# Comparative analysis of different heating systems based on the surface area of a household

**C Cristea[1], M Cristea[2], R Tirnovan[3] and C Fagarasan[4]**

[1,2,3] Electrical Engineering Faculty, Technical University of Cluj-Napoca, 26-28 Baritiu Street, Cluj-Napoca, Romania
[4] Machine Building Faculty, Technical University of Cluj-Napoca, 103-105 Muncii Avenue, Cluj-Napoca, Romania

[1]ciprian.cristea@emd.utcluj.ro

**Abstract.** The scope of this paper was to determine if the efficiency of a heating system depends on the surface area of a household and to identify the surface intervals for which a heating system is most appropriate than others. There were considered nine alternatives for the analysis: five different heating sources (wood boiler, electric boiler, gas boiler, pellet boiler and electric heating carpet) combined with two different heating terminals (radiant floor heating and the classic radiator), which were evaluated based on initial investment, fuel cost and the total annual expenditure for each heating system. The results indicated that the type of heating system for a household might vary depending on its surface, considering the three comparison factors mentioned before.

## 1. Introduction

When building or renovating a house, the occupant must decide between different heating systems to assure thermal comfort inside, as it can affect both his/her health and productivity [1]. Selecting the most low-priced system does not always mean that is the most efficient. Besides the raw material and installation costs, there are other factors that can differentiate between heating systems: fuel cost, lifecycle cost, impact on the environment, yield, system guaranty. There are other factors that depend on the area where the house is located, like fuel availability or system autonomy. These criteria can influence the decision maker's opinion in selecting the most appropriate heating system for his/her house.

In previous related research, there have been made some comparisons between different heating systems based on multiple factors like efficiency and cost. In [2] a comparative review of heating systems in EU countries, taking into consideration the seasonal efficiency and fuel cost was made. An analysis was conducted, and the lowest cost was established for the geothermal heat pumps; whereas, the highest cost was determined for the electric heating. A similar study was conducted in [3], where an analysis was developed for residential buildings in the Mediterranean climate, by using criteria like the equipment's efficiency, lifecycle cost and the buildings' location, keeping in mind also their environmental impact. The research indicated that the location of the buildings had a significant impact because, as the results showed, in the metropolitan area, natural gas is the most economical solution. For buildings situated in the urban area, the most economical and environmentally friendly solutions are condensing natural gas boilers. In [4], a new method was used to determine the best heating system in the residential sector of Turkey. This method is called the ex-ergo-environmental analysis, and it is a combination between an exergy analysis and lifecycle assessment. There were considered three heating systems: a conventional coal boiler, a condensing natural gas boiler, and a ground source heat pump.

The primary conclusion of this paper was that the condensing natural gas boilers were the best choice, considering all the circumstances taken into account.

In [5], different heating systems were analyzed and evaluated by using criteria like the basis of the investment, costs of operating as well as the emissions and energy consumption. The study was made on single-family dwellings during renovation works, and the main conclusion was that recovering the existing heating installation was the first step in finding the optimal solution. The second step was the installation of a gas condensing boiler. These two steps would also satisfy the environmental and economic criteria. Fuel cost and equipment efficiency were considered in [6] to compare the heating systems used within several residential areas in Greece; as results, it appears that the geothermal heat pumps have the lowest costs and the electrical heating has the highest cost. In [7], an analysis was made on existing Danish buildings with the following purpose: to provide a list of costs and benefits for low-temperature district heating. The results indicated that an investment in the improved heating system would reduce district heating temperatures. The payback for this investment is estimated to be between 0.3 years to 18.7 years for a customer and between 1.3 years to 4.2 years when considering the total energy system. Distributed and centralized heating systems were put under analysis in [1], in the context of a typical apartment situated in Hangzhou, China. These two heating systems were compared: air-source heat pump (distributed heating) and steam/hot water radiator heating (centralized heating). The result showed that the first one renders 34.5% less carbon dioxide emissions than the second one, and it is preferred if this would be the single decision criteria. The cost was not considered in this article.

In this paper nine alternatives were compared based on initial investment, accounting for criteria such as raw material price, boiler price and installation price, fuel cost and total annual expenditure, considering the system reliability. Also, a sensitivity analysis was made to determine whether the efficiency of a system depends on the surface of the household and if so to indicate which heating system is the most appropriate for each surface interval.

## 2. Heating systems and criteria descriptions

In this study were considered nine heating systems for a household located in Satu-Mare County, Romania, which were evaluated against five criteria, considering the information received from a company dealing with electrical installations work. The first alternative (A1) is represented by the wood boiler combined with radiators, and with radiant floor heating for the second alternative (A2). The wood boiler is most used in rural and mountain areas, due to lack of infrastructure, low fuel cost, and existing storage space. In the same areas, it is also used the pellet boiler, combined with radiators (A7) and radiant floor heating (A8). It is one of the most well-known biomass boilers, being used more and more in residential, industrial, and commercial buildings, which have storage space for the fuel.

