is a fairly small difference between the monthly energy parameters calculated between cities in computing zones 1, 2 and 3. This suggests that solar installations will behave similarly for these regions. For the city of Predeal, it is an advantage that it needs two months heating in addition to Bucharest, the solar collector that works worse in winter than other cities, manages to capture heat for heating in the summer, and the intake brought in the additional 2 months is considerable.

With regard to the monthly hot water production of solar systems located in the five cities, it is clear that the warmest climatic zones produce the most significant amount of heat, which was to be expected. The degree of coverage of installations in the case of hot water production has values up to 90%, indicating that in some months the configuration of this system is almost sufficient to serve the needs of the consumer.

All the charts for domestic hot water production have a bell shaped like that in the literature.

The plant's outputs are 20-40% for the domestic hot water preparation, being higher during the hot season, but for the heating case they are much lower in most heating months.

The annual values presented in paragraph 3.2 are intended to expand the previous study and show the variation in system performance according to the mentioned above calculation parameters. Thus, by the $H/(k_c \cdot S_c)$ variation, the non-dimensional ratio between the building transmittance and the capture surface indicators, there are several possible configurations depending on the initial investment budget, but more importantly depending on the building possibilities of the space built according to the height regime. This is determined by the surface of the terrain or the roof of the chosen lens, which often represents the maximum surface area of the solar panels. Thus, for buildings with a P + 2 height regime, a value of the $H/(k_c \cdot S_c) = 3$ ratio can be chosen and 40-60% coverage rates can be obtained for heating. Instead, for values of this ratio $H/(k_c \cdot S_c) = 7$, corresponding to a P + 5 height regime, possible coverage ranges are lower, respectively 24-33% for heating. This recommends using these systems for residential developments developed more horizontally than vertically. In contrast, in the case of domestic hot water preparation, the surfaces are sufficient and depend only on the value of the investment, 40-50% for a minimum investment and over 80% for an average investment.

In the case of hedges obtained for heating, it is noted that they decrease with the decrease of the average monthly computing temperature. However, Predeal is a special case due to the two additional months of heating manages to get surprisingly high coverage. It can be concluded that the coverage levels for heating are generally lower depending on the climate zone from zone 1 to zone 5. In the case of hot water preparation, it is obvious that they decrease with the decrease of the average monthly average temperature, the smallest of which is recorded by the town of Predeal because it has the lowest temperatures of 5. This statement is complemented by the solar hot water system efficiency, which have the same variation and decrease with the decrease of the average monthly average temperature.

For the heating case the values obtained in k_C, the global heat transfer coefficient of the solar collectors, recommends the use of panels with this coefficient only above 2 W / m^2K. At lower values, low coverage rates (under 25%) are insufficient for such applications. This is also supported by the output of plants that decreases with increasing kC. Thus, the differences between the vacuum tube and the flat plate panels are notable, only those with vacuum tubes (with over 30% coverage) being recommended for heating. The use of high performance solar panels (with plant efficiencies above 25%) leads to 40-60% coverage in the case of the maximum investment allowed by the built space. This shows that these solar-only systems need an alternative heat source. Instead, for hot water preparation, these systems can produce enough heat to provide an 80% coverage even for an average investment. In this case, flat plate panels, less thermal performance, can also be used by increasing the capture surface. Although for the case of heating, it is noted that the best efficiency of the installation are obtained by vacuum tube panels, in the case of domestic hot water preparation, there is no the same decrease with the increase of k_C. This is mainly determined by the consumer who cannot use much of the heat input produced by the system. In other words, the higher the degree of coverage, the lower the efficiency of the system than the consumer because it is limited by the heat demand for domestic hot water. Thus, the best system efficiency can be obtained for the kC values of the flat plate solar collectors.

The study in chapter 3.3 made it possible to get an overview of the possibilities of solar systems for the whole of Romania. In addition, temperature control temperatures have also varied, showing their influence on system parameters.

The variation of the heating temperature distribution temperature showed that these systems are recommended for low temperature heating equipment. For a torque of t_{T0} = 70 ° C, t_{R0} = 50 ° C, the coating rate is reduced by about 30-50%, compared to the temperature distribution t_{T0} = 50 ° C, t_{R0} = 30 ° C. Similarly, system performance is also reduced.

The graphs in chapter 3.3 for the case of heating show a relatively constant variation in the coverage and solar system efficiency calculated using the existing calculation methodology. Excluding some cities, there is a decrease in these calculation parameters according to the computing area. However, the highest average coverage ranges in climate zone 2, and the lowest average coverage ranges in computing area 4. This is due to the fact that Zone 1 generally has fewer months of heating than zone 2, and computing areas 4 and 5 have similar outdoor average temperatures and may have months of heating in addition to zone 2 and 3. There is and some cities that are excepted from the rule, and record very low coverage rates, especially due to a very low heating time (required by monthly computing conditions). Thus, it is recommended to use average coverage rates for each computing area in the case of cities with different values from the rest of compartments 1 and 2 (Drobeta Turnu Severin, Moldova Veche, Câmpina, Giurgiu). The cities most exposed to calculation errors due to the monthly method are those in the extreme South of the country (Danube Meadow).

For domestic hot water, the efficiency and coverage levels for all 79 cities in Romania depend on the average outdoor temperature values, decreasing with these. Thus, for the city of Sinaia (altitude 1400 m), the lowest values were obtained due to this variation. It can therefore be concluded that in this case the most favored climate zone is zone 1 and the most disadvantaged are zones 4 and 5.

The values of efficiency and coverage rates varied greatly depending on the case, the evolution of the main parameters presented being decisive for the performance of the system. Thus, there are heating system configurations that provide over 30% coverage (vacuum tube panels), but also configurations that provide coverage levels below 5% (flat plate panels). Similarly, system configurations that produce domestic hot water can reach over 60% coverage rates and other configurations can reach coverage levels below 20%. At national level, we can determine an average for each computing area of each case studied. Thus, the study can be extended by nomograms that determine the degree of graphical coverage.

Creating a database for the whole of Romania, depending on the variation of the main factors, generates the premise of using these data by all those interested in using solar systems (Romanian state, users, designers, etc.). This study demonstrates the possibility of using different configurations of thermal solar panels on the territory of Romania. For the case of domestic hot water preparation, the study has shown that the monthly method used is sufficient for the sizing of solar energy systems. Nevertheless, the vulnerability of using the monthly method for certain cities for the heating case has been shown, and there has been a need to improve this method.

Thus, the innovative calculation method used in point 3.4 simplifies the present calculation in the existing methodology, but also responds to a new approach to determining the actual operating behavior of the solar panel system during actual sunshine hours. This proposed method, with simplifying assumptions (solar systems capture thermal energy only during the monthly preset months of sunshine) can improve the monthly calculation method by getting more values to reality. This has the advantage of determining the coverage rates and more accurate annual results (resulting from the research) for the case of heating and can also be used successfully for the preparation of hot water.

The identical results obtained from the research validate the new calculation method in case of using identical calculation principles (the same I monthly environment), having the advantage of simplifying the existing method. By modifying the average hourly computing intensity, new possibilities are created for assessing the actual hourly efficiency of solar installations. Thus, it can be noticed that although the actual hourly efficiency of the installation increases over the year, the hourly efficiency of the system that includes the heating needs of the consumer decreases due to the limitation of the required heating energy. These conclusions provide a new insight into the way solar systems are treated and suggest some changes that need to be made in the sizing of solar systems. Thus, due to a considerably higher heat input over a certain period of the day, it is concluded that these systems work much better in case of additional storage of this energy (higher storage tank) or by introducing higher adjustment temperatures (by automation) during this solar charging regime.

The values of the annual coverage rates of the plant using the monthly sunshine period are 40-50% higher, and the differences between the different setting temperatures decrease. Annual efficiency increase to the same extent, especially for the winter, due to the fact that the plant works better for a shorter period of time and the energy is stored in the storage tank. The comparison of the efficiency obtained using the two innovative ways of determination indicates that this calculation method has a better degree of accuracy than the method currently described in MC001.

In the energy study, it is concluded that there may be solar configurations that generate a heating energy saving needed to heat residential buildings at around 30-40% nationwide in the case of easy installation of these systems in most homes. This value is considerable and can lead to greater energy independence of Romania. For hot water preparation, solar panel systems can fully provide the heat demand, being more efficient and less restrictive than heating.

The economic study in Chapter 4 and Annex 1 presents a new, simplified calculation method that has been adapted and can only be used to determine the main economic indicators needed in calculating solar systems. This comes as a complement to the existing methodology and serves to help all those interested in using solar systems (Romanian state, users, designers, etc.).

The recovery times for the heating case exceed in most cases 10 years, indicating the need for a subsidy from the Romanian state to encourage the development of such applications. Instead, in the case of domestic hot water preparation, recovery times are up to one year in most cases, which prompts the use of these systems.

An economic analysis that uses the innovative method of energy determination of thermal solar installations can lead to much lower recovery times for the heating case. This would encourage investments in such systems at national level for both heating and domestic hot water.

The energy and economic analysis presented in this report, which addresses the use of solar energy systems for the preparation of thermal energy serviced by a residential consumer, has demonstrated both the capabilities and limitations of these systems used on the territory of Romania. This report is the basis for improving the existing methodology and provides a sufficient database to develop new simplified calculation methods for the energy and economic calculation of thermal solar systems. The new method may include simplified nomograms that reduce computational times and complexity, benefiting from a degree of acuteness in terms of computational values obtained from the current method used in the methodology. This can be further developed by replacing the additional fossil fuel source with a thermal source that also relies on renewable energy sources of heat.

The database outlined in this report encourages local governments (79 cities and their associated areas) to invest in solar thermal systems, providing the necessary data to initiate new investments to provide residential heat consumers.

List of Notations

α – absorption coefficient of the collecting plate, -;

τ – transparency coefficient, -;

ΔE_t – the heat economy of the building achieved through the application of the energy modernization solutions, in the average year, representative of the locality in which the building subject to the energy audit activity is located, kWh / year;

1.163 – transformation factor, W.h/l.K;

a – specific heat flow, m^3/s;

DHW- domestic hot water;

a_R^* - specific reference flow (design flow), l/m^2h;

$C_{(m)}$ – the investment cost of the energy modernization project at the level of year "0", Euro;

C_0 – total investment cost in year "0", Euro;

C_E – annual energy cost consumed at the reference year level, Euro / year;

c_k - represents the current cost of the energy unit k, Euro / kWh;

C_M – the investment cost of the energy modernization project at the level of year "0", Euro/ year;

Cp- specific heat, J/kgK;

d_1, d_2, d_3 – distance between cities;

E - energy, Wh;

E_C – thermal module of the capture surface, -;

E_{CONS} – energy demanded by the consumer, kWh;

E_{CP} – the solar energy captured by the solar loop, kWh;

E_{CS} – solar thermal loop thermal module, -;

E_I – solar energy incident to the capture area, kWh;

E_S - Thermal Module Solar Heat Exchanger Module, -;

$E_{t(m),(a)}$ – the heat consumption of the modernized / non-modernized building to achieve the thermal and physiological comfort conditions (space heating and hot water consumption) in the average year, representative of the locality in which the building is located energy audit [kWh/year];

f – annual growth rate of heat cost, -;

F' – factor of efficiency of solar captures, -;

F_C – the solar collector-loss-factor characteristic factor, m^2K/W;

f_{cap} – correction factor of the global solar radiation intensity due to the angle of inclination of the solar collectors and the angle of deviation from the SUD orientation of the solar collectors, -;

F_{INC} – dimensional correction factor, -;

F_R – capture efficiency -;

F_{RB} – correction factor of solar thermal capture, -;

F_{RBC} – correction factor of the captured thermal flow due to the consumer, -;

F_{RC} –correction factor of the captured heat flow due to the consumer, -;

GAE – the degree of energy coverage of the solar loop, -;

GAET – the thermal energy coverage of the solar loop, -;

G_{CONS} – daily average hourly flow rate of hot water consumption, l/h;

G_{INC} – heat flow rate of the heating medium, l/h;

H – building transmittance, W/K;

I – solar radiation intensity, W/m^2;

i – the annual depreciation of the currency (Euro), - ;

k- global heat transfer coefficient, W/m^2K;

k_C – global heat transfer coefficient of solar collectors, $W/m^2.K$;

N – the physical life span of the analyzed system, years;

N_S – lifetime of energy modernization solutions, essential for achieving technical performance, years;

N_{zl} – number of days in month, day / month;

p- pressure, bar;

P_{CONS} – thermic power needed by consumer, W;

P_{CP} – thermic power for consumer, W;

Pe- electric power, W;

P_{EL} – Mean daily solar pump power, W;

P_P – Pump power in the solar loop, W;

Q- thermal power, W;

R_{INC} – thermal resistance of the consumer heating system, m2.K/W;

S_{INC} – the area of the consumer's central heating installation, m2;

t- temperature,°C;

T- temperature ,K;

tc – hot water temperature, ^{o}C;

t_E – equivalent temperature, ^{o}C;

t_e – outdoor temperature, ^{o}C;

t_m – average temperature of the thermal agent in the capture area, ^{o}C;

tr – cold water temperature, ^{o}C;

$VNA_{(m),(a)}$ – the updated net amount of the upgraded / non-modernized investment and exploitation works over the N-year calculation period N ani, Euro;

ΔC_E – Reduction of annual operating costs following the implementation of energy modernization projects at the reference year level, Euro/year;

ΔE_k - represents the estimated annual energy k, obtained by implementing an energy modernization measure, kWh/year;

θ – external calculation temperature, ^{o}C;

φ_{NEC0} – the heating demand of the consumer building, W.

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ANNEXES

ANNEX 1- Economic charts for cases in 79 cities

Diagrams obtained for each case (depending on H / ($k_c \cdot S_c$) ratio, k_C variation, supply temperature variation) are as follows:

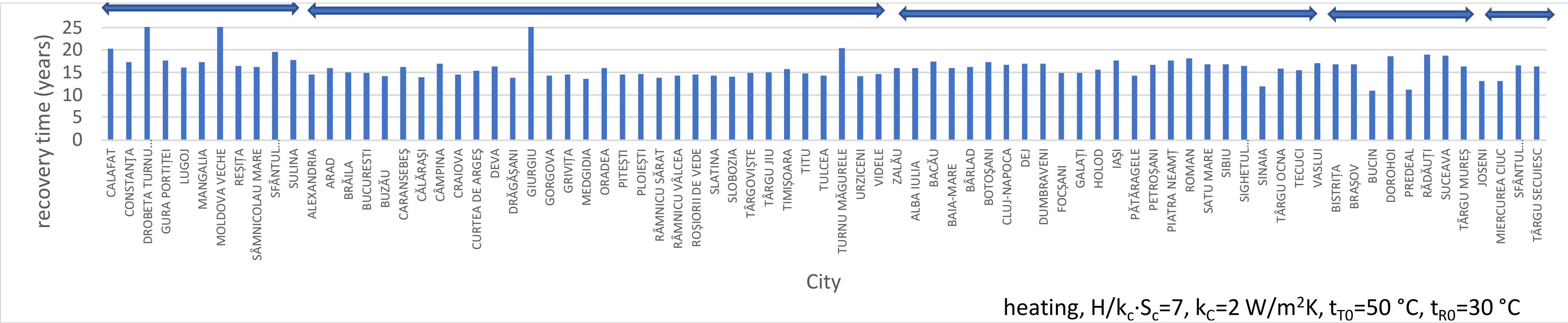

Fig. 127- Recovery time calculated for heating, $H/k_c \cdot S_c$=7, k_C=2 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

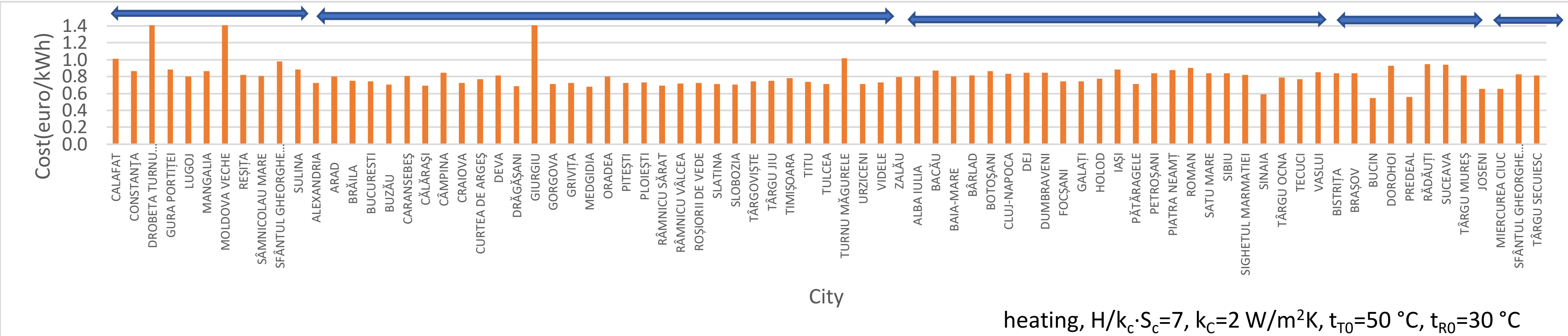

Fig. 128- Specific investment cost calculated for heating, $H/k_c \cdot S_c$=7, k_C=2 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

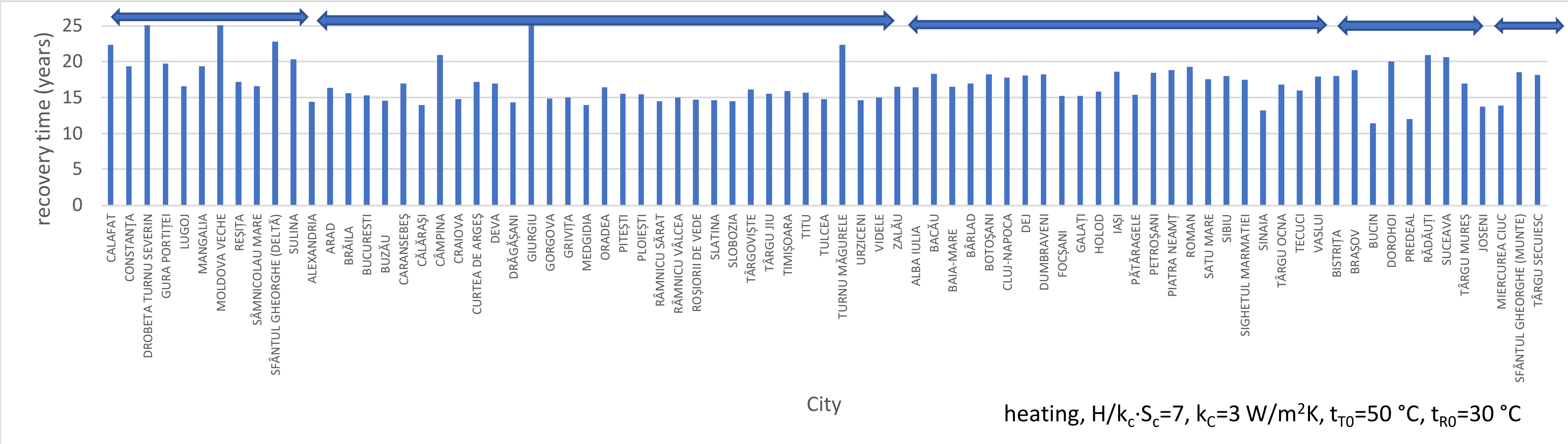

Fig. 129- Recovery time calculated for heating, $H/k_c \cdot S_c=7$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

