A Comparison of Various Heating Systems in Greece Based on Efficiency and Fuel Cost

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"Abstract". Scope of the study is to compare the most commonly used heating systems in the residential building sector in Greece, using as criteria equipment efficiency and fuel cost. Due to the insufficient thermal protection in the majority of buildings, space heating is the major energy consuming activity in the building sector. This fact, combined with the current economic crisis as well as the high cost of energy carriers, has caused a great concern regarding heating expenses in buildings. Therefore over the past five years the cost of energy is usually the most dominating factor in determining the selection of a heating system. Nowadays a variety of technologies are available, with each heating system having distinct advantages and disadvantages, therefore it is necessary to examine various alternatives before the final selection and installation at a house. Selecting an appropriate heating system, either as a replacement or for a new home, requires a basic understanding of the different types of systems, their pros and cons, their efficiency ratings and running costs. This study aims to facilitate this selection by describing and comparing different heating systems, by identifying their advantages and disadvantages, and by giving a classification based on their running cost.

Keywords: heating system; residential building; efficiency; fuel cost; operating cost

1. Introduction

Buildings worldwide constitute one of the biggest energy consumers with 32% of the total final energy consumption, while in terms of primary energy consumption they represent around 40% in most countries according to the International Energy Agency. In the United States commercial and residential buildings use almost 41% of the total primary energy consumption [1]. The same trend is also evident in Europe as the building sector accounts for 40,7% of the total final energy consumption (1.103,8 million tons of oil equivalent in 2013) in EU-28 of which 295,8 million tons of oil equivalent in residential buildings and 152,3 in non-residential buildings. Space heating represents 69% of total household consumption, followed by water heating at 11% for 2013 [2]. Moreover, residential buildings are the fourth largest source of CO_2 emissions in the EU and account for 9,9% of total emissions in 2007, while emissions from non-residential buildings are ranked fifth and account for 3,9% of the total CO_2 emissions in EU-27 [2].

The residential sector in Greece was responsible for 29,44% of the total final energy consumption in 2012 [3]. According to a recent survey [4], every household in the country consumes, on average, 10,2 MWh of thermal energy, for space heating, hot water production and cooking and 3,75 MWh of electricity for the various electrical appliances.

According to the same survey, almost every house (98,9%) in Greece has some form of space heating with the majority using diesel heating oil (Type 2 diesel) as their fuel of choice and electricity, natural gas and biomass following with less than 12% each. As most buildings date before the 1980's they are either not thermally insulated or poorly insulated. In most parts of the country, a home's heating and cooling system is its largest energy user, so it's important to have an efficient, economical and reliable system.

A number of different studies have dealt with the energy consumption of households and its correlation with various socio-economic parameters for various countries worldwide [5, 6, 7, 8]. In these studies the main parameters that were considered were the average household size, their income and the thermal characteristics of the building. In other studies, various heating systems were compared and evaluated with the use of exergy and environmental analysis [9, 10]. For Greece in particular, previous studies include the statistical analysis of the Greek building stock with emphasis on the cities of Northern Greece [11], as well as an assessment of energy, economic and environmental performance of heating systems in Greek buildings [12] in the mid-2000. According to the latest Greek Regulation of the Energy Performance of Buildings (KENAK) [13], as well as Directive 2009/28/EC [14], Greece, in line with all member states in EU, should increase the use of renewable energy sources along with energy efficiency and savings by 20% until 2020. Nevertheless, during the last six years Greece is facing a severe economic crisis which is characterized by a reduction in energy consumption for heating and a trend of contraction of the households' budget spent for domestic heating purposes, as a consequence of the inhabitants' income reduction [15]. There is also a tendency of changing the central heating systems to individual ones and a shift to alternative heating systems, not always the greener or the most sustainable ones, but with either low installation cost or low fuel price. It is noteworthy that diesel oil and electricity consumption for heating was decreased between 2011 and 2013, while natural gas installations (in cities with natural gas grid infrastructure) and the use of biomass as an energy source for heating were impressively increased [16]. The hours of heating systems' operation as well as the indoor temperatures were also reduced.

