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# Central Heating by Seasonal Sensible Heat Storage of Solar Thermal Energy

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## Abstract

Production of required thermal energy to heat residential buildings is a considerable issue in energy studies. Kabul city is a city in which the coal-fired central heating systems for providing the mentioned energy is in expansion process. And, coal as feeding source of these systems with generation of carbon dioxide ($CO_2$) is the main cause of greenhouse gases (GHGs) emissions in winter. Fortunately, Kabul city has maximum solar radiation in summer warm season which can be used for fulfilling of this demand in winter cold season. The method which can perform this task is the central heating by seasonal sensible heat storage of solar thermal energy. But, the economic and environmental feasibility and viability of this method is a discussable issue. In this study, the central heating by seasonal sensible heat storage of solar thermal energy and its economic and environmental feasibility and viability is studied. It is tried that this system is compared in a logical method with current coal-fired systems. The economic feasibility study is accomplished by comparison of initial or capital cost and annual operation and maintenance cost with the usage of existing data and thermodynamic analytic methods. The environmental viability study is accomplished by comparison of annual emissions of $CO_2$ with the usage of online emissions calculator. Unfortunately, it is found that seasonal sensible heat storage of solar thermal energy is not an economically feasible method for central heating due to its high initial cost and cannot be used in an economically beneficial manner for central heating. But fortunately, it is an environmentally viable method and environmentally friendly way due to its no and/or zero $CO_2$ emissions. To sum up, it is suggested that, this method should be used for district heating which can make this system economically feasible.

**Keywords:** Solar Thermal Energy, Coal-Fired Central Heating, Thermal Energy Storage, Seasonal Sensible Heat.

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**Transparency:** The authors confirm that the manuscript is an honest, accurate, and transparent account of the study was reported; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained.
**Ethical:** This study follows all ethical practices during writing.

## 1. Introduction

The heating of space and providing of needed thermal energy or heat is a discussable issue in engineering designs and analyses. Unfortunately, production and generation of this need thermal energy and heat is too much discussable for the emissions of greenhouse gases especially carbon dioxide gas due to its generating air pollution in environmental and energy studies. In Kabul city, the usage of coal as feeding source of central heating system in buildings is in expansion process and its usage is extending which is the major cause of greenhouse gases emission especially carbon dioxide. For the above reason, a method should be found that in spite of having a high cost can be used as an alternative system instead of coal-fried central heating system. The only system that can be recommended as an alternative system is central heating by seasonal sensible heat storage of solar thermal energy. Fortunately, Kabul city has the chance of installation of the central heating by seasonal sensible heat storage of solar thermal energy for having maximum, enough and extra amount of solar radiation and solar energy in hot weather of summer warm season months which can be stored for a season, and can be used in cold weather of winter cold season months. In this article, the economic and environmental feasibility and viability of both coal-fired central heating system and central heating by seasonal sensible heat storage of solar thermal energy is analyzed, discussed and compared according to their capacity and scale with the consideration of initial or capital cost, annual operation and maintenance cost and yearly carbon dioxide emission production.

In this paper, it is tried to find the following points:

- To find the economic and environmental problems of coal-fired central heating systems
- To find the whether the central heating systems by seasonal heat storage of solar thermal energy can solve the above mentioned problems.
- To make a comparison and comparative analysis of both above mentioned systems according to their economic and environmental considerations.

Production of thermal energy for space heating is a considerable issue in energy studied. Kabul city with having a maximum demand to heat energy for heating of residential buildings in the winter is a city in which the coal-fired central heating systems made many environmental and economic problems. But fortunately it is a city which have maximum solar thermal radiation in summer too. Therefore, the coal-fired central heating systems can be changed to central heating systems by seasonal heat storage of solar thermal energy to meet the need for required energy and solve the economic and environmental problems. Sensible heat storage is considered as one of the mature, best-known, and most widespread technologies. Example of this technology is the domestic hot water tank. The storage medium can be a liquid such as water or thermo-oil, or a solid such as concrete or the ground. Thermal energy is mainly stored due to the change of temperature of the storage medium. The capacity of a storage system is defined by the specific heat capacity and the mass of the medium used. Thermal energy is stored in this system by raising the temperature of a solid or liquid. During the process of charging and discharging, system utilizes the heat capacity and the change in temperature of the material. The amount of heat stored depends on the specific heat of the medium, the temperature change, and the mass of storage material as shown in the Equation 1 [1]. In this system heating a liquid or a solid is without changing phase, for this; this method is called sensible heat storage. The Equation 1 is the theoretical model for sensible heat storage system.