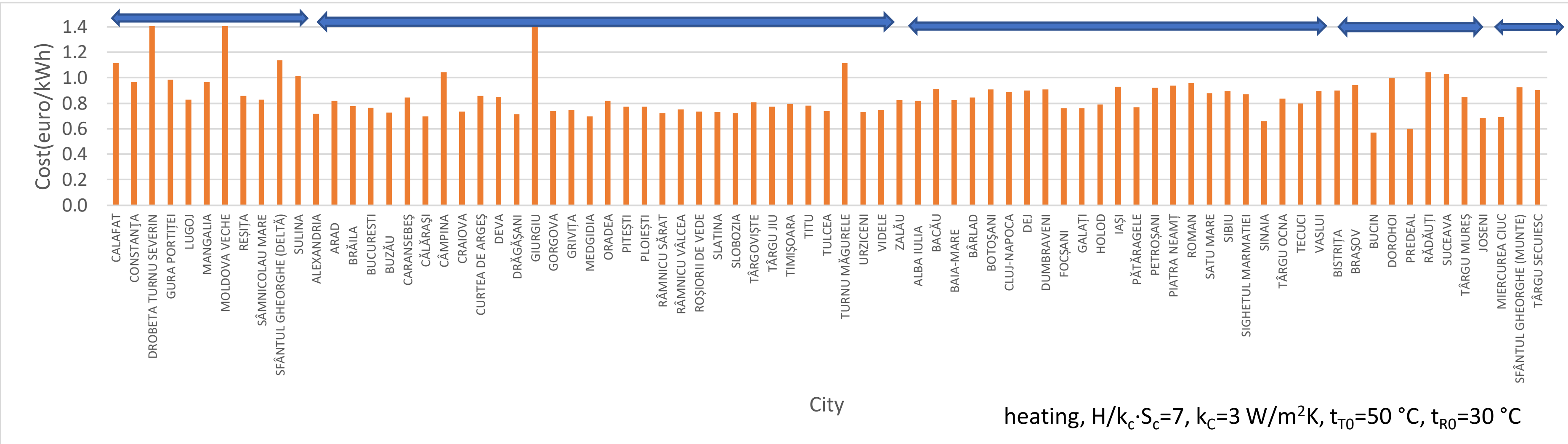

Fig. 130- Specific investment cost calculated for heating, $H/k_c \cdot S_c=7$, $k_C=3$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

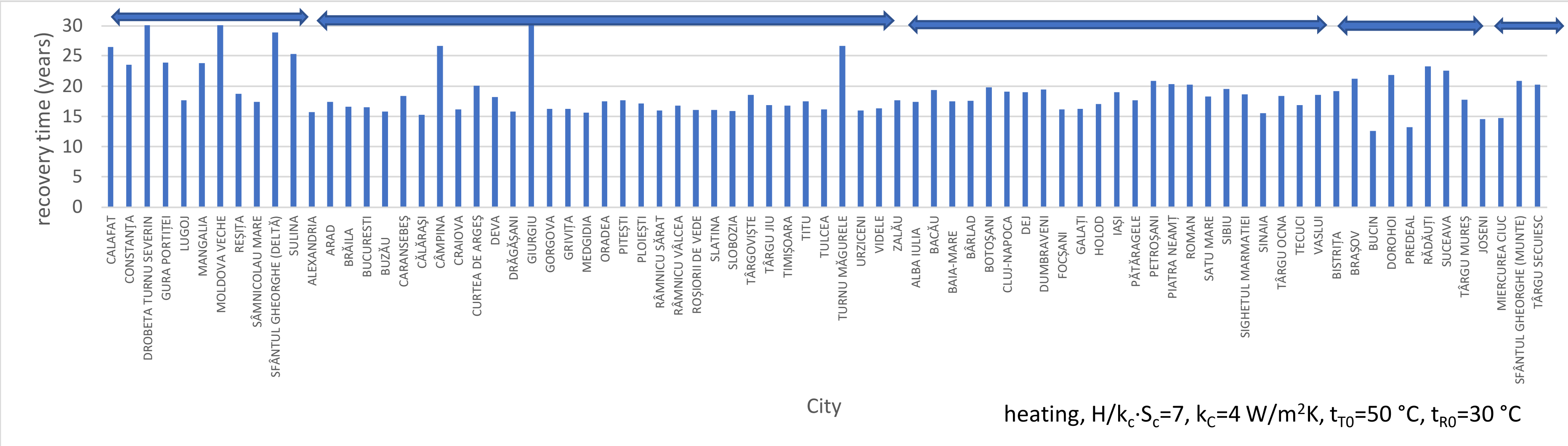

Fig. 131- Recovery time calculated for heating, $H/k_c \cdot S_c=7$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

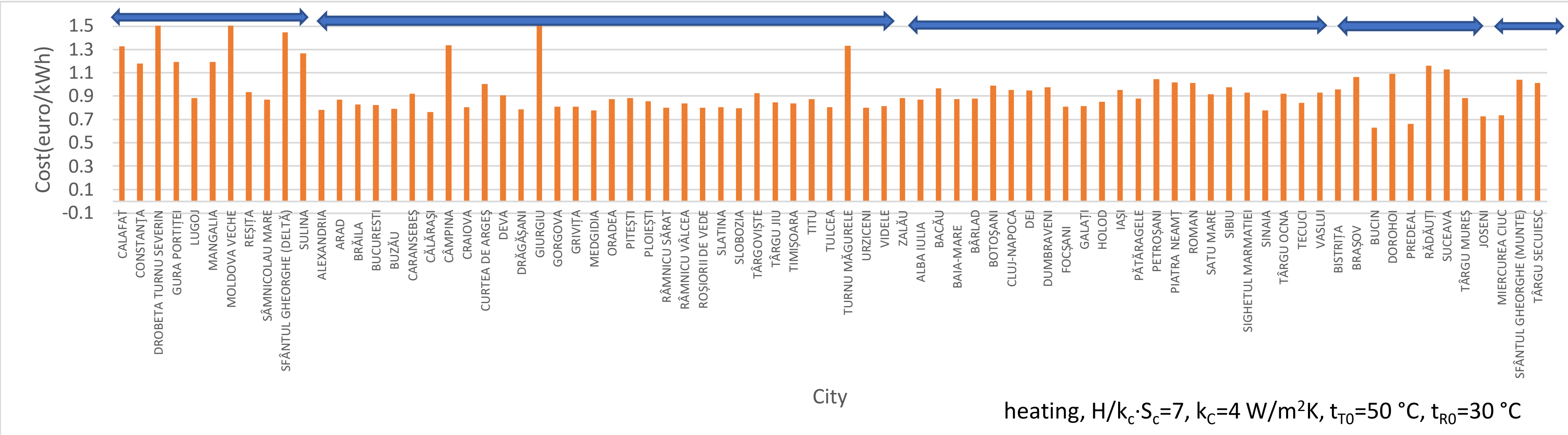

Fig. 132- Specific investment cost calculated for heating, $H/k_c \cdot S_c=7$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

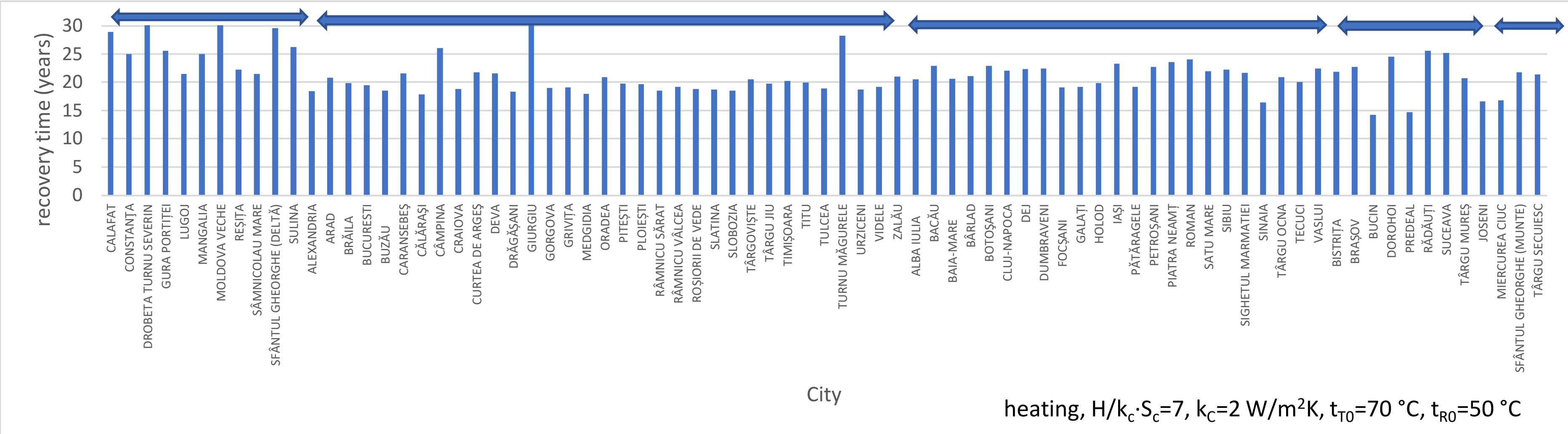

Fig. 133- Recovery time calculated for heating, $H/k_c \cdot S_c=7$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

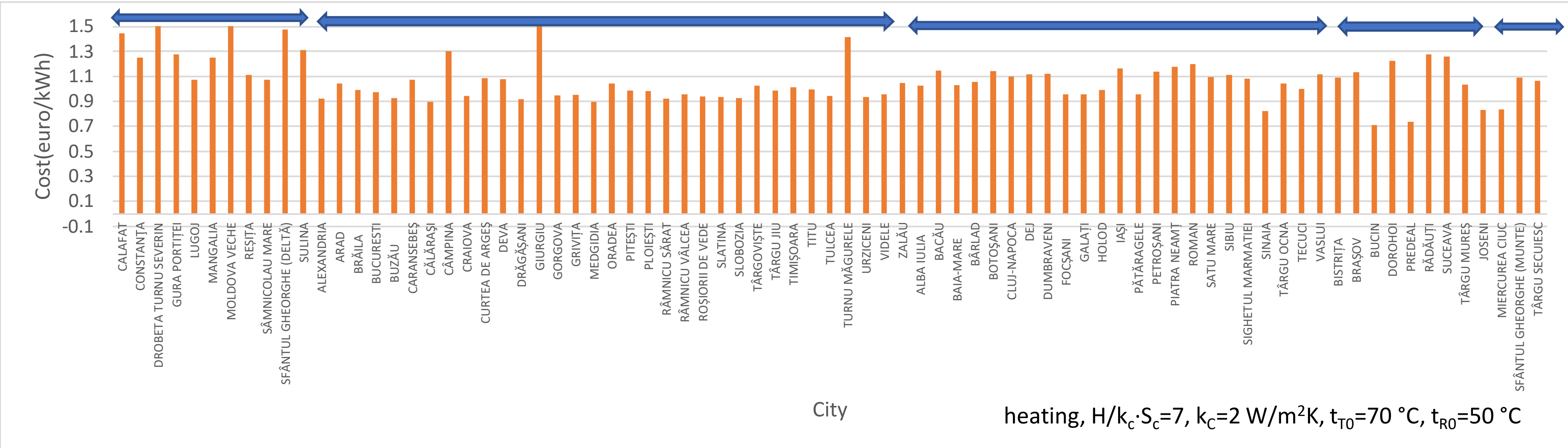

Fig. 134- Specific investment cost calculated for heating, $H/k_c \cdot S_c=7$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

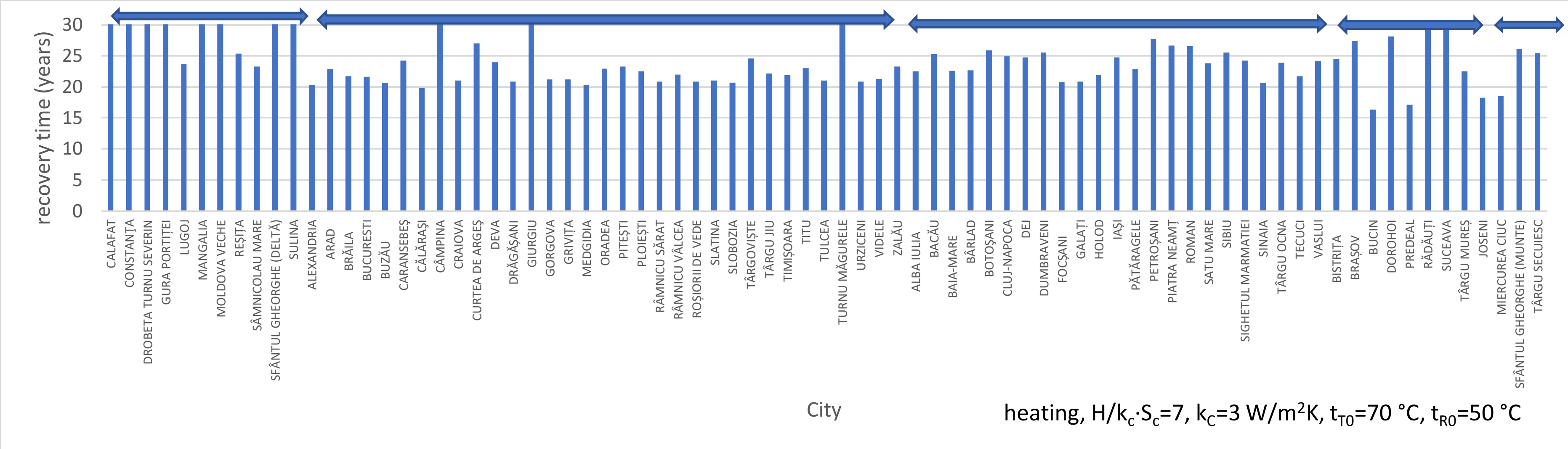

Fig. 135- Recovery time calculated for heating, $H/k_c \cdot S_c$=7, k_C=3 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

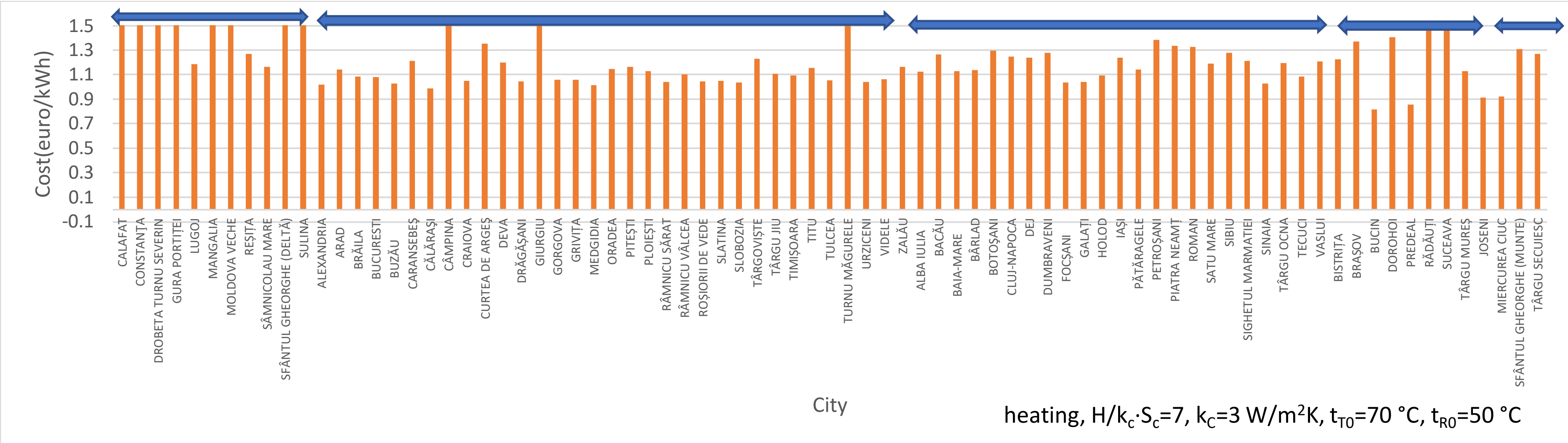

Fig. 136- Specific investment cost calculated for heating, $H/k_c \cdot S_c$=7, k_C=3 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

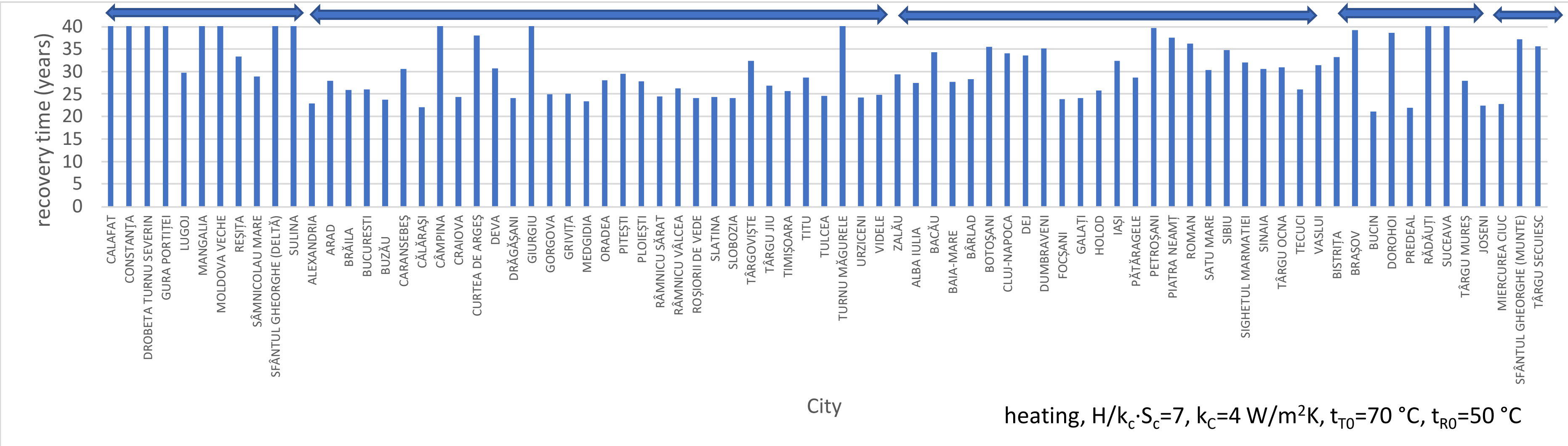

Fig. 137- Recovery time calculated for heating, $H/k_c \cdot S_c=7$, $k_C=4$ W/m²K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

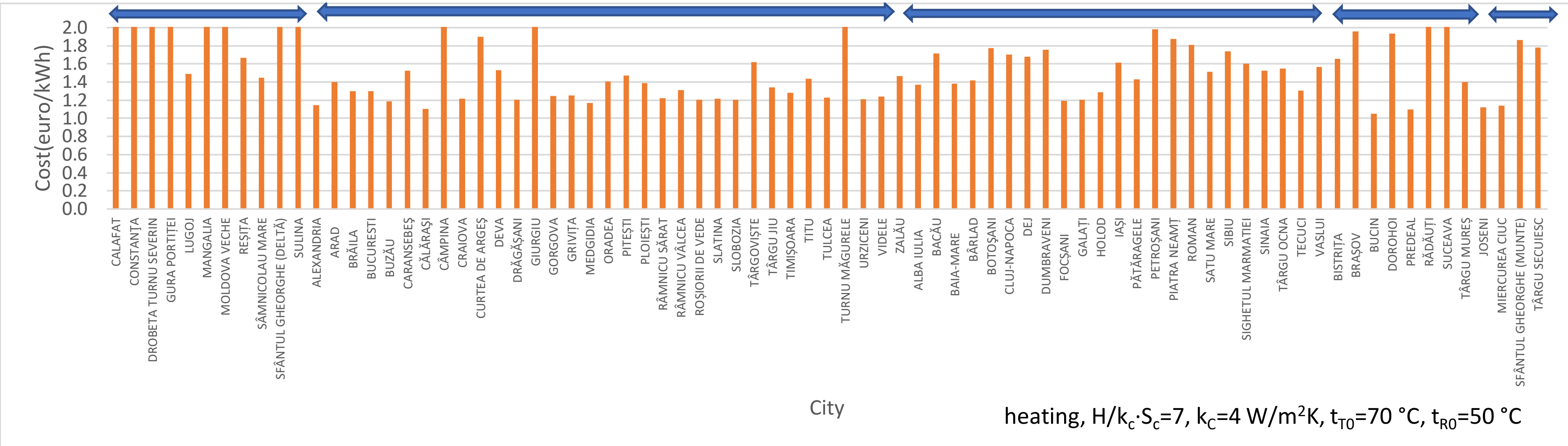

Fig. 138- Specific investment cost calculated for heating, $H/k_c \cdot S_c=7$, $k_C=4$ W/m²K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

Fig. 139- Recovery time calculated for heating, $H/k_c \cdot S_c=5$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

Fig. 140- Specific investment cost calculated for heating, $H/k_c \cdot S_c=5$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