The next two alternatives use as a heating source, the electric boiler, which is combined with radiators (A3) and radiant floor heating (A4). This type of boiler is often used in residential and office buildings located in the cities, where the infrastructure is well developed, and the possibility for fuel storage is limited. Another choice for the type of buildings mentioned above is the gas boiler, combined with radiators (A5) and radiant floor heating (A6). This type of boiler is fuelled by natural gas and is considered less expensive than the electric boiler and electric heating carpet (A9).

The alternatives described above are compared against five criteria, and their performances are presented in table 1. The first criterion is the raw material price ([RON/m$^2$]), representing the cost of the heating terminals, calculated per square meter. There are three different values (currently applied on Romanian internal market, more specific in Satu-Mare County): for radiators (60 RON/m$^2$), radiant floor heating (65 RON/m$^2$) and electric heating carpet (45 RON/m$^2$). Depending on the quality of the material, there are different prices on the market. For this paper were considered average values for each type of heating terminal. Another criterion is the boiler's price, which depends on the surface of the household (kW output) that needs to be heated and on the type of fuel. The smaller ones (smaller wattage) have a lower price, while the ones used to heat larger interior spaces are more expensive. Also, the boilers fuelled with natural gas are the cheapest, while the ones fuelled with pellets (an environment-friendly material) have the highest price. The A9 alternative does not need a boiler, electric heating carpets being connected to the house's electrical installation. The installation price ([RON/m$^2$]) is the amount needed to install the entire heating system and depends on the surface of the house. Table 1 briefly presents the performances of the analyzed heating systems.

**Table 1.** Heating systems performances.

| | Raw material price [RON/m$^2$] | Boiler price [RON] | Installation price [RON/m$^2$] | Fuel price [RON/m$^2$/year] | System reliability [years] | |
|---|---|---|---|---|---|---|
| | | | | | Raw material | Boiler |
| **A1** | 65 | 3000-5000 | 85 | 28.36 | 40 | 10 |
| **A2** | 60 | 3000-5000 | 80 | 28.36 | 20 | 10 |
| **A3** | 65 | 2700-3800 | 85 | 138.24 | 40 | 10 |
| **A4** | 60 | 2700-3800 | 80 | 138.24 | 20 | 10 |
| **A5** | 65 | 3000-8000 | 85 | 34.45 | 40 | 10 |
| **A6** | 60 | 3000-8000 | 80 | 34.45 | 20 | 10 |
| **A7** | 65 | 8000-18000 | 85 | 64.36 | 40 | 10 |
| **A8** | 60 | 8000-18000 | 80 | 64.36 | 20 | 10 |
| **A9** | 45 | - | 95 | 180.78 | 50 | - |

The fuel price ([RON/m$^2$/year]) is another criterion used to evaluate the alternatives. For each type of heating system was calculated, the fuel consumption needed to heat a square meter per hour, which was multiplied by the number of hours of operation per year. The annual consumption was then multiplied by the fuel price for each consumed unit to obtain the fuel price per year for each heating system. The last criterion ([years]) represents the lifetime of each heating system, which differs based on the quality of the product. The system reliability is divided considering the two components: heating terminals (raw material) and a heating source (boiler type).

## 3. Comparison factors

To perform the sensitivity analysis, the performances of the nine alternatives (A1-A9) were evaluated against three factors: initial investment, fuel cost and total annual expenditure, which were calculated for various surface, ranging from 100 to 300 square meters. The first factor, initial investment ($I$), is calculated for each alternative considering the raw material price ($p_{rw}$), boiler price ($p_b$), installation price ($p_i$) and household surface ($h_s$), with the following formula:

$$I = p_{rw} \cdot h_s + p_b + p_i \cdot h_s \tag{1}$$

The fuel cost ($C_f$) depends only on the fuel price ($p_f$) criterion and the household surface ($h_s$):

$$C_f = p_f \cdot h_s \tag{2}$$

The last factor, total annual expenditure ($C_T$), was calculated based on raw material price ($p_{rw}$), boiler price ($p_b$), installation price ($p_i$), household surface ($h_s$), raw material reliability ($r_{rw}$), boiler reliability ($r_b$) and fuel cost ($C_f$) with the following equation:

$$C_T = \frac{p_{rw} \cdot h_s}{r_{rw}} + \frac{p_b \cdot h_s}{r_b} + p_i + C_f \tag{3}$$

## 4. Results

To select the optimal heating system for a household located in Satu-Mare County, Romania, a sensitivity analysis was performed to determine which alternative is more appropriate based on the surface of the household. Several heating systems were evaluated considering three significant factors: initial investment, fuel cost, and total annual expenditure.