In that sense, the selection of a heating system has become a subject of great concern. Selecting an appropriate heating system, either as a replacement or for a new house, requires a basic understanding of the different types of systems, their pros and cons, their efficiency ratings and running costs. In this work, a simple analysis is performed for the estimation of running cost of various heating systems, based on their efficiency and the fuel cost.

2. Scope and requirements of heating systems

Heating systems are installed to provide warmth to a closed space or to the whole interior of a building. More precisely, the purpose of a heating system is to maintain a comfort indoor environment during cold periods, so that a thermal equilibrium exists between the human body and its environment, and buildings' occupants feel thermally comfort and physiologically pleasant. The main physical parameters that affect humans pleasantly or adversely are: air temperature, mean radiant temperature, relative humidity and air velocity, which constitute the thermal environment of a closed space.

Heating systems usually affect two of these factors, namely the air and radiant temperature of the surrounding surfaces. The weighted average of these two parameters' values into a single one is the operative temperature, usually the most important indicator of thermal comfort. Relative humidity and air velocity, as well as indoor air quality, may be precisely controlled only by Heating Ventilating and Air Conditioning (HVAC) systems, which are considered most appropriate for creating a "perfect" indoor environment.

In general, a heating system must ensure the following:

1) The operative temperature within the thermal comfort zone must be as uniform as possible, in the range of 20 to 23°C, with a small vertical and horizontal asymmetry.
2) Temperature must be adjustable in a way that the occupants have the ability to adjust the operative temperature in heated spaces within certain limits, depending on their desire. The room temperature should reach quickly the desired limits, namely the heating system must have a quick response time.
3) Indoor air quality must be maintained in acceptable levels. The system must neither release dust, harmful gases and odors nor create air draughts or noise.
4) The use of the system must be easy and the maintenance simple.
5) The operation of the system must not put in danger the building and its occupants, even in the most adverse conditions.
6) The investment and operation costs should be low and the lifetime of the equipment satisfactory.

Various heating systems fulfill these requirements to a greater or lesser extent. Nowadays a variety of technologies are available for creating and keeping a comfortable and healthy environment in the interior of buildings with safety and sufficient cost. Each heating system has advantages and disadvantages therefore it is necessary to examine various alternatives before the final selection and installation at a building. The final choice depends on various criteria like the space or building use, operation time, fuel availability, initial investment, easiness of installation, reliability, operation and maintenance cost as well as on the systems' environmental impact. This study aims to facilitate this selection by describing and comparing different heating systems, by identifying their advantages and disadvantages, and by giving a classification based on their running cost.

3. Classification of heating systems

Heating systems differ in their source of energy, location of the equipment, heat carrier, and method of heat transfer in heated spaces. Based on the location of the device that provides the heat, heating systems are classified in local, central and district heating systems. Most systems have as a source of energy solid fuels, gaseous fuels, diesel oil or electricity. In solar heating systems the main source of energy is solar radiation while certain systems use waste energy. The heat carrier is water, air or electric current, and heat is transferred in the heated space with convection, radiation or by delivering heated air throughout the room.

Installing a good heating system in a space or building is a very important decision, especially in colder regions. Generally there is a large variety of system options in relation to the size, the number of appliances from which they are composed, the operation mode, the control system and the efficiency. Therefore, understanding the operation and performance of space heating systems becomes crucial in improving occupant comfort while reducing energy use. The most commonly local and central heating systems used in the residential building sector in Greece are described in the following paragraphs.

3.1 Local heating systems

Local heating systems produce heat only in the heated space. The heat is transferred directly to the room without any distribution system. They are suitable for small and intermittently used areas. Advantages are fast installation without additional distribution systems, simple operation and low initial cost. The main disadvantages are that they usually do not achieve uniform temperature distribution in space and that each heater needs individual maintenance. Sometimes heaters are also hard to regulate. The most known and widespread local heating systems are:

3.1.1 Open fireplace

Open fireplaces are basically low-efficiency home heating units (only about 10-20% efficient) unless extensive modifications are made in their design and/or operation to reduce the amount of heat lost up the chimney. In actual operation, most of the effective heat from an open fireplace is radiant heat directly in front of the fire. About 80-90% of the heat output goes up the chimney and is discharged outdoors.