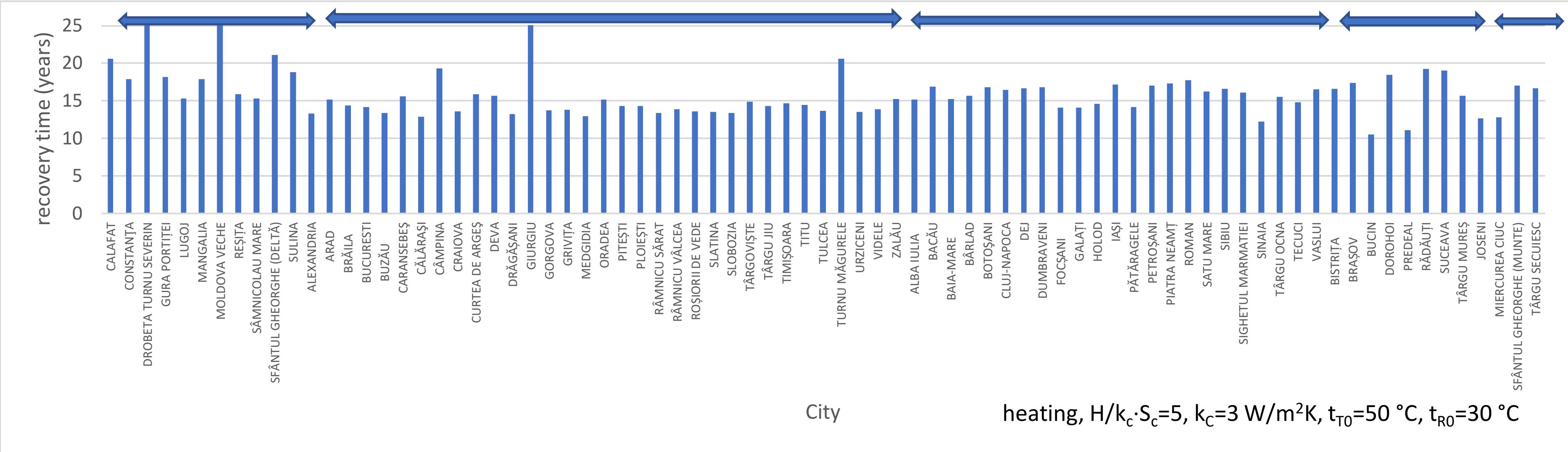

Fig. 141- Recovery time calculated for heating, $H/k_c \cdot S_c$=5, k_C=3 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

Fig. 142- Specific investment cost calculated for heating, $H/k_c \cdot S_c$=5, k_C=3 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

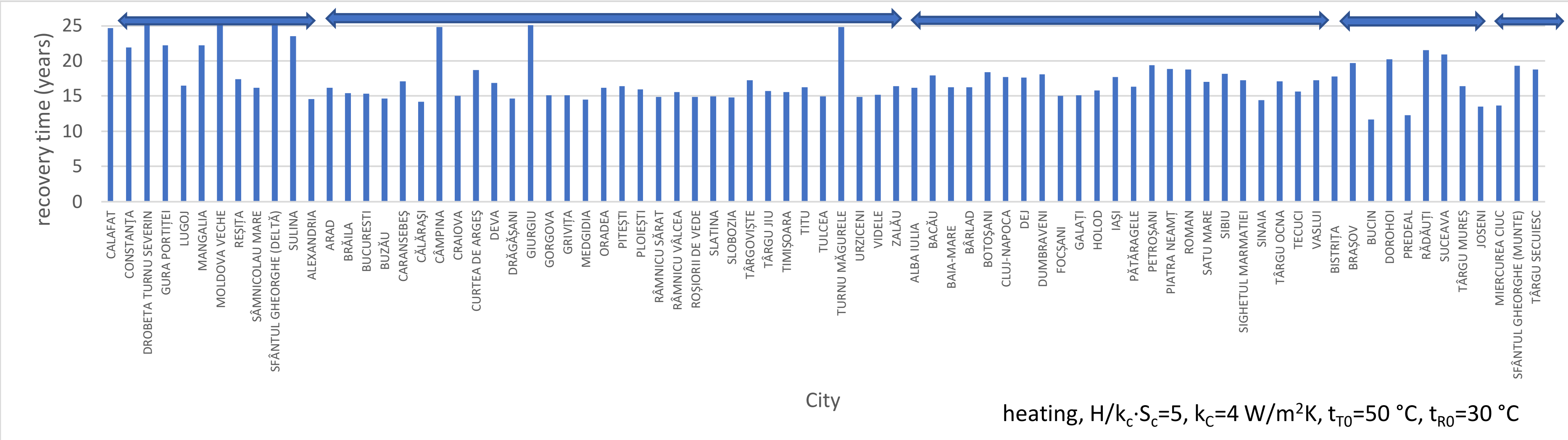

Fig. 143- Recovery time calculated for heating, $H/k_c \cdot S_c$=5, k_C=4 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

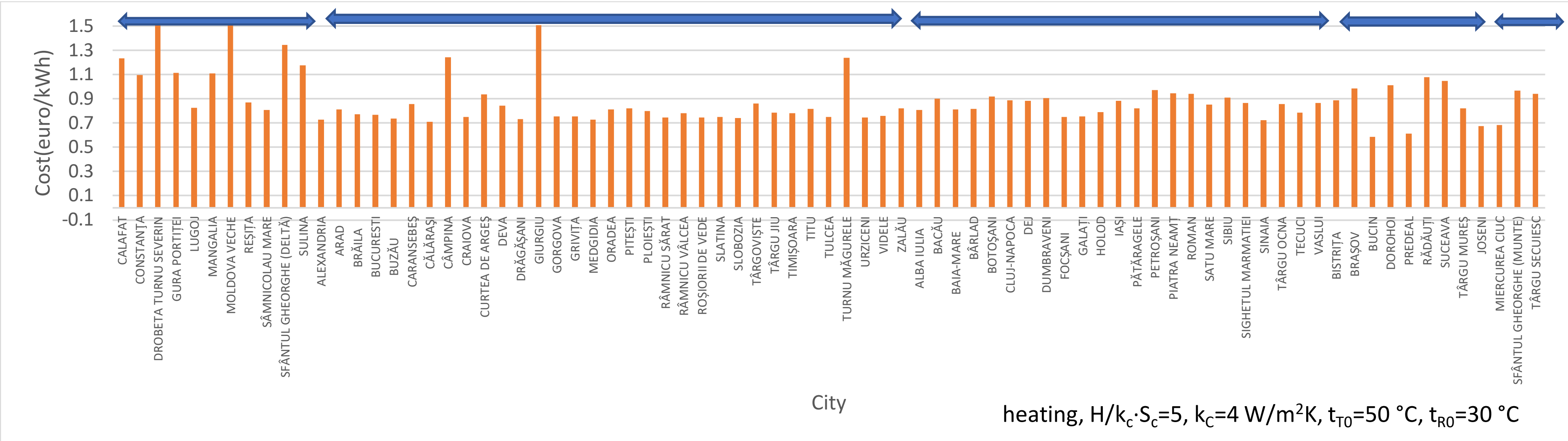

Fig. 144- Specific investment cost calculated for heating, $H/k_c \cdot S_c$=5, k_C=4 W/m^{2}K, t_{T0}=50 °C, t_{R0}=30 °C

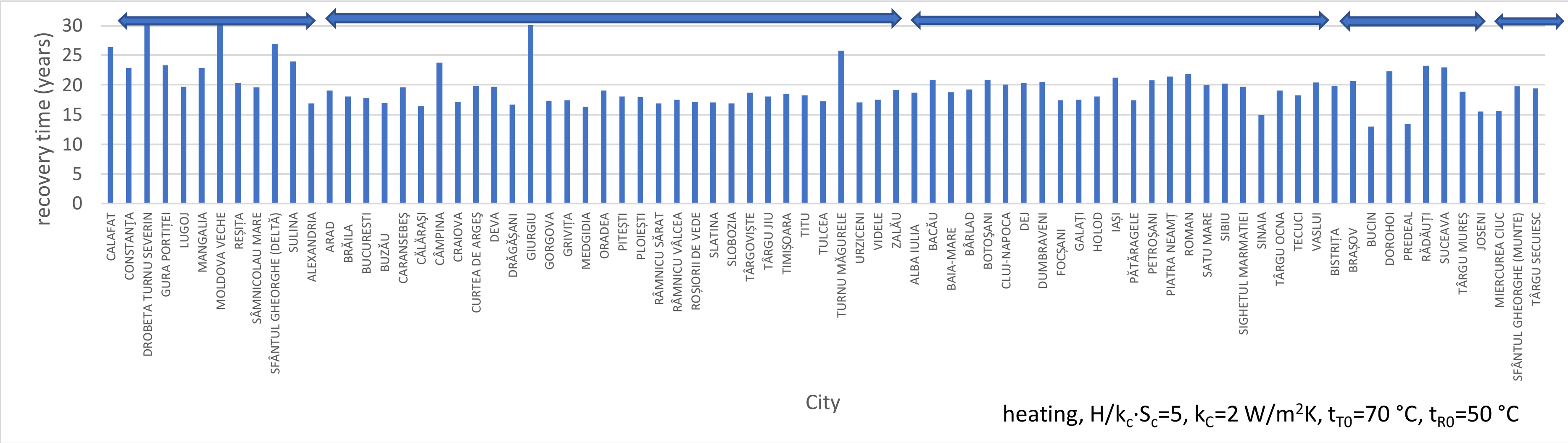

Fig. 145- Recovery time calculated for heating, $H/k_c \cdot S_c=5$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

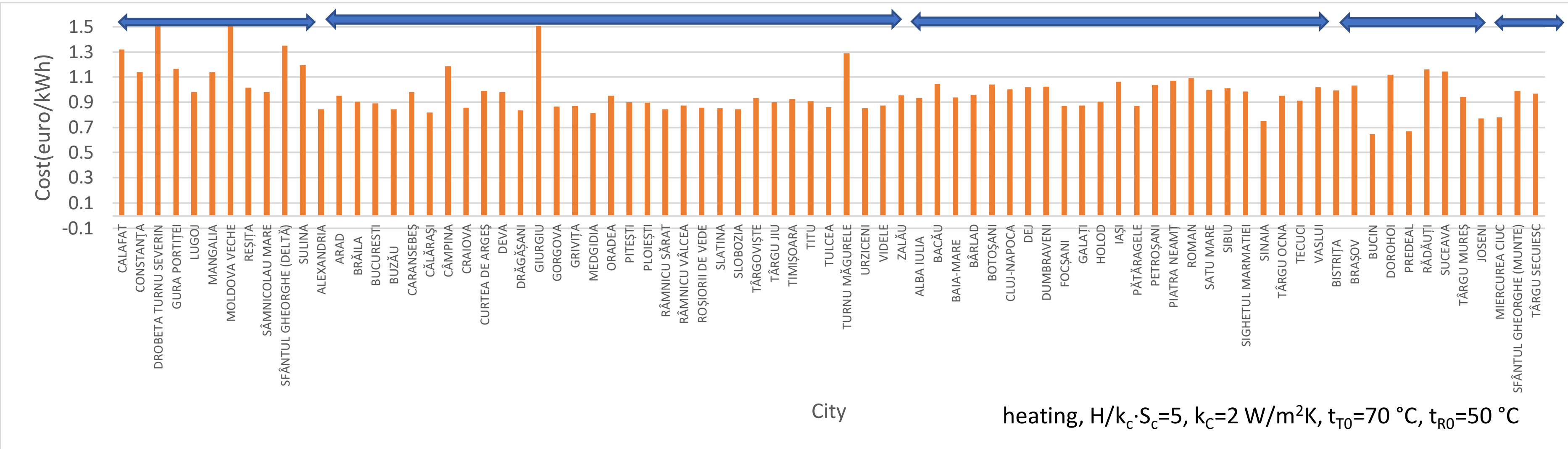

Fig. 146- Specific investment cost calculated for heating, $H/k_c \cdot S_c=5$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

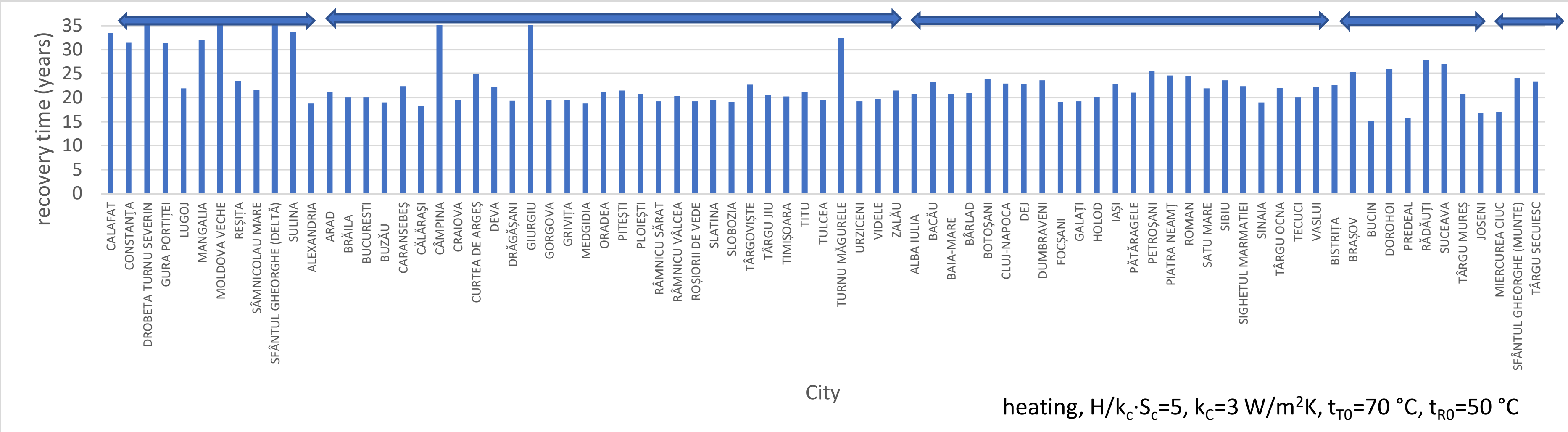

Fig. 147- Recovery time calculated for heating, $H/k_c \cdot S_c$=5, k_C=3 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

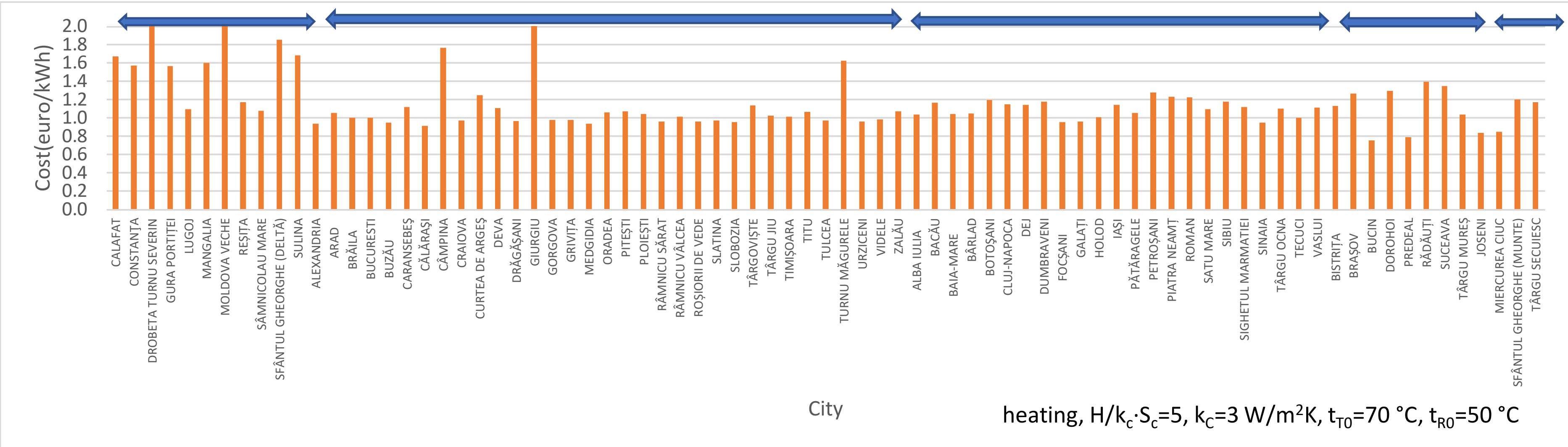

Fig. 148- Specific investment cost calculated for heating, $H/k_c \cdot S_c$=5, k_C=3 W/m^{2}K, t_{T0}=70 °C, t_{R0}=50 °C

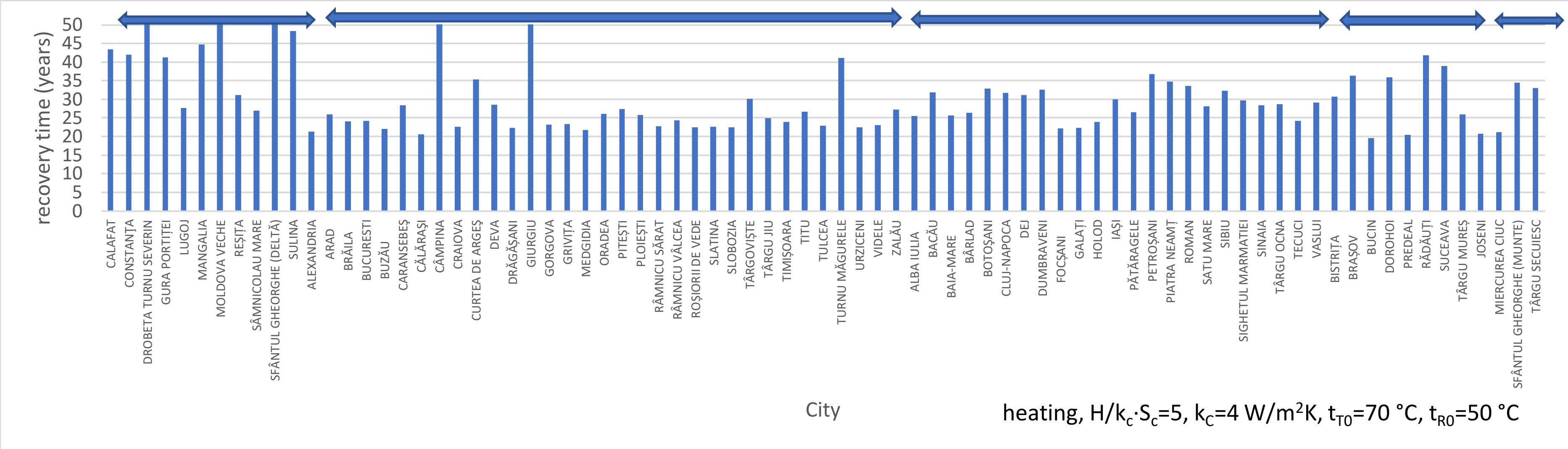

Fig. 149- Recovery time calculated for heating, $H/k_c \cdot S_c=5$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

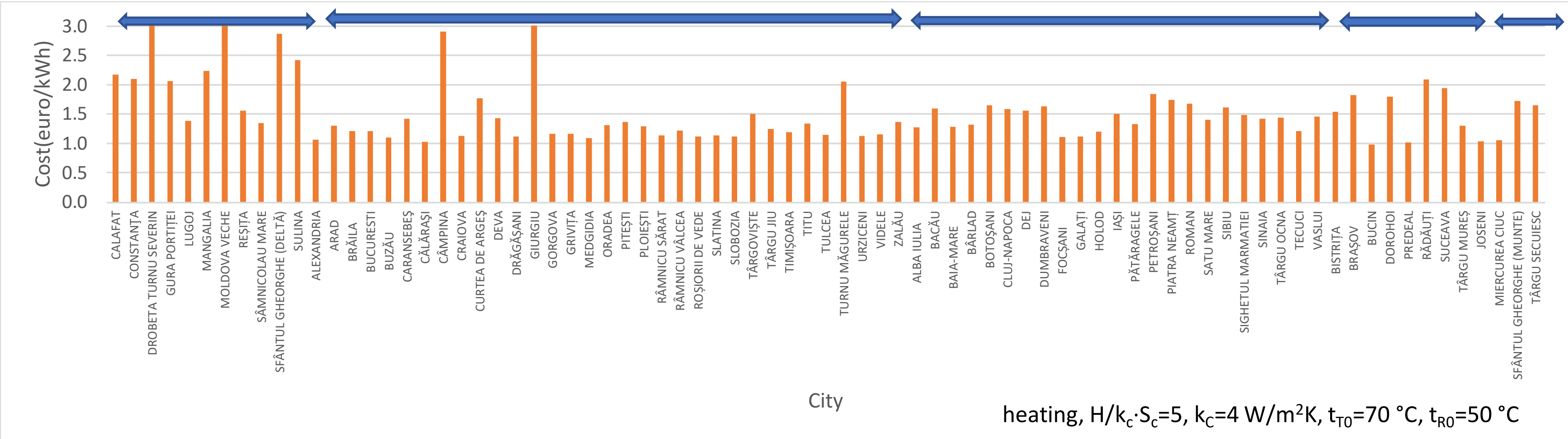

Fig. 150- Specific investment cost calculated for heating, $H/k_c \cdot S_c=5$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