$$Q = mC_p (T_2 - T_1) \qquad (1)$$

Where Q (in kJ) is the amount of heat charged/discharged system, $C_P$ (in kJ/kg K) is the specific heat capacity of the storage material, m (in kg) is the mass of storage material, T1 is the initial store temperature or lower temperature level, and T2 is the final store temperature or upper temperature level which the storage operates. The difference (T2 – T1) is referred to as the temperature swing. Water is considered as the best sensible heat storage liquid available due to its high specific heat and also because it is inexpensive. However, above 100ºC, oils, molten salts, and liquid metals, etc. are usually used. However, rock bed type storage materials are preferred for air heating applications [2].

Central heating by seasonal sensible heat storage of solar thermal energy, as its name suggests; it is a kind of central heating system in which heat supply source is located in a centralized place and the heat generated there is distributed to all dwelling units [3, 4]. In this system this heat is obtained from solar thermal energy which is stored during a specific period of warm season of summer. In warm season of summer, when there is much insolation and enough solar energy; it is gotten by specific devices of getting solar thermal energy of sun [4]. These solar thermal energy receiving devices are called collectors. They can be found in various types of flat plate collectors, evacuated tube collector and etcetera according to required and desired operating temperature range. When the working fluid temperature of the collectors gets higher or in other words the working fluid gets enough specified amount of sensible heat energy, the working fluid goes to a thermal reservoir of over ground or underground type and exchange its sensible heat with storage material reservoir or storage tank. The mentioned sensible heat energy charges the storage material and then the storage material stores the energy for two months. The storage material discharges the specific amount of energy during the cold season of winter and works or functions as the heat providing source or heating source of central heating system [5].

## 2. Literature Review

Seasonal storage of solar thermal energy for space heating purposes has been under investigation in Europe since the mid-1970s within large-scale solar heating projects. Most large-scale solar systems have been built in Sweden, Denmark, The Netherlands, Germany and Austria [6]. The first demonstration plants were developed in Sweden in 1978/1979, based on results from a national research program [7]. The seasonal storage concept research work continued within the IEA

‘‘Solar Heating and Cooling” program. Experiences have been gained and exchanged in Task VII ‘‘Central Solar Heating Plants with Seasonal Storage (CSHPSS)” since 1979 in many countries. In the past decade, the main activities have been within the work initiated in the CSHPSS Working Group, IEA Solar Heating and Cooling Program as well as the work carried out in Europe within the EU/APAS-project ‘‘Large-Scale Solar Heating Systems” [8]. So far, the development of seasonal storage has been aimed at heating large district system stores in order to fulfill technical viability and cost effectiveness by using large storage volumes. Fisch et al. reviewed large scale solar plant development in Europe during the 1990s [8]. The work refers to two large-scale solar heating applications: systems with short-term (diurnal) storage designed to supply 10–20% of the annual heating demand or 50% of the domestic hot water; and systems with long-term (seasonal) storage capable of supplying 50–70% of the annual heating demand. Within the findings of that work was that large-scale solar applications benefit from the effect of scale. Compared to small solar domestic hot water systems, the solar heat cost can be cut at least in third. Among the main results of the evaluation of the existing projects was the need to reduce the cost-benefit ratio for CSHPSS. Figure 1 shows a scheme of a CSHPSS (distributed rooftop solar collectors, central plant with heat pump, solar collector and heat distribution networks).