3.1.2 Fireplace with room air circulation chamber

An open fire's efficiency can be greatly improved by installing an air circulation chamber, usually with inlets under the firebox and outlets between the firebox and the ceiling. The cold room air passes through the inlets, circulates behind the firebox and returns warm back in the living area. When equipped with tight-fitting glass doors and a blower to force air from the room through the heat exchanger, these fireplaces increase their efficiency up to 30-40%. Room air can also be warmed with curved tube convection heaters, located below the fire grate and burning logs, and usually equipped with a blower.

3.1.3 Fireplace with embedded heat exchanger

An internal water-to-air heat exchanger mounted in the flue gas stream can absorb large amounts of heat energy, otherwise wasted through the chimney. Water passes through the heat exchanger and is circulated through a pipe network to radiators or to an underfloor heating system in the heated areas.

Another alternative is the gas-to-air heat exchanger with an air duct system through which hot air is distributed from the fireplace to selected rooms through a network of flexible insulated ducts. Fireplaces with embedded heat exchangers may have an output efficiency of up to 70-80% and may be considered as central heating systems. In such systems a control system is necessary while in the water system the installation of a buffer tank is suggested. This is also of importance in order to amortize rapid changes of the demand, as the fireplace cannot be switched off like a burner. All fireplaces require manual filling and ignition.

3.1.4 Wood and pellet burning stoves

Wood burning stoves with correct air flow and ventilation can offer an efficiency of about 75% which may increase up to 85% if they contain underneath or to the side an oven that is used for baking. Wood burning stoves often deliver a high heating effect but for a limited time period, thereby creating temperature spikes in the surrounding space. Pellet burning stoves are more efficient, about 85 to 90%, and offer more convenience by way of automatic pellet ignition and a built-in fuel store at the rear of the stove. Automatic pellet feeding from the storage container with a feeder device, like a large screw, ensures an autonomous running for a number of hours, depending on the size of the stove and of the outside temperature. Most pellet stoves cycle themselves on and off under thermostatic control and have a small computer to govern the pellet feed rate. They need to be cleaned more rarely that the wood stoves and fireplaces since they produce less ash output. They also require electricity to run fans, controls, and pellet feeders. A typical room stove supplies heating to a single space through forced air ventilation. Some models have a back boiler for heating water which circulates to a piping/radiator circuit in a number of heated spaces.

Generally, in all wood or wood-derived biomass fuel heating systems a storage room is required. Another disadvantage is that the combustion of wood releases particulate matter and soot. Emissions, caused mainly by incomplete combustion, include particulate matter (PM), carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), and volatile organic compounds (VOC). The design of pellet stoves achieves a better and more efficient combustion, thus less emissions are released.

3.1.5 Electric heaters

Electric heaters convert electric current to heat. Various types of electric heating devices are available.

Storage heaters take advantage of cheaper, off-peak electricity tariffs during low demand periods such as afternoon and night. A storage heater stores heat in clay bricks and then releases it during the day when required. A room thermostat monitors room air temperature and regulates heat delivery as needed.

Electric panel heaters supply heat through a combination of radiation and natural convection. About 90% of the heat comes from convection, while only 10% is radiated from the front of the panel. A thermostat is controlling the operation and the heat release.

Radiant electric heaters heat surfaces, objects and occupants via infrared radiation emitted by the heater. They do not heat the air within the room directly, namely only surfaces in a direct line of sight to the element are heated. The room air starts to be heated, as long as the temperature of the surrounding surfaces will rise above the air temperature. Radiant heaters can be useful for heating briefly and intermittently occupied spaces or large size spaces where they provide heat locally to the occupants, i.e. in production halls. Their effectiveness decreases drastically in non-insulated rooms, especially if there are problems with moisture and condensation.

There are also various other types of electric heaters like portable infrared heaters, convection oil-filled heaters, electric fireplaces and underfloor heating. The efficiency of all electric heating devices, from the consumer's point of view, is considered 100% since almost all purchased energy is converted to heat.