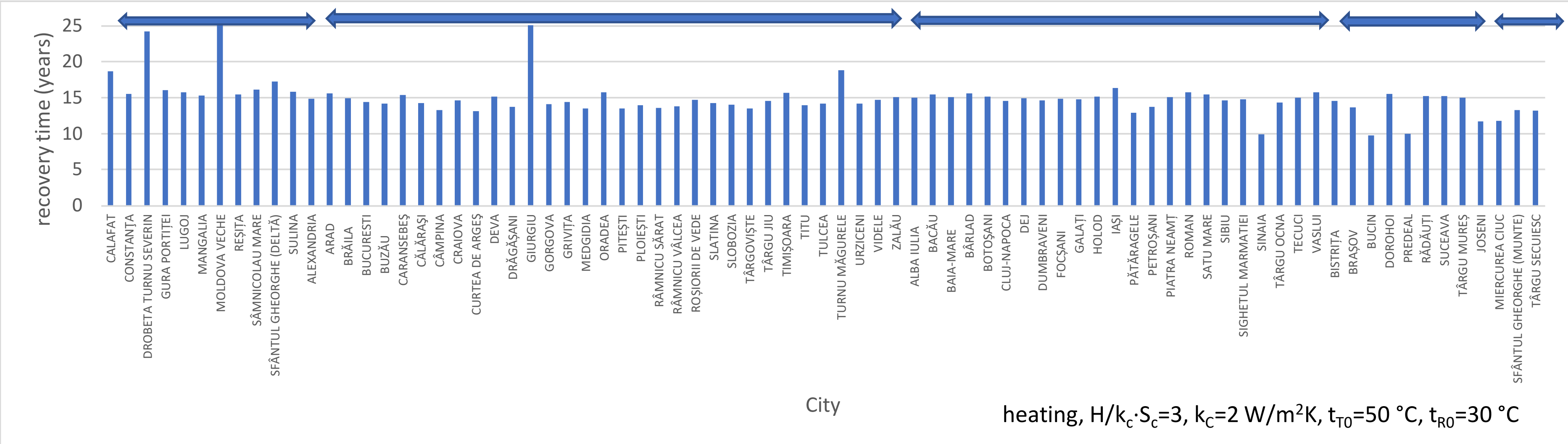

Fig. 151- Recovery time calculated for heating, $H/k_c \cdot S_c=3$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

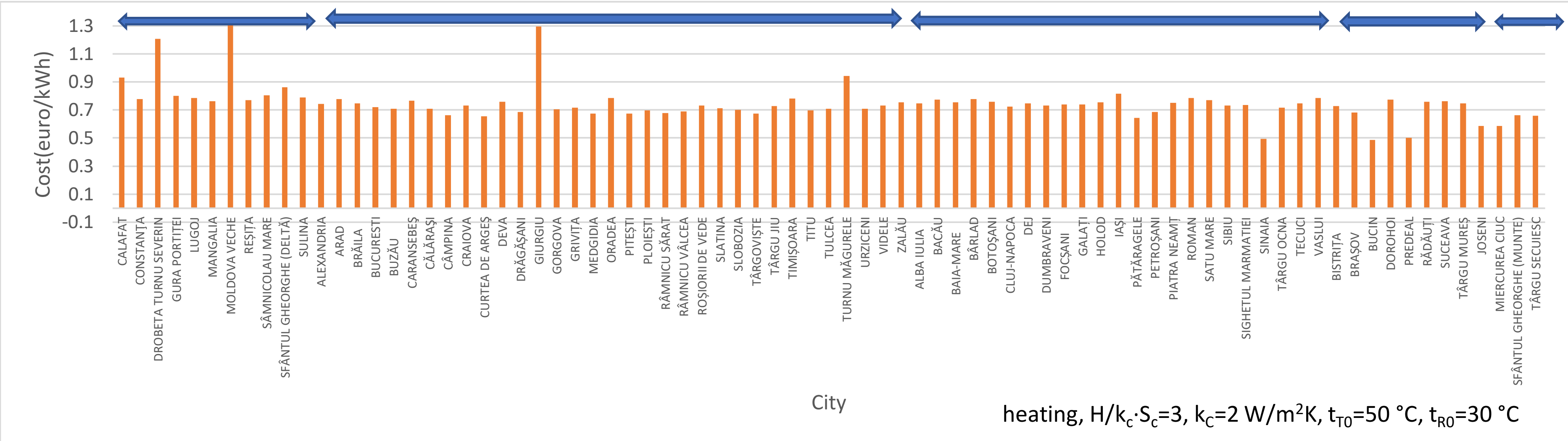

Fig. 152- Specific investment cost calculated for heating, $H/k_c \cdot S_c=3$, $k_C=2$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

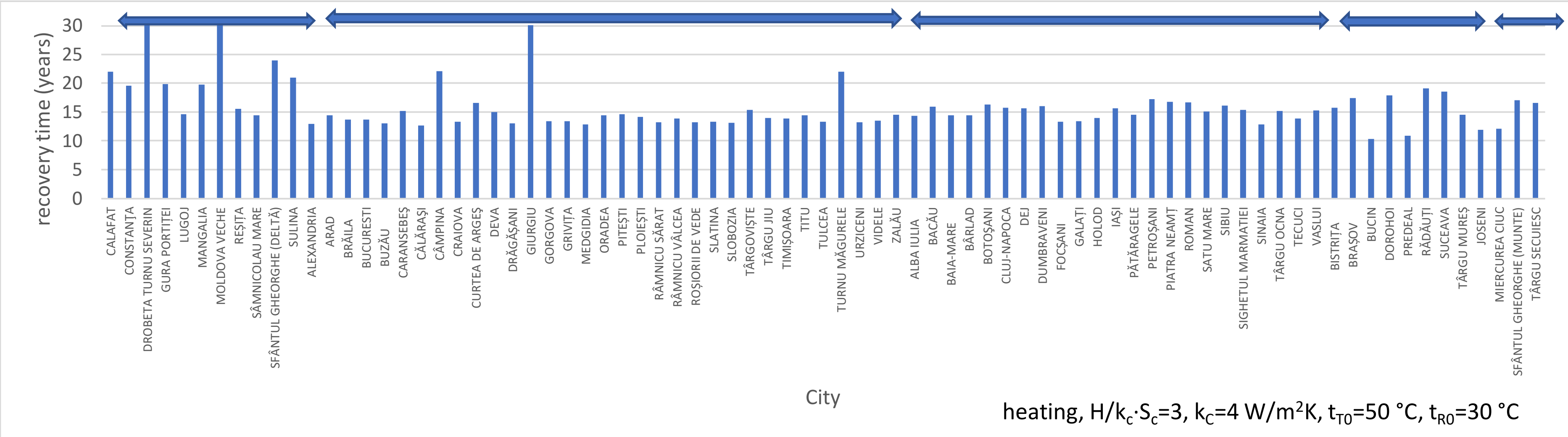

Fig. 153- Recovery time calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

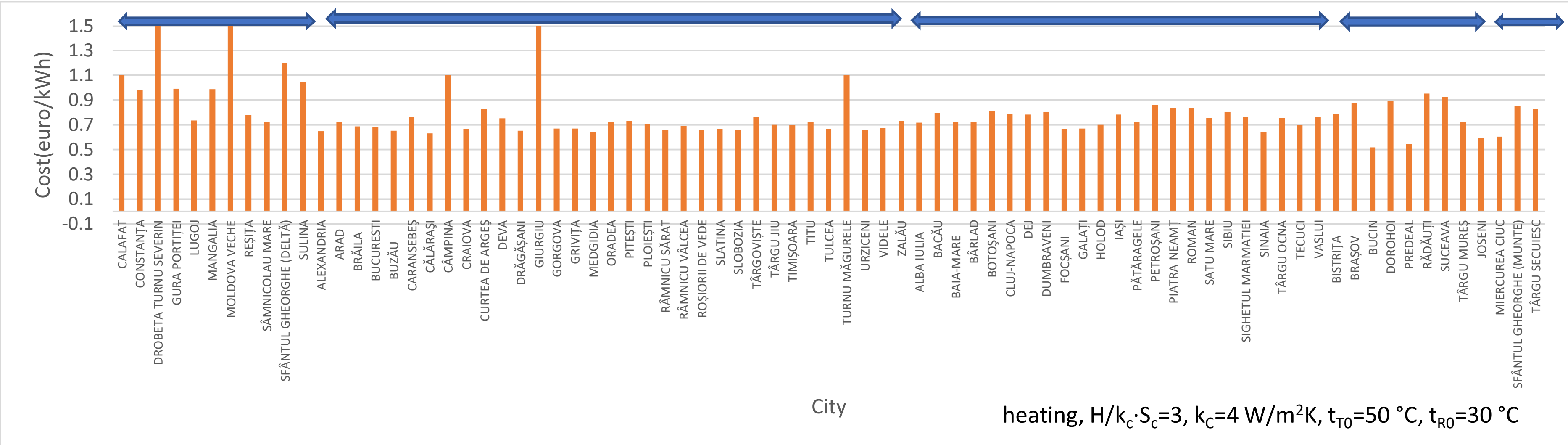

Fig. 154- Specific investment cost calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=50$ °C, $t_{R0}=30$ °C

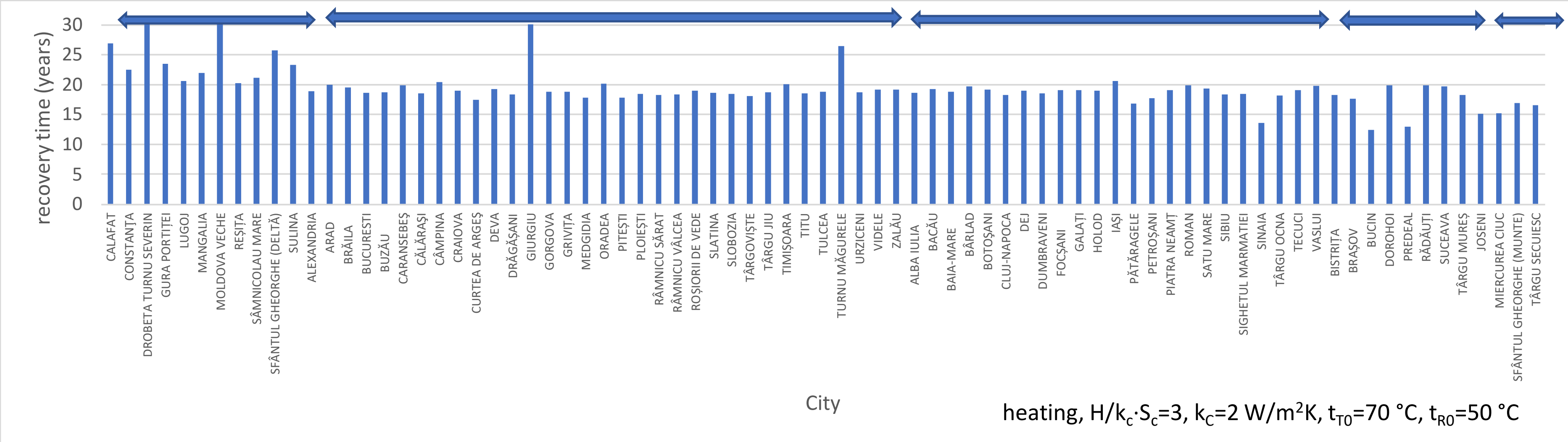

Fig. 155- Recovery time calculated for heating, $H/k_c \cdot S_c=3$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

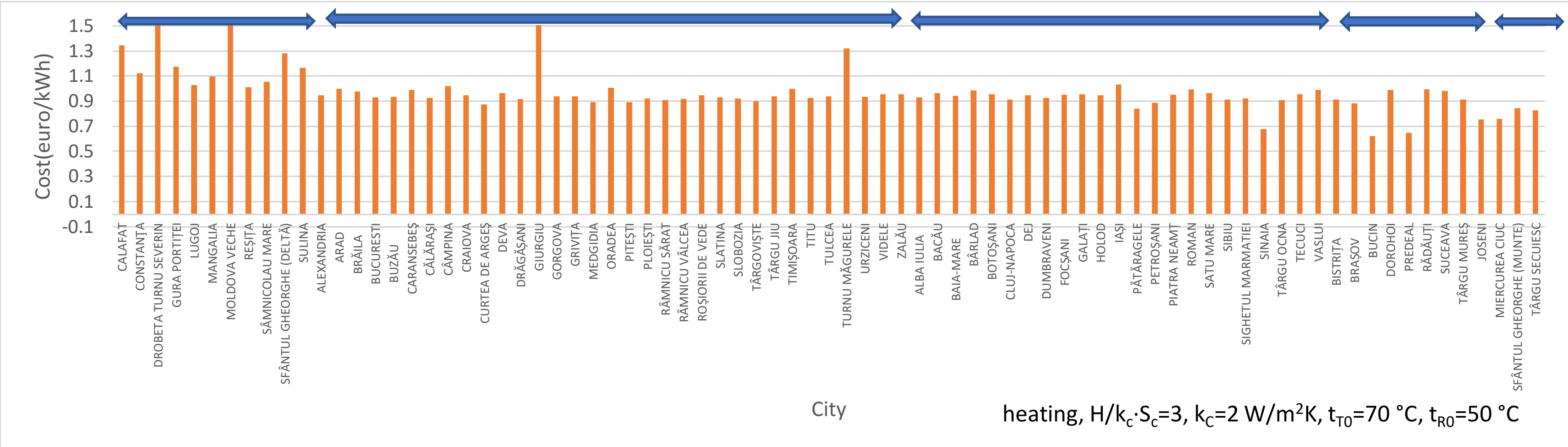

Fig. 156- Specific investment cost calculated for heating, $H/k_c \cdot S_c=3$, $k_C=2$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

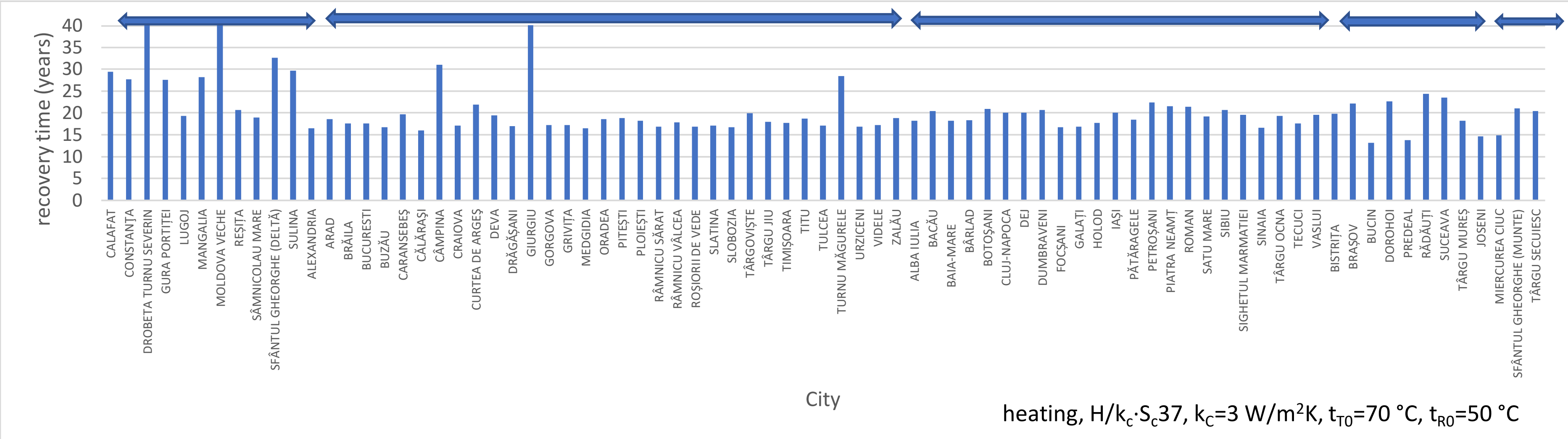

Fig. 157- Recovery time calculated for heating, $H/k_c \cdot S_c=3$, $k_C=3$ W/m^2K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

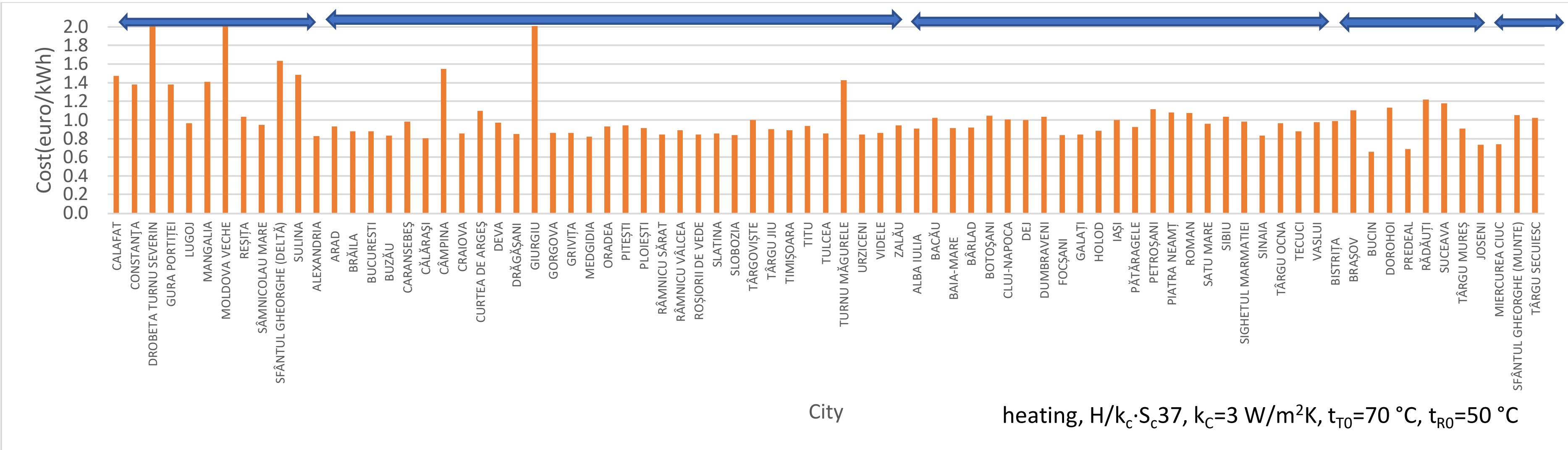

Fig. 158- Specific investment cost calculated for heating, $H/k_c \cdot S_c37$, $k_C=3$ W/m^2K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