The results obtained after the first simulation, where the performances of the analyzed alternatives were evaluated considering an initial investment, are presented in table 2. The evolution of each alternative, considering the household surface is described in figure 1. It can be noticed that for a household which has the surface area between [100-160] square meters, the most appropriate solution is A4, followed closely by A2 and A6. The alternatives with the highest initial investment for the same surface are A7, A8, and A9. For the surface interval [160-290] square meters, the initial investment fluctuates, determining the change of places between the alternatives, until [290-300] square meters, where the ranking is: A4, A2, A3, A1, A6, A5, A9, A8, A7.

**Table 2.** Alternatives performances considering the initial investment.

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 |
|---|---|---|---|---|---|---|---|---|---|
| **100** | 18,000 | 17,000 | 17,700 | 16,700 | 18,000 | 17,000 | 23,000 | 22,000 | 19,500 |
| **110** | 19,500 | 18,400 | 19,200 | 18,100 | 19,500 | 18,400 | 24,500 | 23,400 | 21,450 |
| **120** | 21,000 | 19,800 | 20,700 | 19,500 | 21,000 | 19,800 | 26,000 | 24,800 | 23,400 |
| **130** | 22,500 | 21,200 | 22,200 | 20,900 | 22,500 | 21,200 | 27,500 | 26,200 | 25,350 |
| **140** | 24,000 | 22,600 | 23,700 | 22,300 | 24,000 | 22,600 | 30,000 | 28,600 | 27,300 |
| **150** | 25,500 | 24,000 | 25,200 | 23,700 | 25,500 | 24,000 | 31,500 | 30,000 | 29,250 |
| **160** | 27,000 | 25,400 | 26,700 | 25,100 | 27,000 | 25,400 | 33,000 | 31,400 | 31,200 |
| **170** | 28,500 | 26,800 | 28,200 | 26,500 | 28,500 | 26,800 | 34,500 | 32,800 | 33,150 |
| **180** | 30,000 | 28,200 | 29,700 | 27,900 | 30,000 | 28,200 | 36,000 | 34,200 | 35,100 |
| **190** | 32,500 | 30,600 | 31,500 | 29,600 | 32,500 | 30,600 | 38,500 | 36,600 | 37,050 |
| **200** | 34,000 | 32,000 | 33,000 | 31,000 | 34,000 | 32,000 | 40,000 | 38,000 | 39,000 |
| **210** | 35,500 | 33,400 | 34,500 | 32,400 | 35,500 | 33,400 | 42,500 | 40,400 | 40,950 |
| **220** | 37,000 | 34,800 | 36,000 | 33,800 | 37,000 | 34,800 | 44,000 | 41,800 | 42,900 |
| **230** | 38,500 | 36,200 | 37,500 | 35,200 | 39,500 | 37,200 | 46,500 | 44,200 | 44,850 |
| **240** | 40,000 | 37,600 | 39,000 | 36,600 | 41,000 | 38,600 | 48,000 | 45,600 | 46,800 |
| **250** | 41,500 | 39,000 | 40,500 | 38,000 | 42,500 | 40,000 | 50,500 | 48,000 | 48,750 |
| **260** | 43,000 | 40,400 | 42,000 | 39,400 | 45,000 | 42,400 | 52,000 | 49,400 | 50,700 |
| **270** | 45,500 | 42,800 | 43,500 | 40,800 | 47,500 | 44,800 | 55,500 | 52,800 | 52,650 |
| **280** | 47,000 | 44,200 | 45,000 | 42,200 | 49,000 | 46,200 | 57,000 | 54,200 | 54,600 |
| **290** | 48,500 | 45,600 | 47,300 | 44,400 | 51,500 | 48,600 | 59,500 | 56,600 | 56,550 |
| **300** | 50,000 | 47,000 | 48,800 | 45,800 | 53,000 | 50,000 | 63,000 | 60,000 | 58,500 |

The same procedure was used to compare the alternatives considering the fuel cost. The results are presented in figure 2 and indicate that the most appropriate heating source is the wood boiler (A1 and A2), followed by the gas boiler (A5 and A6). Also, it can be noticed that the alternatives A3, A4, and A9 have a more pronounced growth of the fuel cost than the other alternatives.