3.1.6 Room air conditioners

These devices are electrically driven air-to-air heat pumps that operate on the vapor-compression refrigeration cycle. They draw low-grade heat energy from outside air and move this heat into the space to be heated. During summer the refrigeration cycle is reversed so that the interior space is cooled and the warm air is discharged outside. Heat pumps can deliver three or four kWh of heating energy for every kWh of electricity purchased, with the amount of heating energy delivered being a function of equipment efficiency as well as the temperature difference between the outdoor air and the building interior. The efficiency of air source heat pumps is measured by the coefficient of performance (COP). In very mild weather, the COP is above 4 (in models with inverter technology), but as the external temperature falls, it may drop significantly.

Air-to-air heating systems are amongst the most widespread in Greek buildings, especially in those without any other heating system, since they are used for both heating and cooling. They are much more energy-efficient than other types of electric heaters, especially in regions with mild winters. Table 1 shows the main characteristics as well as the advantages and disadvantages of local heating systems.

3.2 Central heating systems

In a central heating system, heat is produced from a single apparatus which is located in a central place of a single house or apartment (not necessarily at the "central" geometric point), or in a mechanical room for a large building. There are two main categories of central heating systems: hydronic or "wet" systems and forced-air or "dry" systems. Generally, a central heating installation consists of three separate parts: a unit where heat is created, a distribution system for the heat produced, and a control system that regulates the operation of the various devices.

The most popular and widespread heating systems in the Greek residential sector are hydronic systems. They consist of a set of interconnected devices and instruments, namely from a boiler, a burner, a circulation water pump, a fuel tank (for oil), piping, radiators, various safety devices and the control equipment. Hot water can be produced by a variety of heating equipment: natural gas or oil burning boiler, biomass (wood or pellet) boiler, heat pump, solar collectors or a combination of them. The water is circulated by a pump via steel, plastic or copper pipes and distributes heat. The required energy is transferred to the heated spaces by various types of baseboard radiators and convectors, or through pipes enclosed in the floor slab which then radiate the heat evenly throughout the room. A control system consisting of sensors, actuators and software algorithms controls the on and off switching of the boiler, and often also the boiler feed temperature, for the purpose of achieving the predefined room temperatures.

Table 1. Local heating systems. Characteristics, advantages and disadvantages

OPEN FIREPLACE	**FIREPLACE WITH ROOM AREA CIRCULATION CHAMBER**	**FIREPLACE WITH EMBEDDED HEAT EXCHANGERS AND AIR OR WATER CIRCULATION**	**WOOD-BURNING STOVE**	**PELLET STOVE**
Low efficiency 10-20% Serves usually as supplemental heating system Manually wood filling Release of particulate matter and smoke Need for space ventilation Constant supervision because of the risk of fire Provides only radiant heat to a small area in front the fire Continuous ash release Requirement of a large wood storage room Takes up living room	Efficiency 30-40% (with a glass door) Serves usually as supplemental heating system Manually wood filling Release of particulate matter and smoke Need for space ventilation or combustion air duct Safer than open fireplace Warms the air of living area either by natural convection or with a fan Continuous ash release Requirement of a large wood storage room Takes up living room	Efficiency 70-80% (with a glass door) by installing internal heat exchangers which absorb heat from flue gas stream and transfer it to circulating air or water. Air circulation with fan / water circulation with a pump for heating of more than one spaces Need of a control system Water systems need a buffer tank Manually wood filling Release of particulate matter and smoke Requirement of a large wood storage room Takes up living room	Efficiency ~ 75% or 85% (with a cooking oven) Heating of a single space Manually wood filling Need of a chimney Release of particulate matter and smoke Continuous ash release Need for space ventilation Routine cleaning of stove pipes and chimney because of the risk of fire Requirement of a large wood storage room	Efficiency 85-90% Good heating quality Automatic pellet feeding from a storage container and a fuel hopper ensures limited autonomy Low emissions Low ash production Automatic ignition and thermostatic control Heating either a single space through forced air ventilation or more rooms through water circulating to a pipe/radiator circuit. Requirement of a pellet storage room
ELECTRIC PANEL HEATER	**ELECTRIC RADIANT CEILING/WALL HEATER**	**ELECTRIC STORAGE HEATER**	**ELECTRIC PORTABLE RADIATIVE HEATER**	**ROOM AIR CONDITIONER (AIR-TO-AIR HEAT PUMP)**
Efficiency 100% Satisfactory thermal comfort conditions Thermostatic control Possible need for new electrical installation Low investment cost High operation cost	Efficiency 100% Provide only radiant heat (infra-red radiation) No air warming Need for new electrical installation High investment cost High operation cost Occupies no interior space	Efficiency 100% Satisfactory thermal comfort conditions Thermostatic control Need for new electrical installation High investment cost Need for electricity lower cost “night tariff”	Efficiency 100% Low thermal comfort conditions Thermostatic control Low investment cost High operation cost	COP 2-2.5 for common devices, up to 4 for inverters Thermostatic control Powered by electricity Moderate thermal comfort conditions COP decreases in low temperatures