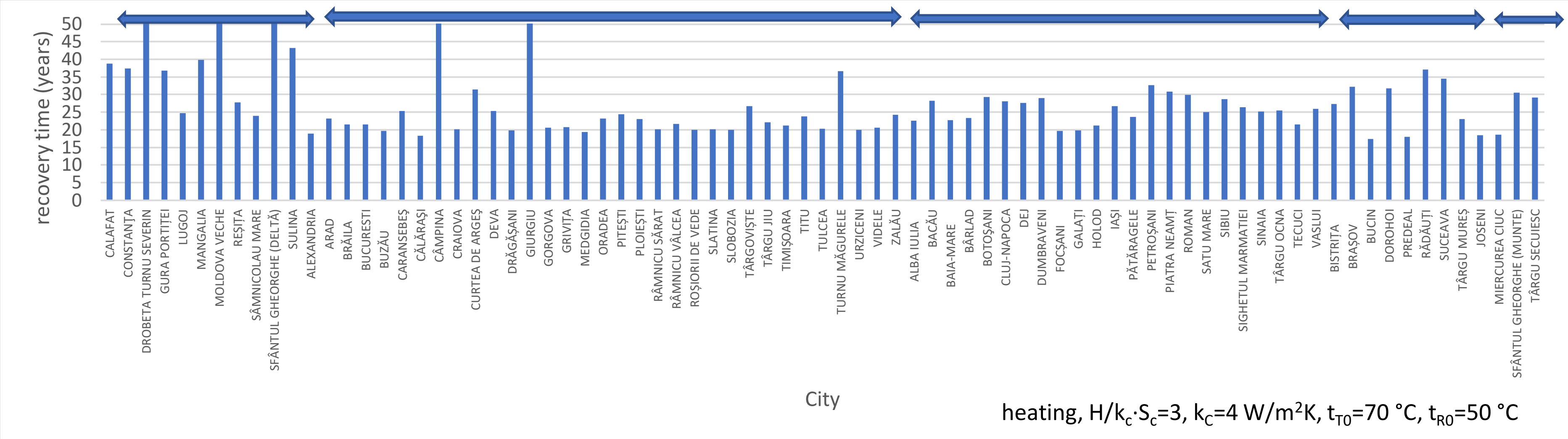

Fig. 159- Recovery time calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

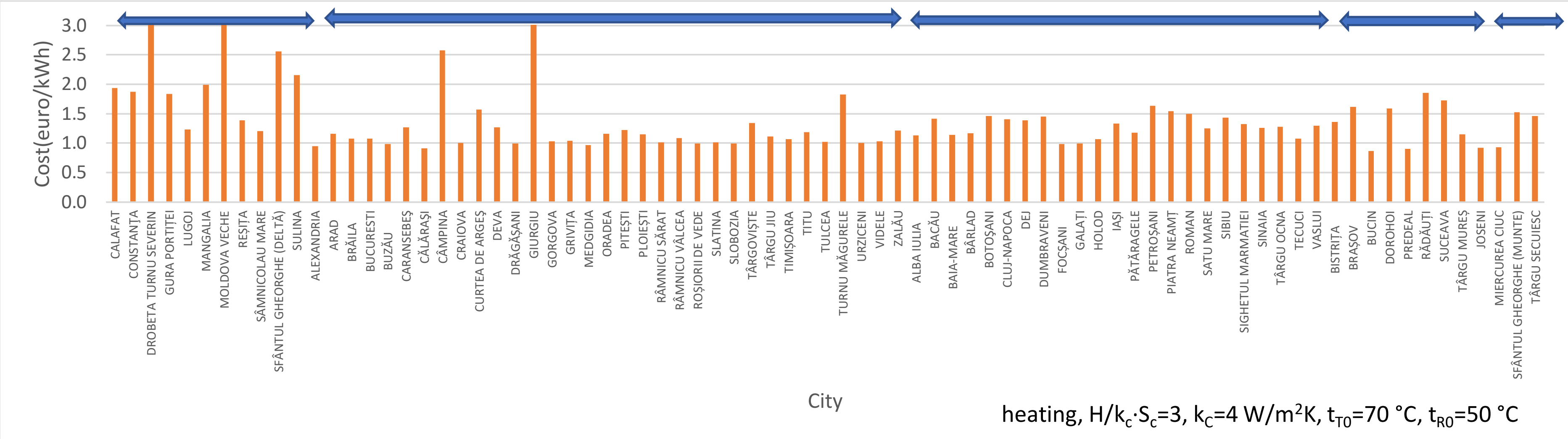

Fig. 160- Specific investment cost calculated for heating, $H/k_c \cdot S_c=3$, $k_C=4$ W/m^{2}K, $t_{T0}=70$ °C, $t_{R0}=50$ °C

Diagramale obținute pentru pentru prepararea apei calde menajere corespunzătoare fiecărui caz (în funcție de raportul H/(kc·Sc), variația k_C, variația temperaturilor de furnizare) sunt următoarele:

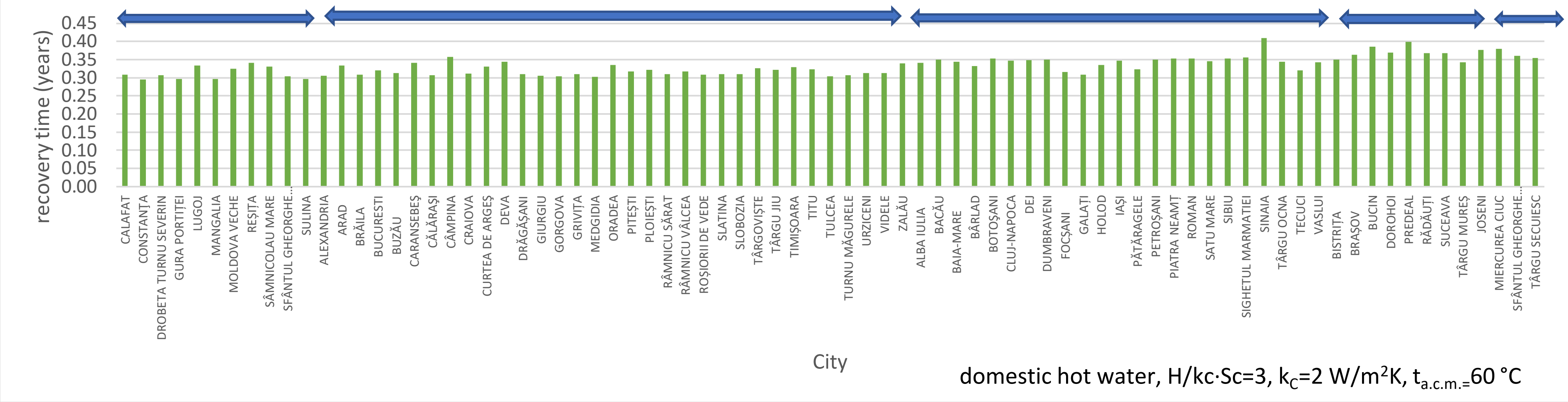

Fig. 161- Calculated recovery time for domestic hot water preparation, H/kc·Sc=3, k_C=2 W/m^{2}K, $t_{a.c.m.=}$60 °C

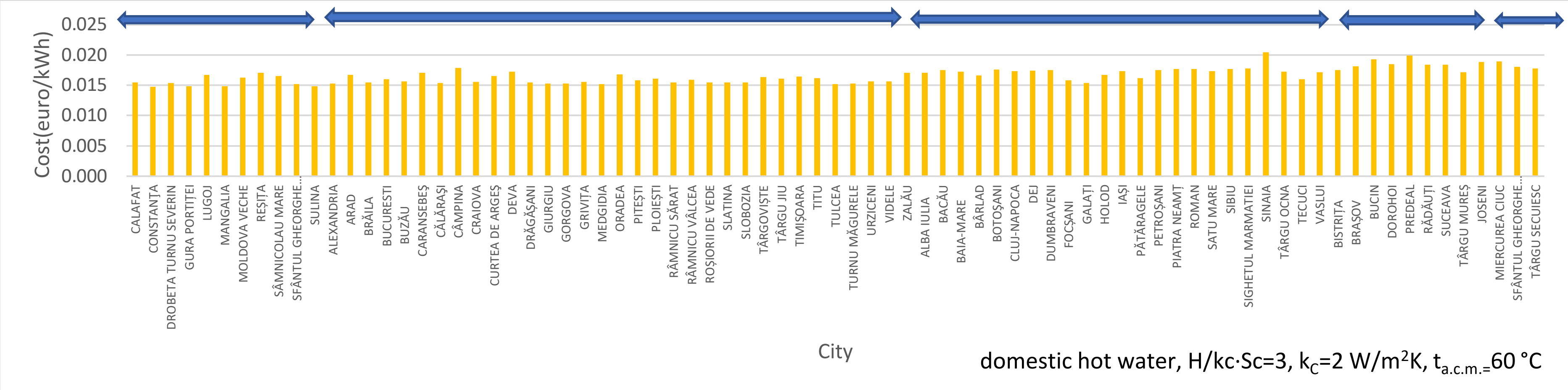

Fig. 162- Calculated recovery time for domestic hot water preparation, H/kc·Sc=3, k_C=2 W/m^{2}K, $t_{a.c.m.=}$60 °C

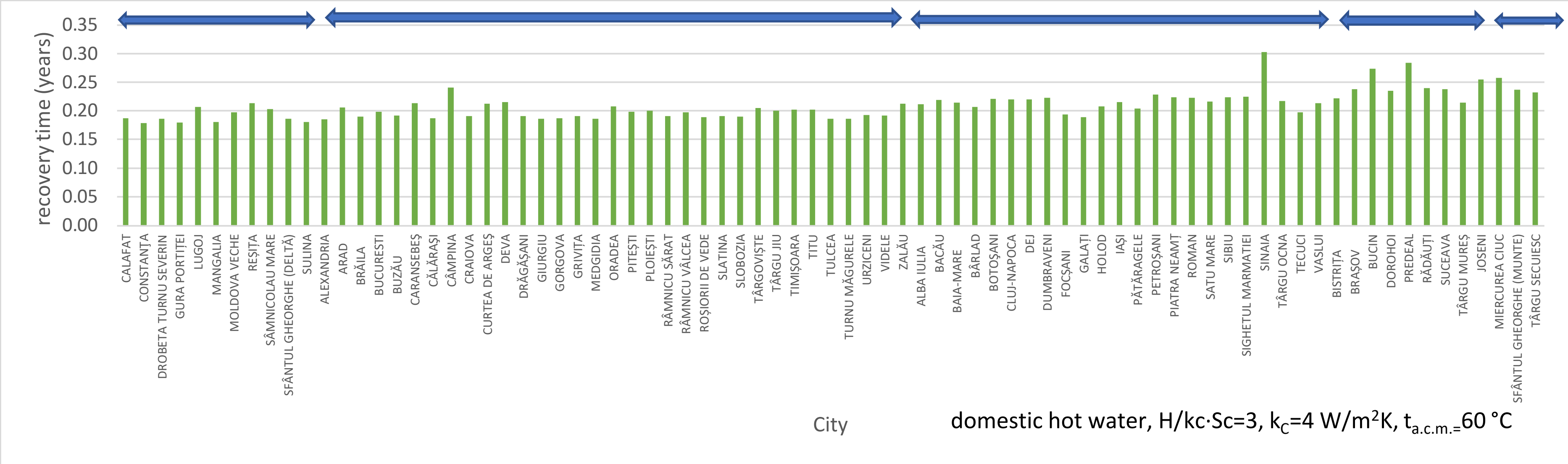

Fig. 163- Calculated recovery time for domestic hot water preparation, H/kc·Sc=3, k_C=4 W/m^{2}K, $t_{a.c.m.=}$60 °C

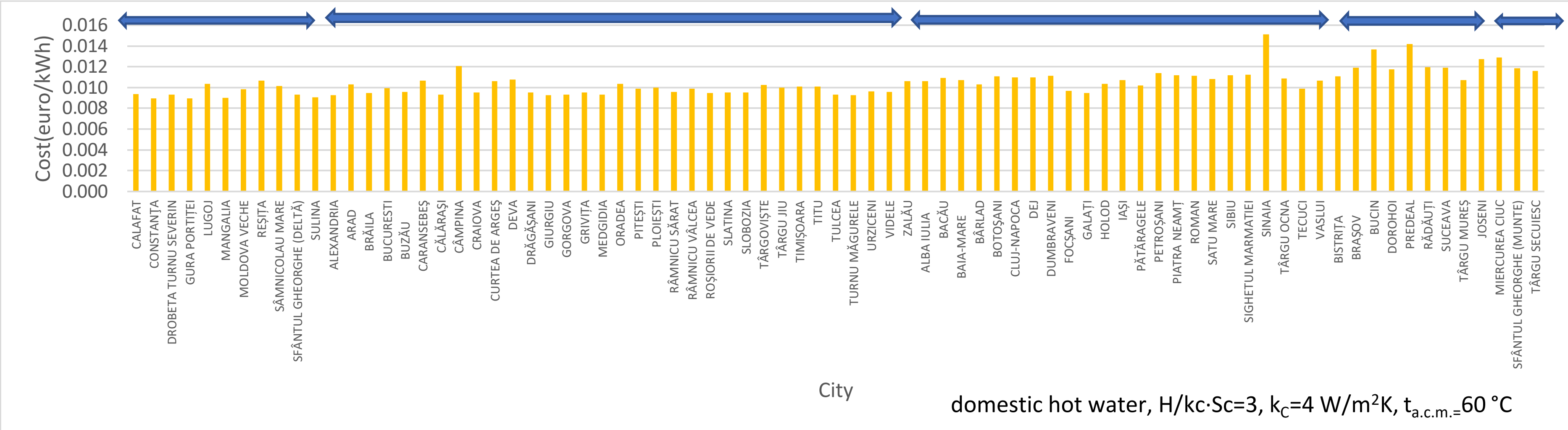

Fig. 164- Calculated recovery time for domestic hot water preparation, H/kc·Sc=3, k_C=4 W/m^{2}K, $t_{a.c.m.=}$60 °C

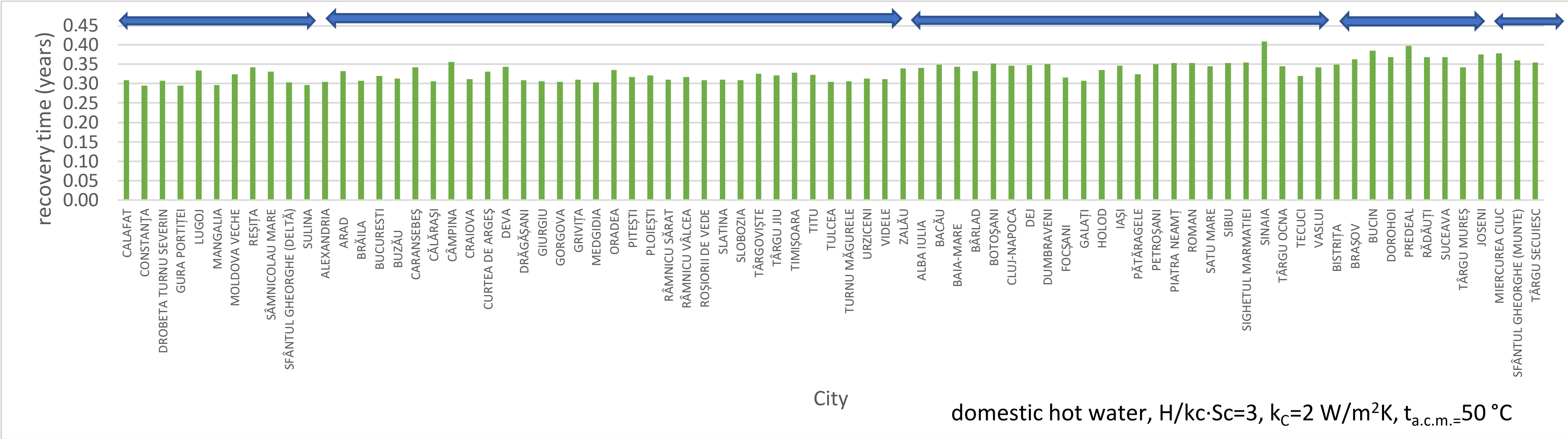

Fig. 165- Calculated recovery time for domestic hot water preparation, $H/kc{\cdot}Sc=3$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=50$ °C

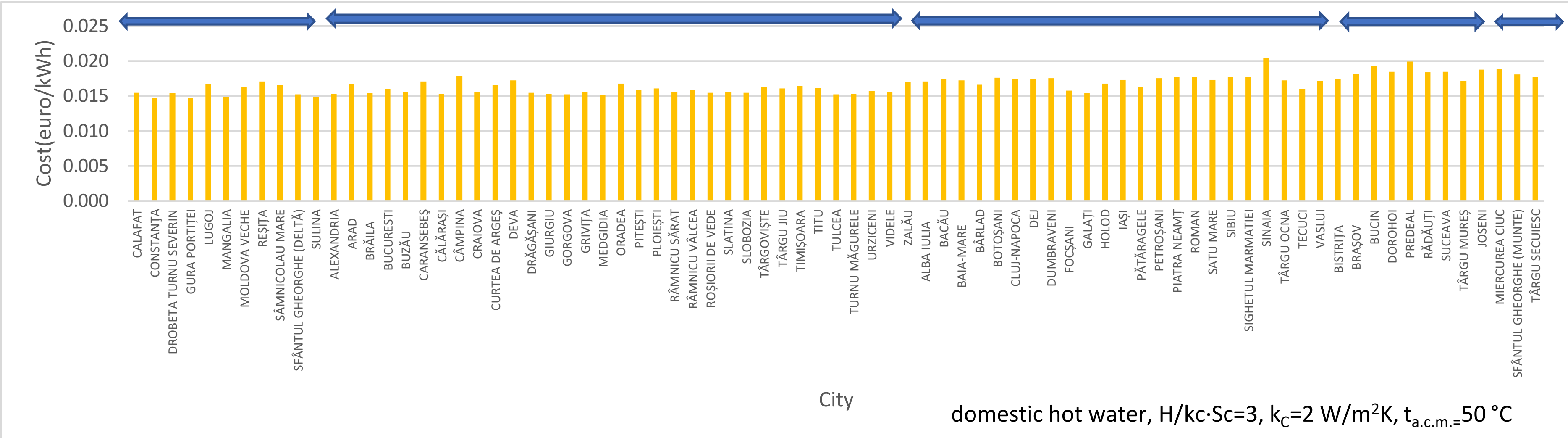

Fig. 166- Calculated recovery time for domestic hot water preparation, $H/kc{\cdot}Sc=3$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=50$ °C

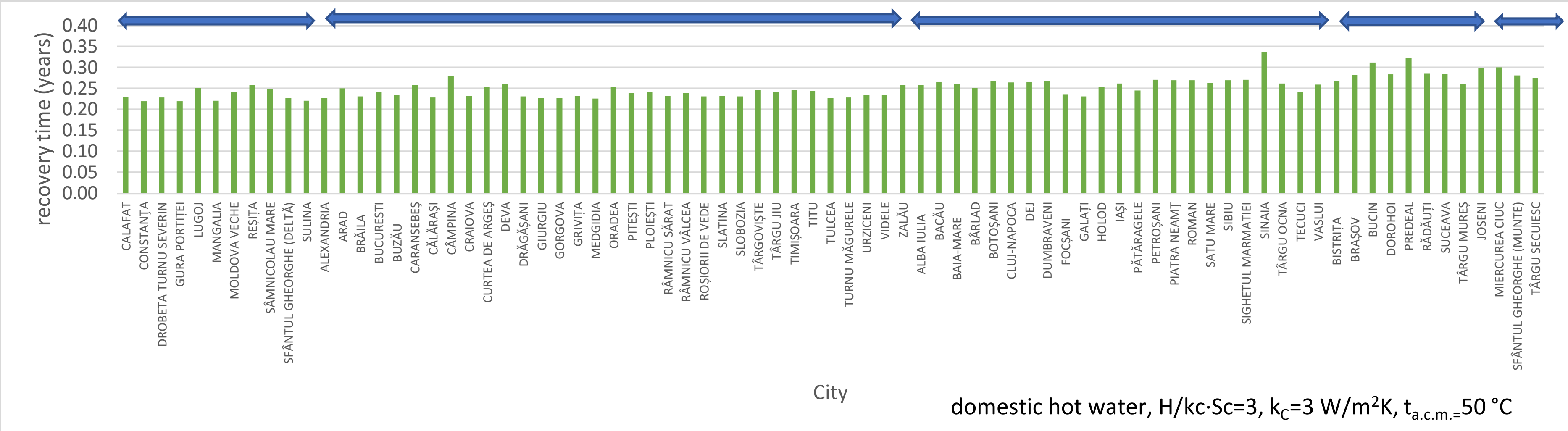

Fig. 167- Calculated recovery time for domestic hot water preparation, $H/k_C \cdot S_C=3$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=50$ °C