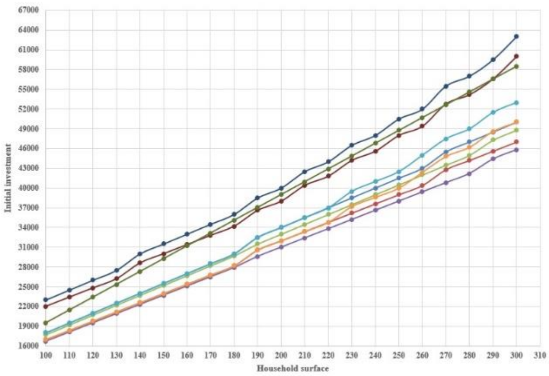


**Figure 1.** Sensitivity analysis based on the initial investment.

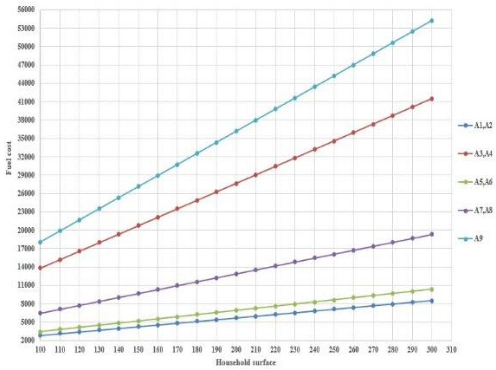


**Figure 2.** Sensitivity analysis based on fuel cost.

The results from the final simulation, regarding total annual expenditure, are described in figure 3. For the surface interval [100-150] square meters, there are four alternatives that can be considered appropriate for a household, and these are: A2, A7, A6, and A5. The total annual expenditure difference between these alternatives is relatively low for the interval surface mentioned above. For [150-200] square meters, it can be noticed a slightly increasing difference between the four alternatives, which becomes higher as the surface of the household grows ([250-300 square meters]).

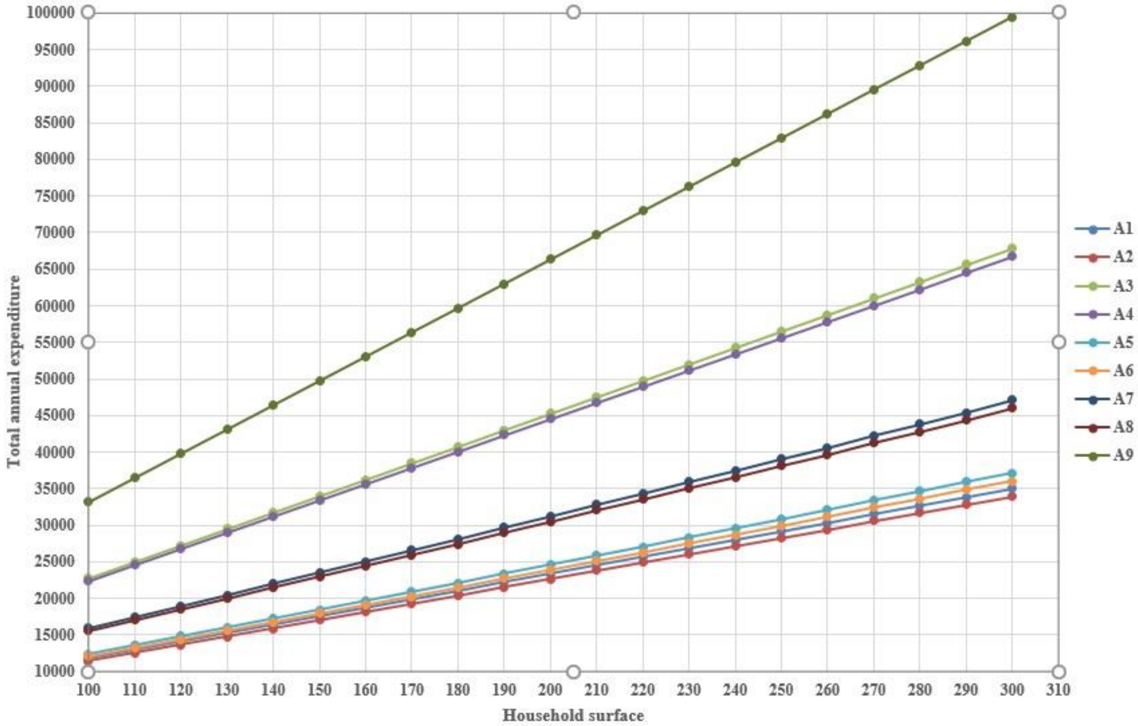


**Figure 3.** Sensitivity analysis regarding total annual expenditure.

## 5. Conclusions

In this study, a sensitivity analysis was performed to determine if the performances of the analyzed alternatives depend on the surface of the household and to identify the optimal solution for each surface interval for a household located in Satu-Mare County, Romania. The results obtained suggest that the type of heating system depends on the surface area of the household, considering the initial investment. The sensitivity analysis performed based on fuel cost and total annual expenditure are robust, but it can be observed an increasingly pronounced growth of costs between the best ranked alternatives and the worst ranked ones, in both cases.

## 6. References

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