Radiators are the most common used heat emitters in hydronic systems. Usually radiators are connected to the heat generation device with two types of piping system: one-pipe and two-pipe systems. In a one-pipe heating system all radiators are connected to the same pipe, which acts as both supply and return pipe. This means that the temperature decreases along the pipe, and the radiators along the pipe line should increase in size correspondingly to provide the same heat output. The one-pipe system has the advantage of providing autonomy in heating to individual apartments, by placing a two- or three-way valve at the central supply/return pipes of each apartment, enabling thus measurement of heat consumption. The two-pipe system was particularly popular in the 1970s, but it is no longer installed in new buildings (other than private houses or where autonomy is not needed i.e. hospitals and schools). With a two-pipe system, two separate pipes go to each radiator, one feeding the radiator (flow) and other taking water back to the boiler (return). A general characteristic of a two-pipe system is that the radiators are dimensioned for the same flow temperature and the same temperature difference, and that it can be balanced properly. Its disadvantage is that it can neither ensure the autonomy in each independent property nor the possibility of measuring the heat consumption.

Radiators supply heat through a combination of radiation and convection, depending on the type of radiator. The majority of the systems are sized with supply/return temperatures of 90/70°C nevertheless during the last years the trend is to size the systems for lower temperatures, in order to reduce heat losses and to take advantage of the higher efficiencies of low temperature or condensing boilers. The size of the radiators increases with the decrease of the supply/return temperatures. The inside temperature can be controlled either with a thermostat in a representative point of the house or with thermostats and control valves in each radiator. Generally there is a big variety of control systems that ensure a comfort environment, an automatic and safe operation as well as energy conservation.

Another popular hydronic system, which has also the advantage of providing autonomy in heating to individual apartments, is the radiant floor system. In this system the heating surface is the floor of the heated space, and heat transfer takes place mainly by thermal radiation. Hot water is pumped through tubing laid in a pattern underneath the floor. The tubing is embedded in the concrete foundation slab, or in a lightweight concrete slab on top of a subfloor. The temperature in each room is controlled by regulating the flow of hot water through each tubing loop via a system of zoning valves or pumps and thermostats. The thermostat can be set several degrees lower, relative to other types of central heating systems, providing in this way energy savings, but the system does not respond quickly to temperature settings due to high thermal inertia. Fuel use may be reduced even more, with sophisticated types of controls which sense simultaneously the floor, outdoor, and room temperature, keeping the home comfortable despite the weather changes.

Radiant floor systems operate with low supply/return water temperatures of 40/30°C. These systems are best suited for connection with air-to-water or water-to-water (geothermal) heat pumps, with gas-fired condensing boilers, even with solar panels. Low temperatures at these levels offer the opportunity for higher COP in heat pumps, and higher efficiencies in condensing boilers and solar panels.

Other types of heating devices in hydronic systems are fan convectors and fan-coil units. Both consist of a finned-tube heating coil, filter and fan section. The dominant heat transfer method is forced convection and heat is distributed into the room by means of the fan. Fan convectors are used in heating only systems while fan-coils can provide cooling as well as heating. Both may introduce outdoor air for ventilation, if they are mounted on outside walls. The desired room temperature can be set using an electronic thermostat. The convector/fan-coil electronics compare the set temperature and room temperature and adjust the three fan levels automatically to reach the set temperature. They can also be controlled manually. In comparison to conventional hydronic systems, it is thereby possible to achieve a high heat transfer, even at low flow temperatures. Their low flow temperatures make fan convectors particularly suitable for use in combination with low-temperature heating systems such as heat pumps.