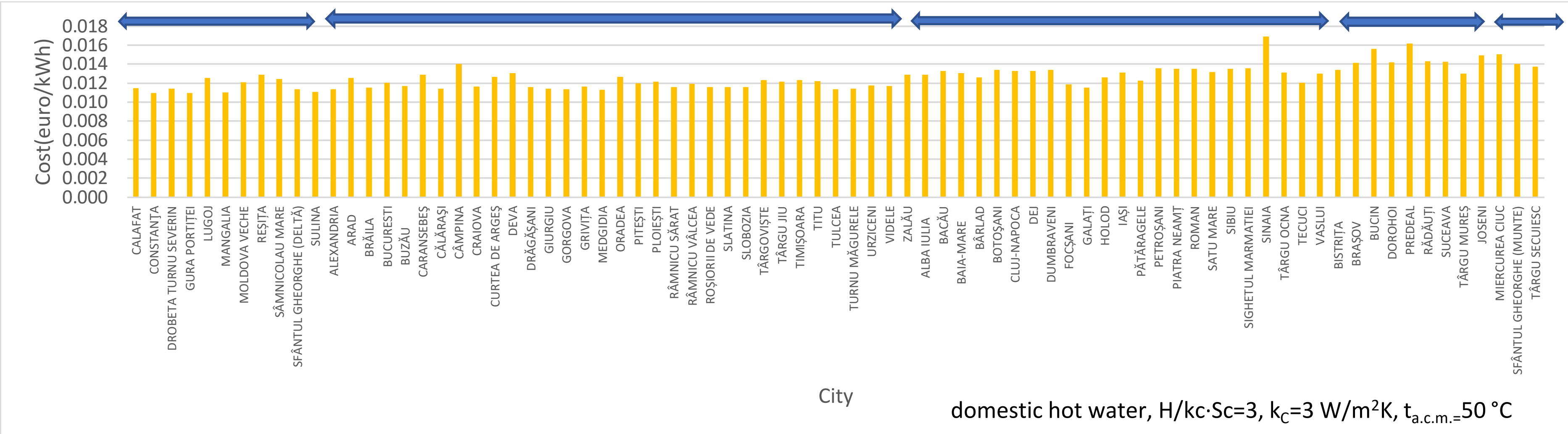

Fig. 168- Calculated recovery time for domestic hot water preparation, $H/k_C \cdot S_C=3$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=50$ °C

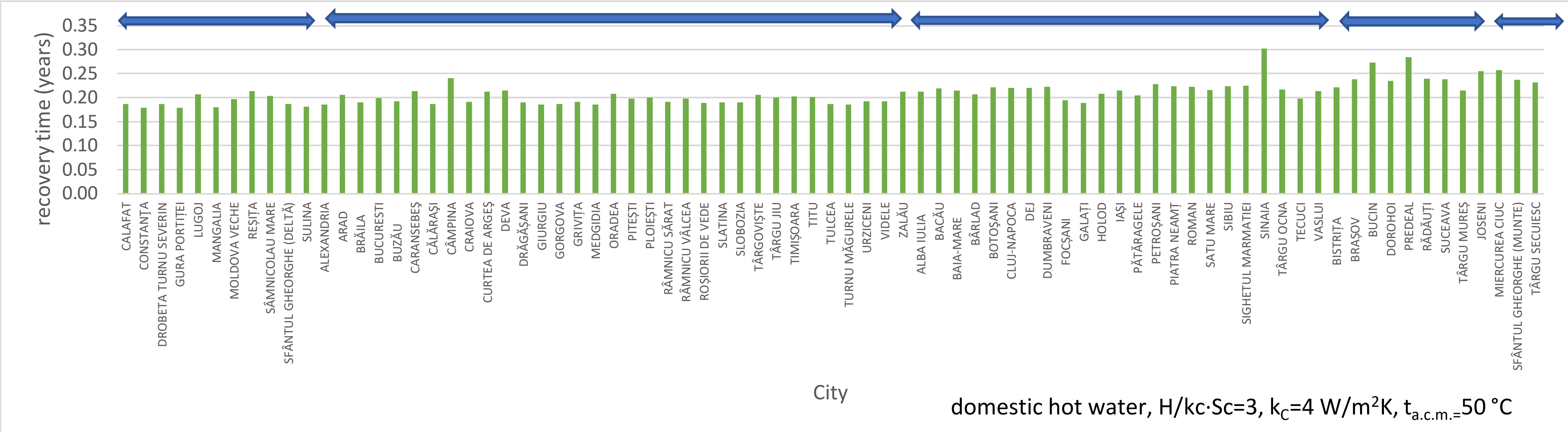

Fig. 169- Calculated recovery time for domestic hot water preparation, H/kc·Sc=3, k_C=4 W/m^{2}K, $t_{a.c.m.=}$50 °C

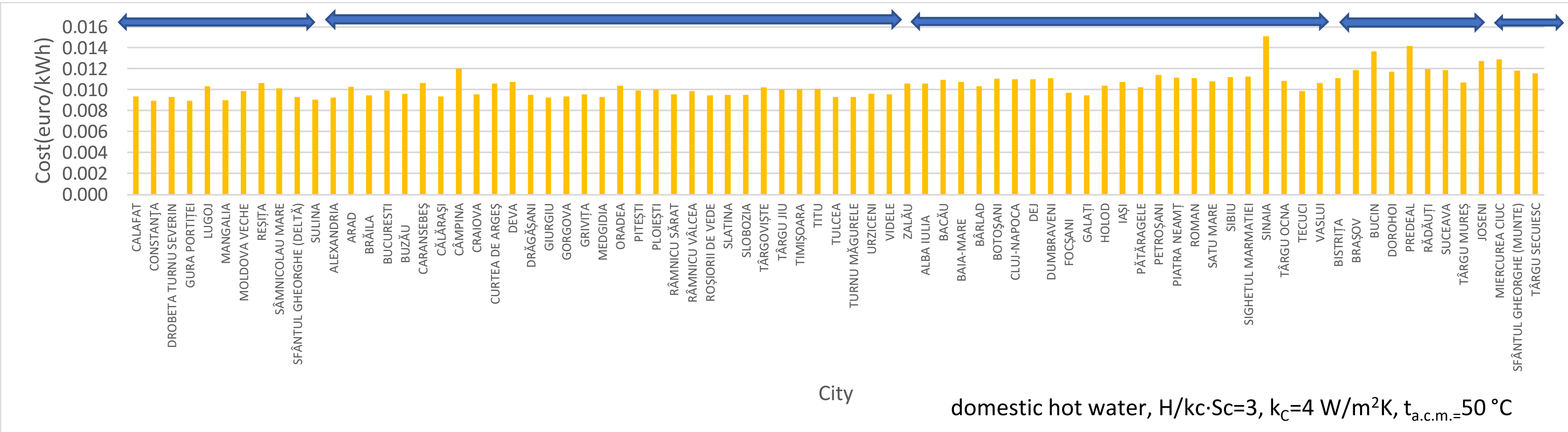

Fig. 170- Calculated recovery time for domestic hot water preparation, H/kc·Sc=3, k_C=4 W/m^{2}K, $t_{a.c.m.=}$50 °C

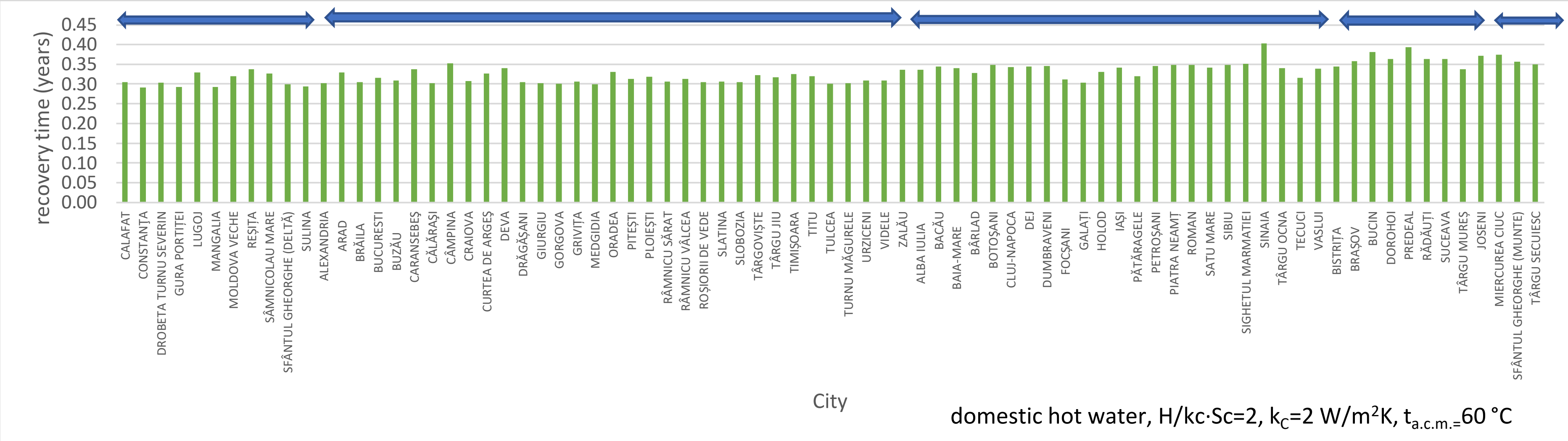

Fig. 171- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=2 W/m^{2}K, $t_{a.c.m.}$=60 °C

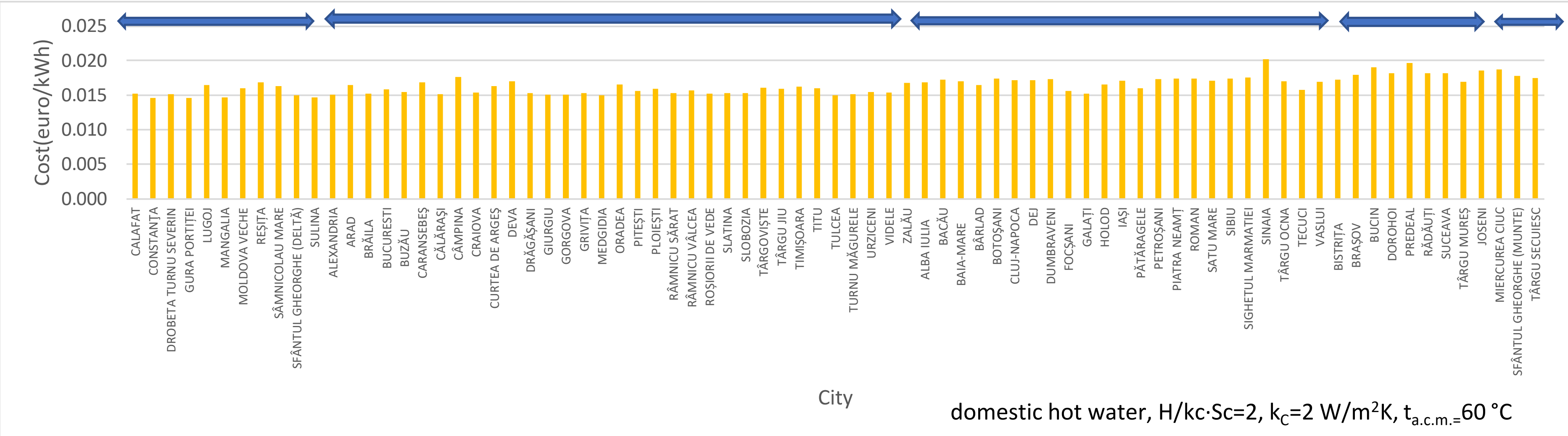

Fig. 172- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=2 W/m^{2}K, $t_{a.c.m.}$=60 °C

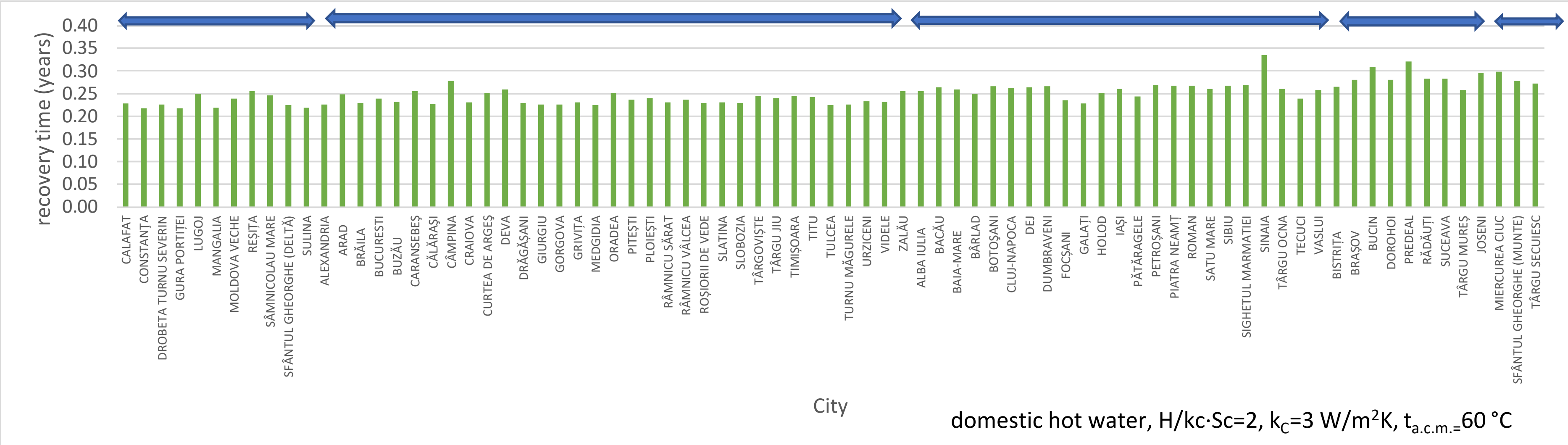

Fig. 173- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=3 W/m^{2}K, $t_{a.c.m.=}$60 °C

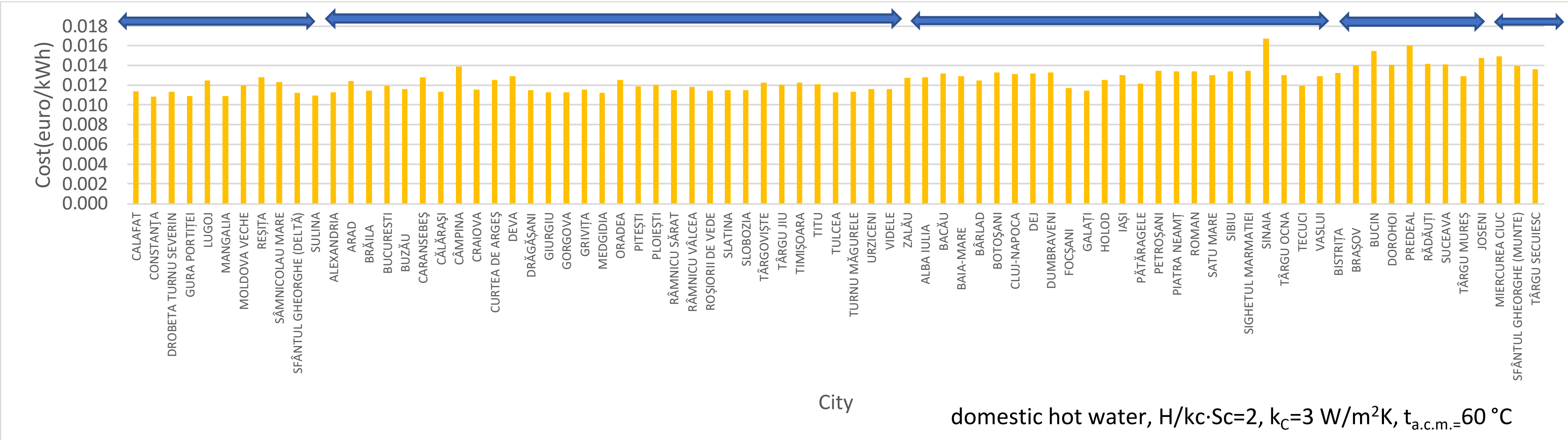

Fig. 174- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=3 W/m^{2}K, $t_{a.c.m.=}$60 °C

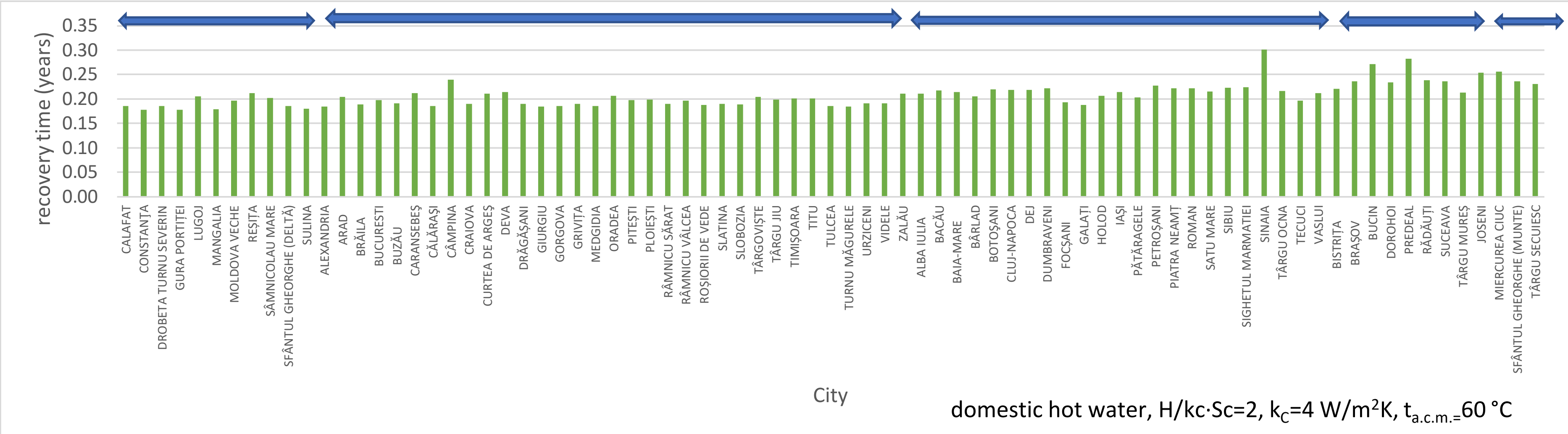

Fig. 175- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=4 W/m^{2}K, $t_{a.c.m.=}$60 °C

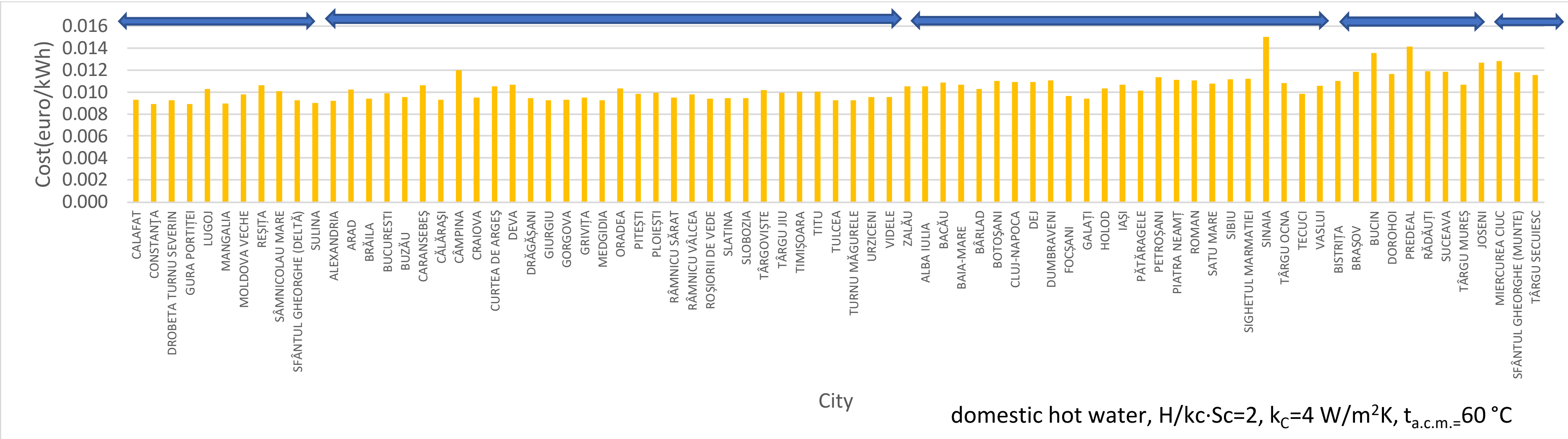

Fig. 176- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=4 W/m^{2}K, $t_{a.c.m.=}$60 °C