There are also various other types of heating units which transfer heat by radiation, convection, forced convection or a combination of these heat transfer methods. The above mentioned are the most frequently installed in heating systems in residential buildings.

Forced-air central heating system use air as heat transfer medium. Generally, they consist of a gas, oil or biomass furnace, and a system of ducts which distributes warm air to heated spaces through wall, floor or ceiling diffusers. An air blower gives the necessary pressure to air to overcome the resistance caused by ducts, dampers and other components of duct system. Like any other kind of central heating system, thermostats are used to control the operation of forced air heating systems. Instead of furnaces, heat pumps may be installed. The main advantage of air heating is that room air is heated quickly, unlike a water-based system of radiators and/or underfloor heating. Usually these systems are used in spaces with high occupancy, where large amounts of outdoor fresh air are needed, or in rarely heated large spaces where the rapid adaptation of the environment to temperature requirements is important. On the contrary, forced-air heating is not commonly installed in Greek houses, where hydronic heating predominates. This happens mostly because hydronic piping can be placed in the walls and easily routed around the home, unlike air systems that require extensive ductwork and occupy usable space. Likewise, hydronic heating equipment is more silent than forced air system devices.

In all central heating systems, the device that provides the heat can be an oil- or gas-fired or a biomass boiler. Efficiencies of modern boilers are higher than 90%. In low water temperature systems, the use of condensing boilers increases the efficiency to more than 100%. The heat source of central systems may also be an electric boiler or an electric heat pump. In regions with mild climate, air source heat pump can achieve a seasonal performance factor of more than 3. In colder climates, geothermal heat pumps are more favorable, with seasonal performance factors between 3.5 and 4.5. The systems with heat pumps can be individually or hybrid (boiler and heat pump). A hybrid heating system is the combination of an air source heat pump (ASHP) or ground source heat pump (GSHP) with a boiler. Hybrid heating systems offer the ability to use both a high-efficiency heat pump and a high-efficiency condensing boiler to improve the overall system efficiency.

Another option is the use of solar thermal systems. Solar hot water heating systems for sanitary use are the most common ones. A variety of different systems can be employed to produce hot water such as: thermosiphon, direct and indirect circulation systems and air systems. In order for the systems to be used without any issues when the air temperature is below freezing indirect circulation systems are usually employed. Common systems consist mainly from flat plate solar collectors, a storage tank with a mounding base and the necessary plumbing. Average annual system efficiency for the conversion of solar radiation to useful energy in the form of hot water varies between 30 – 40%, depending mainly on the type of solar collector used [17, 18] and can achieve annual coverage of as much as 80%, even for locations with harsh winters while exhibiting a payback period of as little as 3 to 4 years, as long as proper sizing for the thermal load needed is achieved [19, 20].

The same layout can be used in order to cover both space heating and hot water for sanitary uses with the only difference being the larger solar collector area and storage tank as well as the possible use of evacuated tube solar collectors. These systems are usually called “Solar Combi”. According to a number of studies [21, 22, 23] the use of a “Solar Combi” system enables the minimization of energy costs as the systems analyzed were proved to be capable of covering more than 42% of the total load and as much as 95% while exhibiting a payback period of less than 10 and as low as 4,4 years in some cases [24].

4. Heating System Selection

Choosing an appropriate heating system which fulfills the functional and aesthetic requirements and ensures an economic operation is not always an easy task. Besides the investment cost, the reliability and the durability of the system, the operating costs should as well be one of the primary decision criteria. Needless to say that thermal comfort and indoor air quality conditions are also important, thought they fall out of this paper’s scope. The two main factors affecting the operative cost of a heating system, which are also the dominant monetary factors for the selection, are fuel costs and the efficiency of the system. The efficiency of the heating appliances has increased over the recent past due to advances in technology. Furthermore the availability of the fuel needed is of the outmost importance, electricity and diesel for instance is available throughout the country, while natural gas is an option in less than 50% of the country yet. On the other hand solid fuels although generally are available countrywide require either a permit for their storage or large spaces making their use difficult in many cases.

Table 2. Cost of various fuels and electricity in Greece, November 2014 (including taxes)

FUEL	€/unit*	kWh/unit	€/kWh
Wood	0,12 ~ 0,16 €/kg	4 kWh/kg	0,03 ~ 0,04
Pellet	0,32 €/kg	4,5 kWh/kg	0,071
Diesel oil	1,01 €/lt	10 kWh/l	0,101
Natural gas	0,80 €/m^3	10,3 kWh/m^3	0,078
Electricity (night tariff)	0,12 €/kWh	-	0,12
Electricity (day tariff)	0,19 €/kWh	-	0,19

When there are more than one alternative that fulfill the set functional requirements, the deciding factor is usually the operating cost that is the cost of the useful thermal energy unit (kWh) and the payback period for the heating system. The operating cost is a function of the fuel cost (€/kWh), the efficiency of the heating system and of the specific heating requirements of the building (kWh/m²). If all of these factors are correlated, a comparative evaluation of the different heating systems regarding their operational cost is possible, making the decision of selecting a heating system easier.

Table 3. Operative cost of various heating systems (€/kWh$_{th}$)- November 2014 (maintenance and pumps operation costs not included)

FUEL	HEATING SYSTEM	Seasonal COP	€/kWh$_{th}$
Wood	Open fireplace	0,15	0,230
	Fireplace with room air circulation chamber	0,35	0,100
	Fireplace with embedded heat exchangers (gas to air/water)	0,70	0,050
	Wood stove	0,80	0,044
Pellet	Stove	0,85	0,083
	Water circulating stove Hot water boiler	0,90	0,079
Natural gas	Hot water boiler	0,88	0,089
	Condensing hot water boiler	1,015	0,077
Diesel oil	Hot water boiler	0,86	0,117
Electricity (night tariff)	Storage heater	1,0	0,120
Electricity (day tariff)	Panel heaters, infrared heaters, radiative heaters, electric boiler, electric fireplace	1,0	0,190
	Air-to-Air/Air-to-Water heat pump	3,0	0,063
	Ground source heat pump	3,7	0,050
Electricity (night+day tariff)	Panel heaters, infrared heaters, radiative heaters, electric boiler, electric fireplace	1,0	0,150
	Air-to-Air/Air-to-Water heat pump	3,0	0,050
	Ground source heat pump	3,7	0,041

The input data that have been used for the heating systems investigated in this study are given in Tables 2 and 3. Fuel prices are averages for November 2014. Table 2 lists the cost of various fuels and the electricity tariff for domestic use (including taxes) in Greece. In the first column, the cost per unit of each fuel is given, in the second the corresponding average calorific value, and in the third the cost of kWh produced by each fuel.

The electricity tariffs are determined by the Public Power Corporation, which is serving the household sector in a monopolistic market. In the case of the natural gas, retail prices have been determined according to Thessaloniki Gas Supply Company pricelist. Table 3 lists the values of assumed average annual efficiency/COP of all heating systems considered in this study, likewise the corresponding operative cost (without taking into account the annual maintenance cost or the cost of any secondary equipment needed).