Fig. 177- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=2 W/m^{2}K, $t_{a.c.m.=}$50 °C

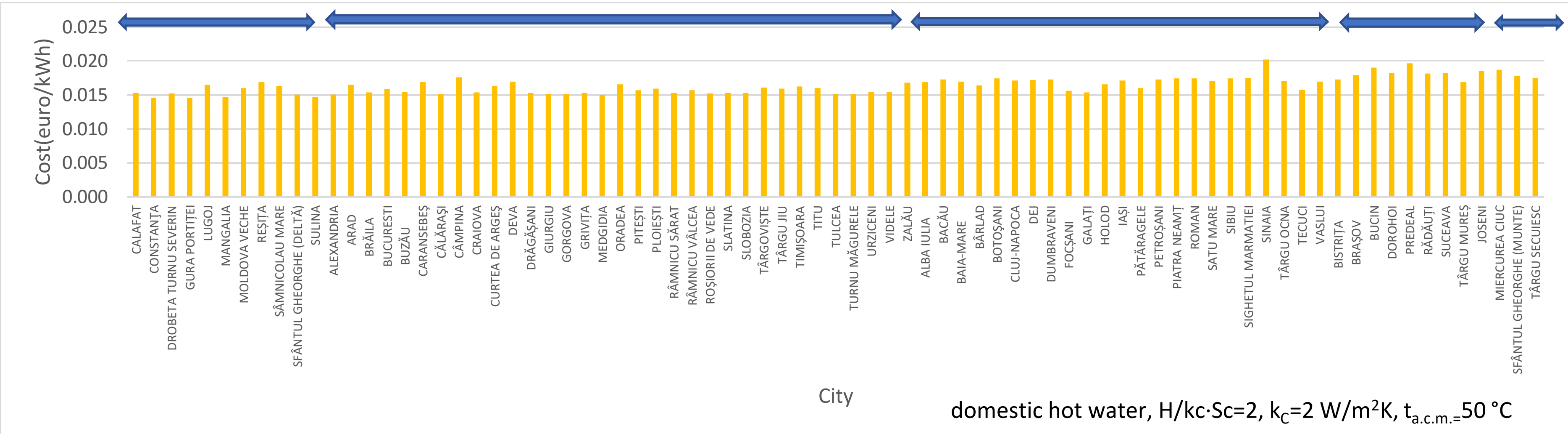

Fig. 178- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=2 W/m^{2}K, $t_{a.c.m.=}$50 °C

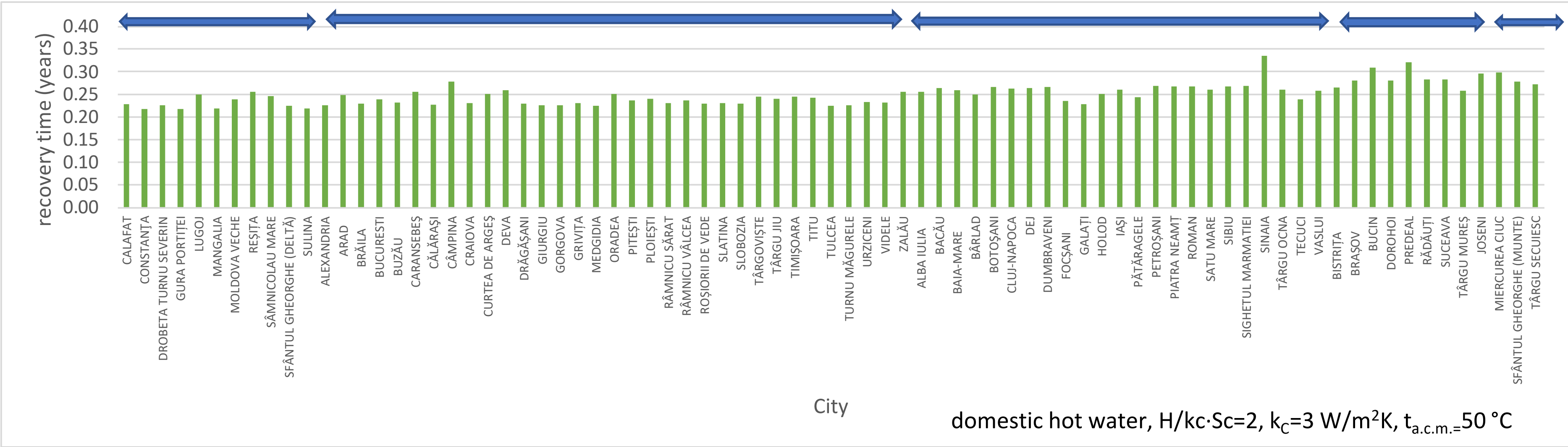

Fig. 179- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=3 W/m^{2}K, $t_{a.c.m.=}$50 °C

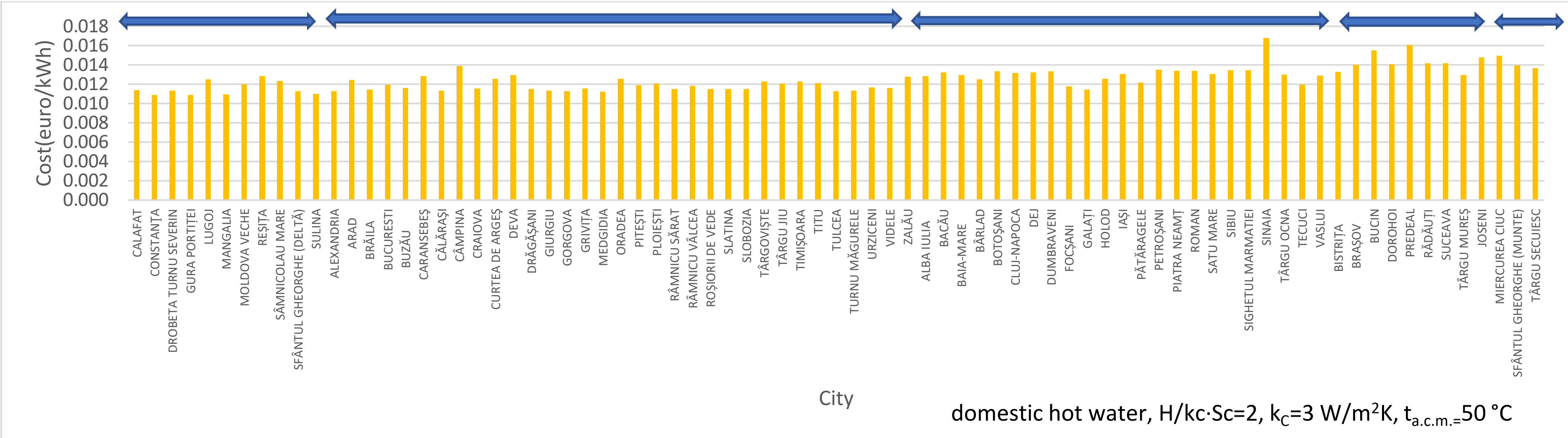

Fig. 180- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=3 W/m^{2}K, $t_{a.c.m.=}$50 °C

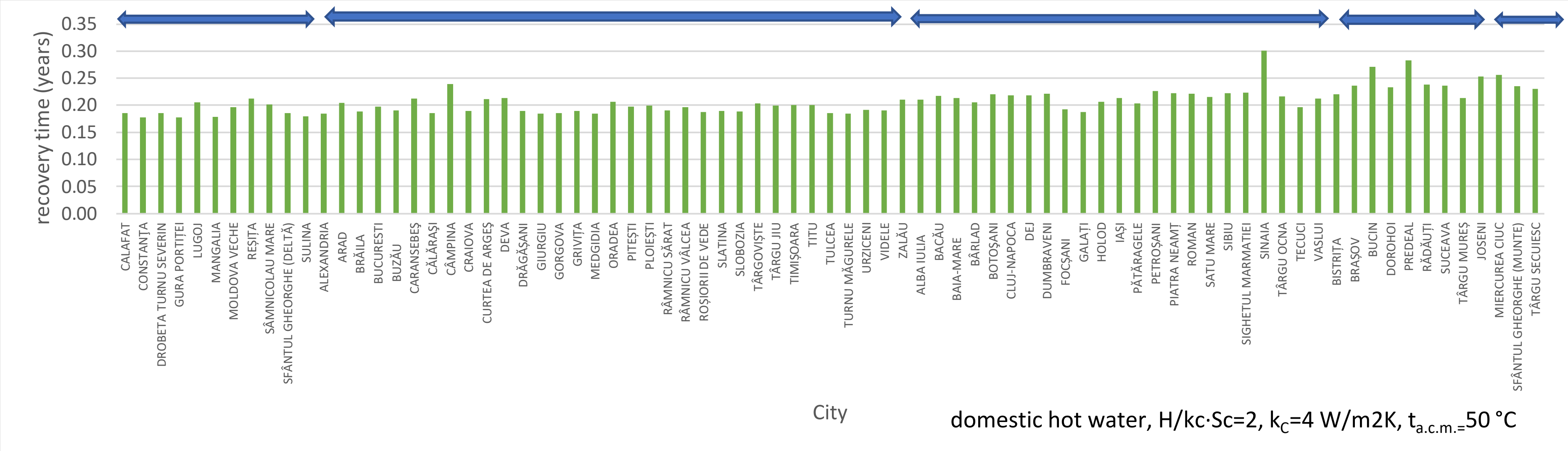

Fig. 181- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=4 W/m2K, $t_{a.c.m.=}$50 °C

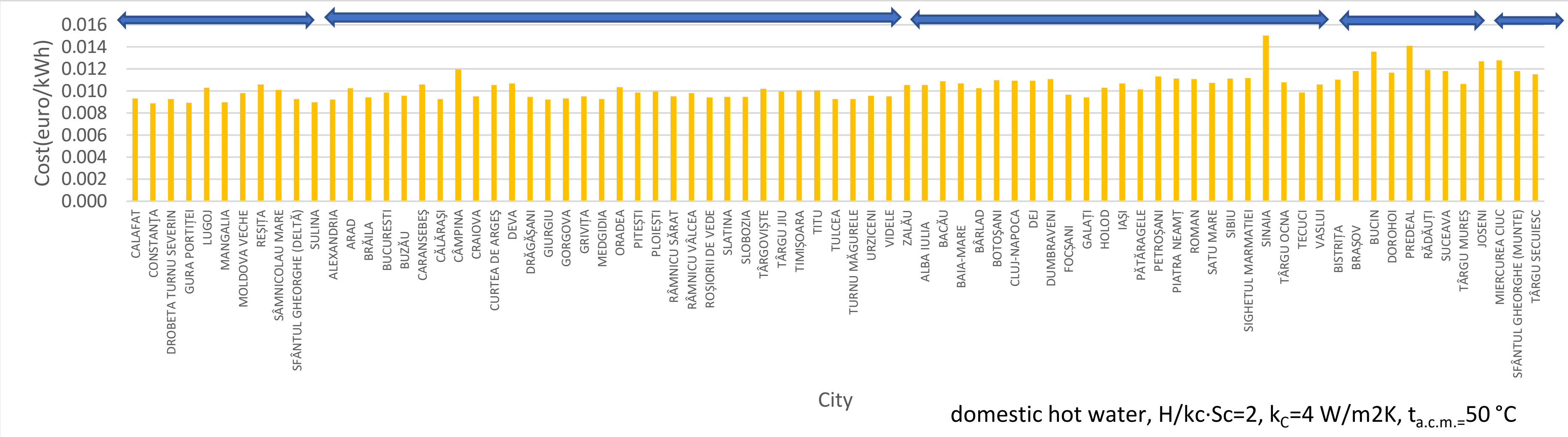

Fig. 182- Calculated recovery time for domestic hot water preparation, H/kc·Sc=2, k_C=4 W/m2K, $t_{a.c.m.=}$50 °C

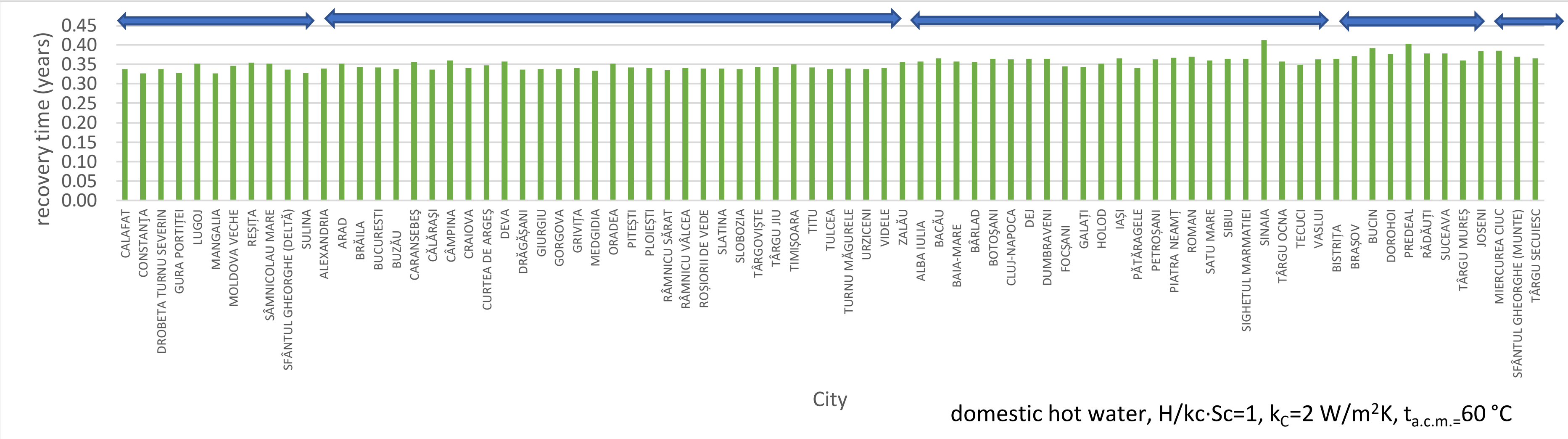

Fig. 183- Calculated recovery time for domestic hot water preparation, H/kc·Sc=1, k_C=2 W/m^{2}K, $t_{a.c.m.}$=60 °C

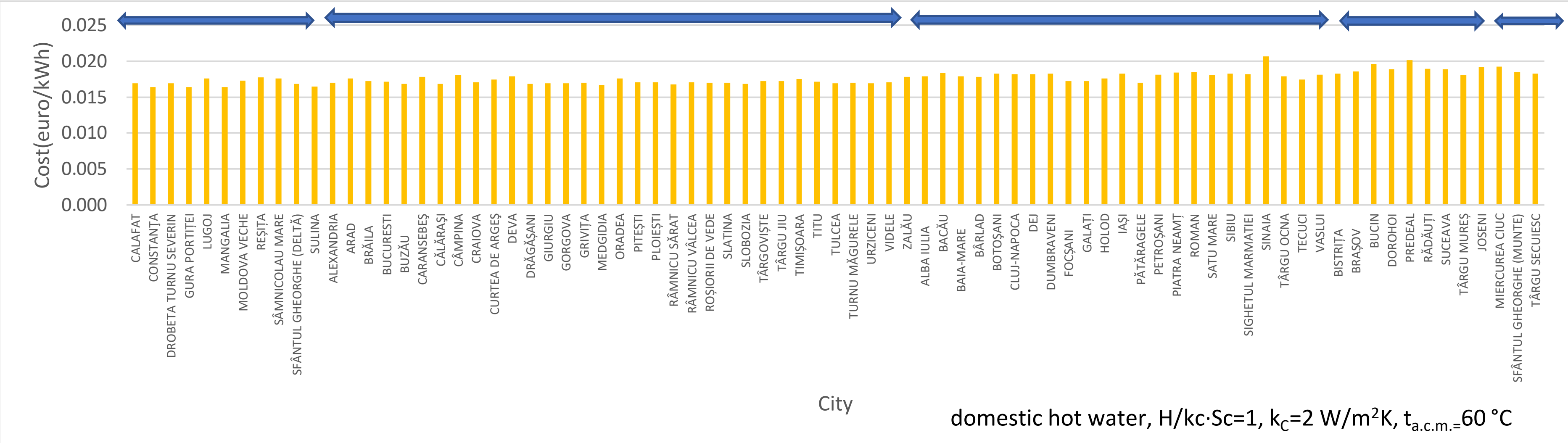

Fig. 184- Calculated recovery time for domestic hot water preparation, H/kc·Sc=1, k_C=2 W/m^{2}K, $t_{a.c.m.}$=60 °C

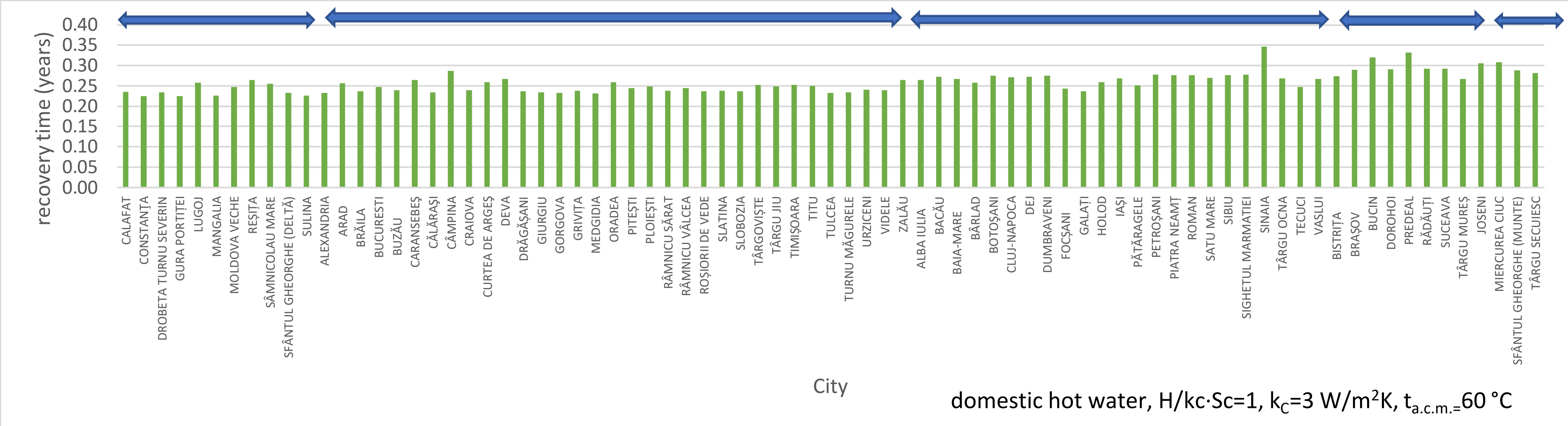

Fig. 185- Calculated recovery time for domestic hot water preparation, $H/k_c \cdot S_c=1$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=60$ °C

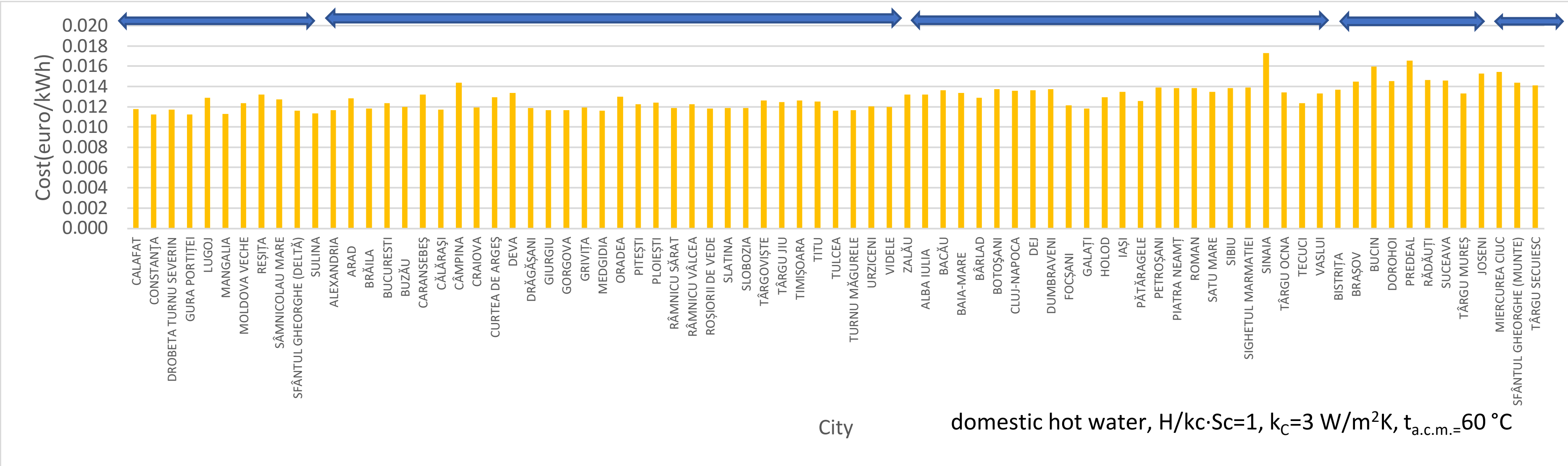

Fig. 186- Calculated recovery time for domestic hot water preparation, $H/k_c \cdot S_c=1$, $k_C=3$ W/m^{2}K, $t_{a.c.m.}=60$ °C