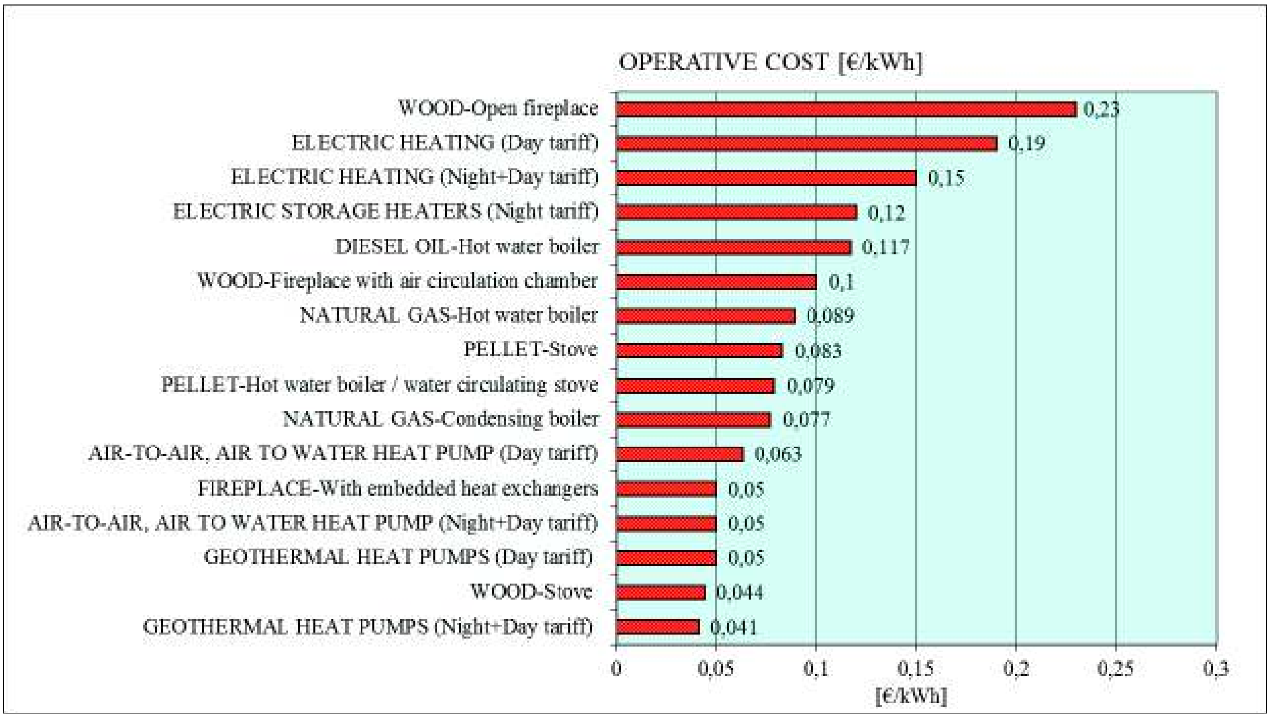

Figure 1. Operational Cost per kWh for the different heating system options (maintenance and pump operation costs not included)

The final operative cost in Euros per thermal kWh is calculated by taking into account the average seasonal efficiency or COP for each system. Operative cost values for the different heating system options are presented in Figure 1. Of course, this shorting could change depending on price fluctuations of the different fuels. It should be noted that solar systems were excluded from this research due to the high installation costs and the relatively long payback period.

5. Conclusions

In this study, a simple analysis for the estimation of running cost of various heating systems commonly used in the residential building sector in Greece was performed, based on their efficiency and the fuel cost.

According to the results, geothermal heat pumps appeared with the lowest cost while electrical heating had the highest with diesel heating coming up second. Geothermal systems can be installed easier in detached houses because a piece of land is needed. Other solutions for houses in the country are wood stoves and fireplaces with embedded heat exchangers. Their operation cost is comparable to that of geothermal heat pumps (with day-time electricity tariff) or of air-to-air and air-to-water heat pumps (with a mixture of night and day-time electricity tariff), but a manual filling of wood is needed. Pellet hot water boilers and pellet stoves have almost double operation cost as compared to geothermal heat pumps but their cost of installation is lower. In comparison with wood stoves they have the advantage of autonomy for a certain time period. For buildings inside towns, where the use of biomass is prohibited, the most economic and environmentally friendly solutions are condensing natural gas boilers, in low water temperature systems, followed by natural gas boilers in high water temperature systems, a fact that explains its rapid penetration in the cities where it is available.

The use of natural gas is constrained by the existence of the natural gas distribution grid. In areas without natural gas grid, systems with diesel oil are still widely used, despite the higher fuel price. As a rule electric heating is used as a solution for individual room heating, when no other central heating system exists or when the operation time of the central system is not sufficient for maintaining thermal comfort in the interior of the buildings.

Despite the results concerning the operative cost, the final decision of a heating system should be based on other criteria as well, like availability of fuel, initial investment, ease of installation, maintenance cost, payback period, and environmental impact. On the other, since the annual cost for heating is defined by the heat demand of the building, the priority should be the thermal insulation and air-tightness, even before installing a new heating system, an investment that enables to render energy sources more economical. Finally, one should not fail to notice, that distortion in the final prices of competitive energy sources, i.e. due to taxation, have long-lasting impact on the energy sector, frequently leading to irrational solutions considering the efficient and rational use of energy.

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