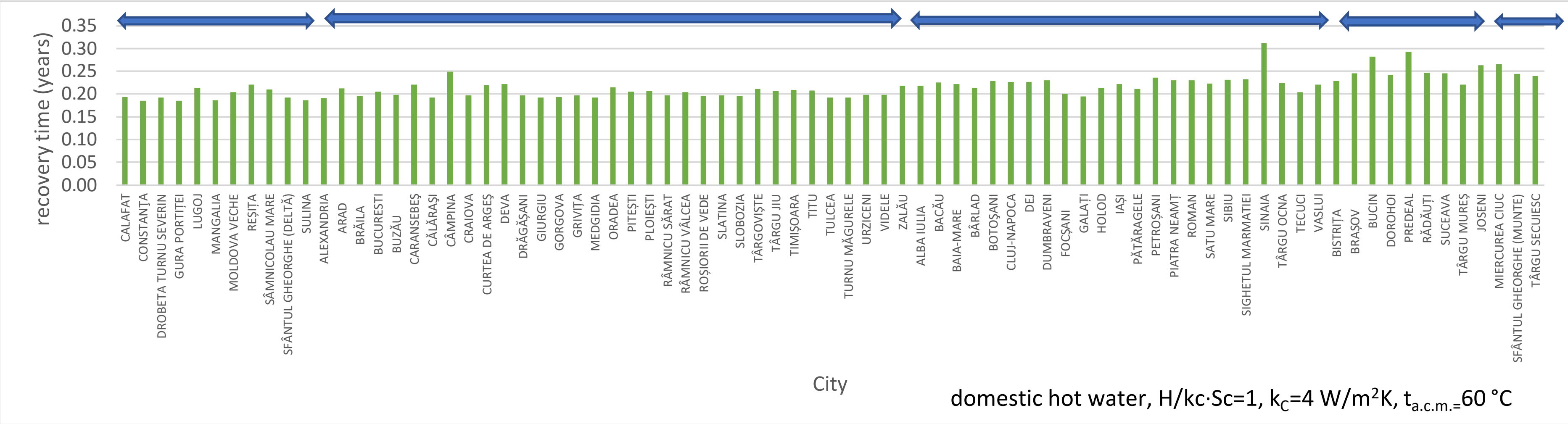

Fig. 187- Calculated recovery time for domestic hot water preparation, H/kc·Sc=1, k_C=4 W/m²K, $t_{a.c.m.=}$60 °C

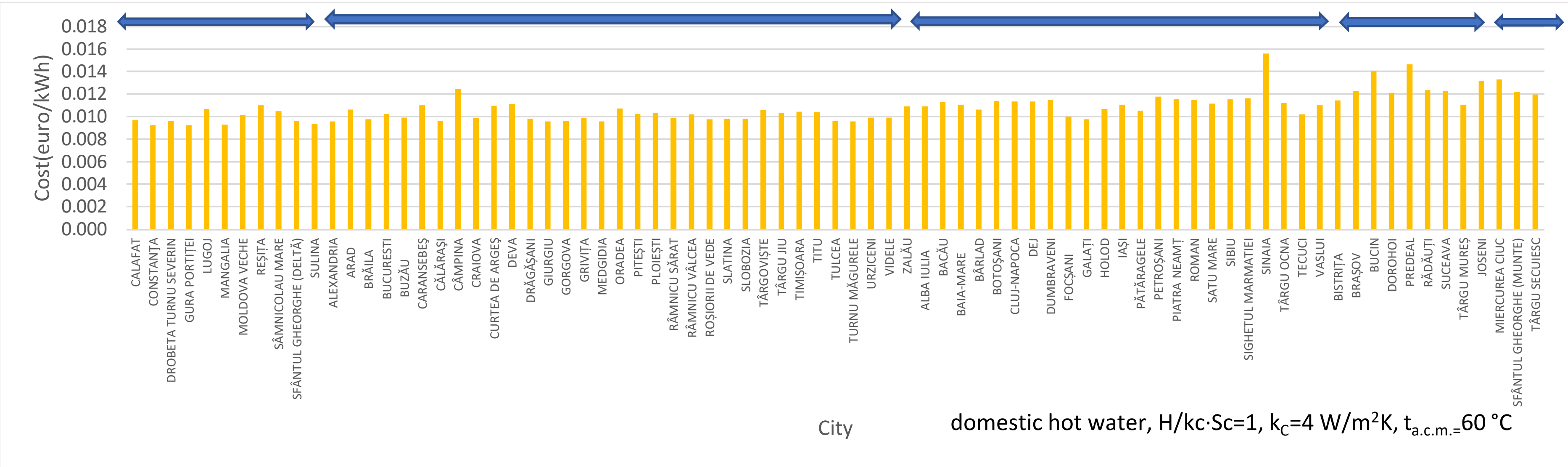

Fig. 188- Calculated recovery time for domestic hot water preparation, H/kc·Sc=1, k_C=4 W/m²K, $t_{a.c.m.=}$60 °C

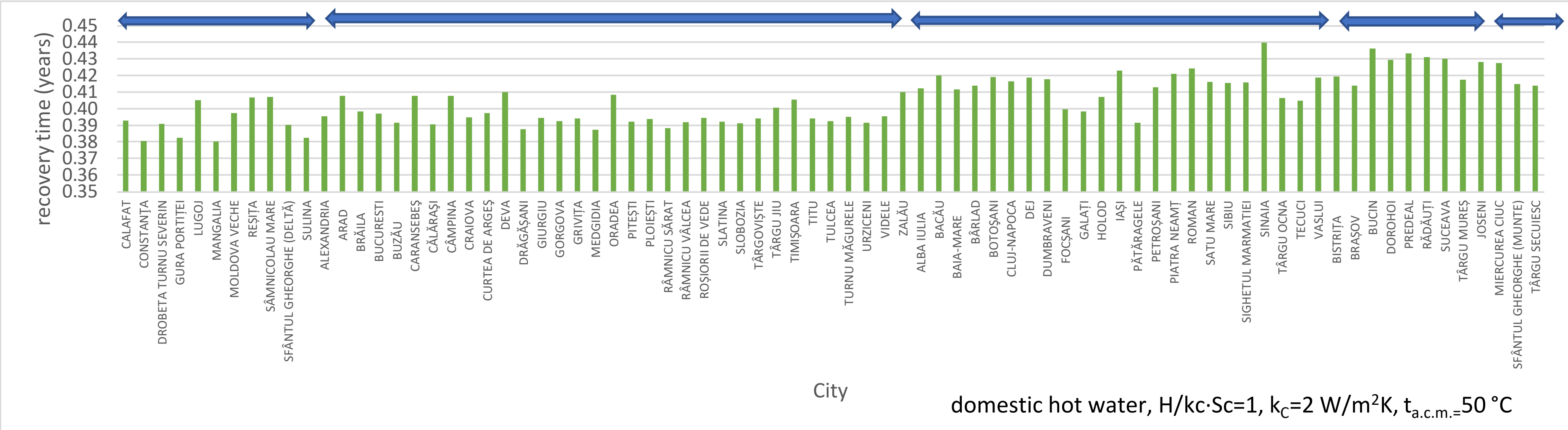

Fig. 189- Calculated recovery time for domestic hot water preparation, $H/kc{\cdot}Sc=1$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=50$ °C

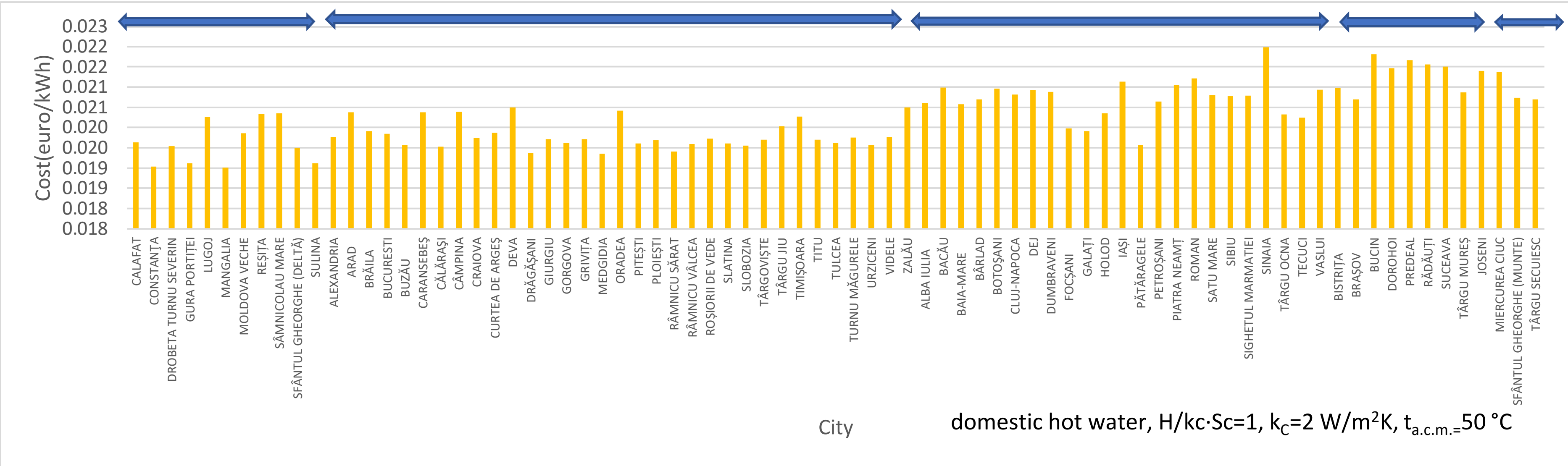

Fig. 190- Calculated recovery time for domestic hot water preparation, $H/kc{\cdot}Sc=1$, $k_C=2$ W/m^{2}K, $t_{a.c.m.}=50$ °C

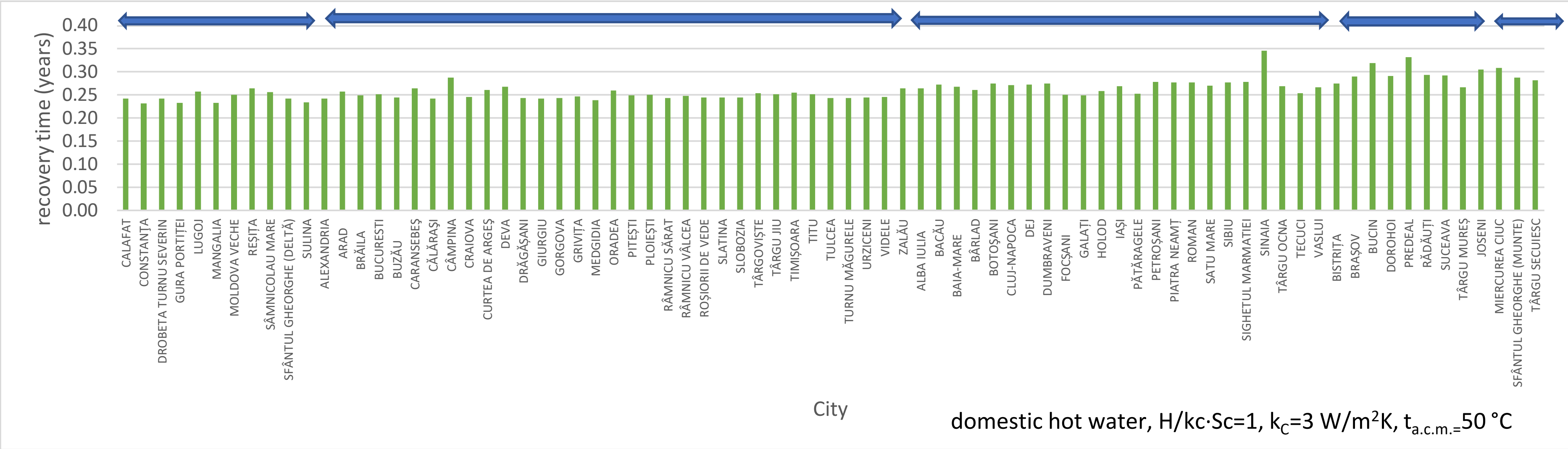

Fig. 191- Calculated recovery time for domestic hot water preparation, $H/k_C \cdot S_C=1$, $k_C=3\ W/m^2K$, $t_{a.c.m.}=50\ °C$

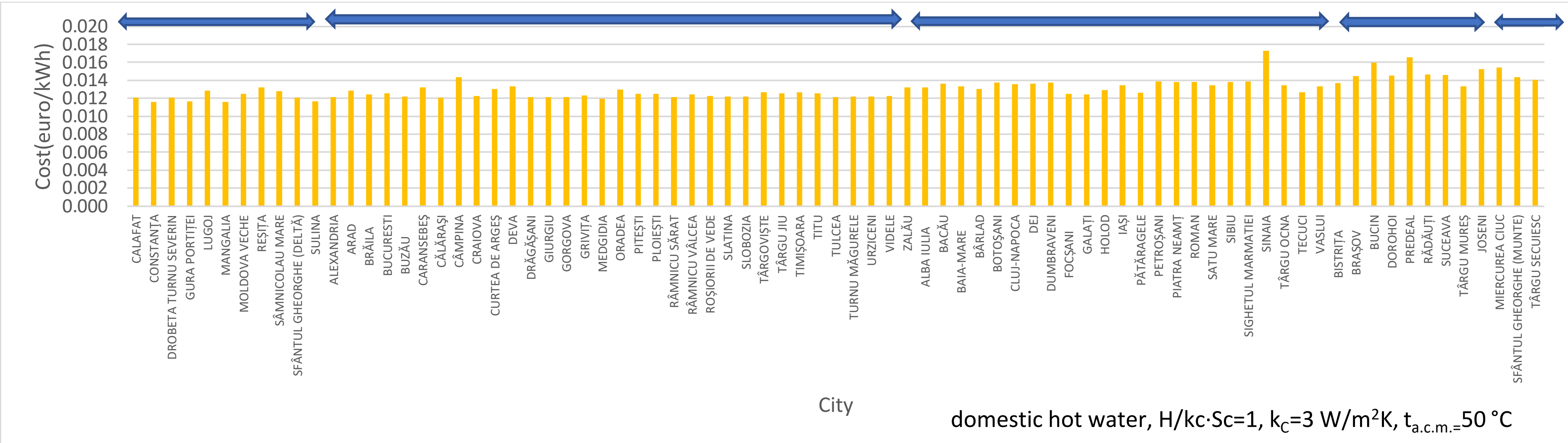

Fig. 192- Calculated recovery time for domestic hot water preparation, $H/k_C \cdot S_C=1$, $k_C=3\ W/m^2K$, $t_{a.c.m.}=50\ °C$

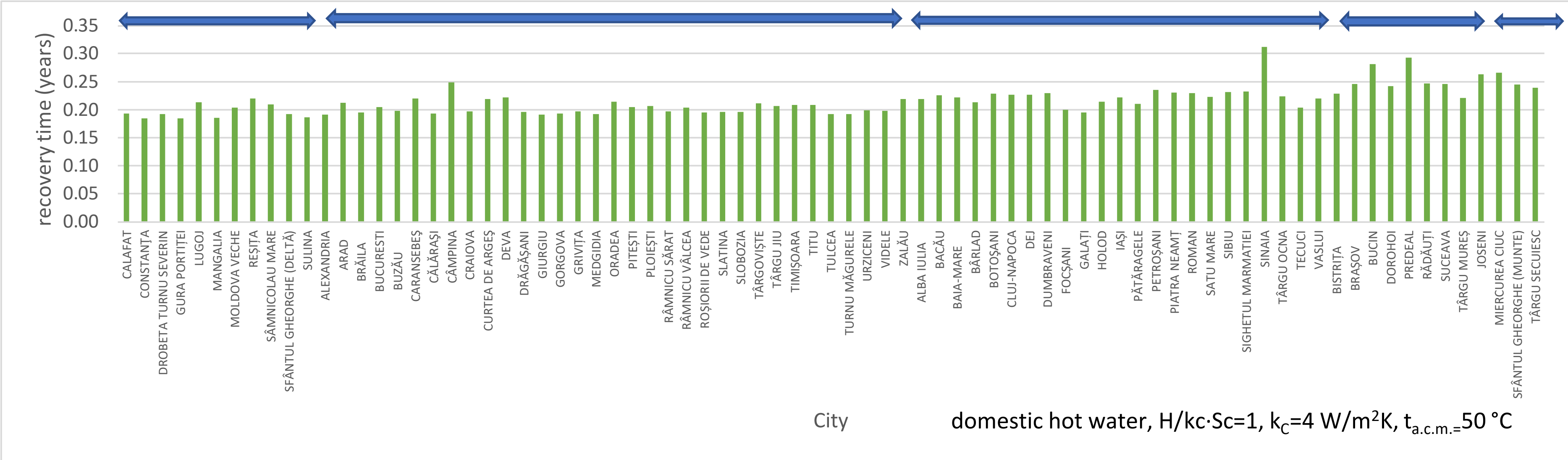

Fig. 193- Calculated recovery time for domestic hot water preparation, H/kc·Sc=1, k_C=4 W/m^{2}K, $t_{a.c.m.=}$50 °C

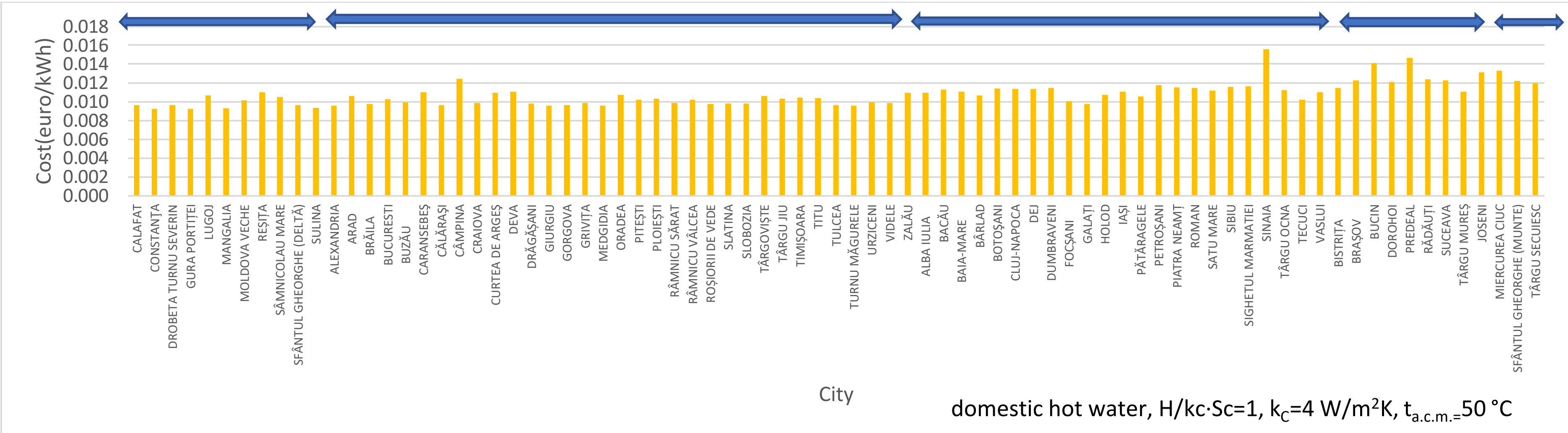

Fig. 194- Calculated recovery time for domestic hot water preparation, H/kc·Sc=1, k_C=4 W/m^{2}K, $t_{a.c.m.=}$50 °C