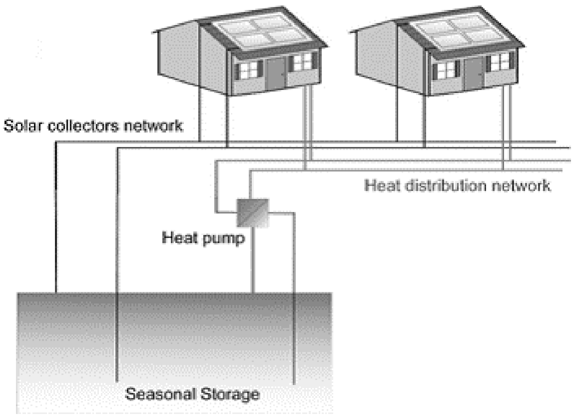


**Figure-1**.
Scheme of a Central Solar Heating Plant with Seasonal Storage [9].

The experimental plants built in some European countries involve the development of new concepts of seasonal storage such as duct storage, natural aquifer, and pit storage concepts using high performance concrete and new construction technologies. Lottner et al. reviewed long-term national monitoring program Solarthermie-2000 of large-scale solar heating plants, with and without seasonal storage, in Germany [10]. The study reveals that at present the specific storage costs for seasonal storage of solar energy are still too high and many efforts must be made to achieve technical and economic feasibility. Schmidt et al. reviewed detailed results of the same monitoring program [11]. The technology of central solar heating plants is described and advices about planning and costs, for improving and optimizing the installations in order to make such concepts more economic, are given. In Bauer et al. monitoring results of CSHPSS of the same program and its continuation Solarthermie-2000plus are reviewed [9]

## 3. Methodology

In this research, in order to achieve a good result; the comparative and comparison method is used. First, to have a concept and better understanding of heating and heating system; the two systems of coal-fired central heating system and central heating system by seasonal sensible heat storage of solar thermal energy are briefly discussed. Then, for the novelty of the second above mentioned system; it is studied comprehensively to become well-known for all. All its usable and applicable methods are described broadly and systematically with their related issues and aspects. After that, in the comparison side of these systems, it is possible that they can be compared according to three technical, economic and environmental analyses. But, as the technical analysis wants interdisciplinary and multidisciplinary knowledge, it is tried that they should be compared in a logical manner of economic and environmental analyses in below stages and steps which is easy to get considerable results. First, a typical sample building related to Kabul city was chosen which have a considerable size and area. Second the heating load (power) and demand (energy) of the chosen building was calculated. Then, cost of making a coal-fired central heating system and a central heating system by seasonal heat storage of solar thermal energy will be found and the amount of coal used in the system during the winter season was found. Then, the economic analysis was done by consideration of the cost of amount of coal used in the coal-fired central heating system and cost of making the existing system and new system (capital or initial costs and operating and maintenance costs). Next, an environmental analysis was done by finding the amount of one, two or more GHGs such as $CO_2$ produced in coal-fired central heating system by the combustion of found amount of coal in winter season.

Finally, the results are compared between the existing system and new system and conclusion will be obtained by consideration of them. At the final stage, related discussions are done and obtained conclusions are listed. Feasible and viable recommendations are given. The building that is chosen to be analyzed is a building with 6 floor and 1 ground floor. Each floor has 2 apartments. The apartments have 4 rooms and the ground floor has also 8 rooms. The heating load of this apartment is calculated from its riser sketch and radiator data (radiators number in each floor and radiators load). The following calculations shows each floor radiators total load. If the radiators operate from 4:00 P.M. to 8:00 A.M. (16 hour) and maintain the rooms temperature on 21.1ºC, the building daily demand is obtained in Table 1. More information about Table 1 is given in Appendix A. If the floors daily demands are summed, and the building loads are summed, then the total building demand and total building load is obtained. From the obtained data seen in Table 1, the building daily, monthly and seasonally (cold season) heating demands are found. The found data of demand and load of heating is used directly or indirectly to find the cost of both coal-fired central heating system and central heating system by seasonal sensible heat storage of solar thermal energy.

**Table-1.**
Building heating load and heating demand.

| **Floors** | **F. 1** | **F. 2** | **F 3** | **F 4** | **F 5** | **F 6** | **F 7** |
|---|---|---|---|---|---|---|---|
| Floor Load (kW) | 16.9 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 21.7 |
| Heating Hour (h) | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| Floor Daily Demand (kWh) | 270.4 | 291.2 | 291.2 | 291.2 | 291.2 | 291.2 | 347.2 |
| Building Load (kW) | 129.6 | | | | | | |
| Building Load (Ton) | 36.9 | | | | | | |
| Building Daily Demand (kWh) | 2073.6 | | | | | | |
| Building Monthly Demand (kWh) | 62208.0 | | | | | | |
| Cold Season Demand (kWh) | 248832.0 | | | | | | |

In this part, the initial/capital cost of the coal-fired central heating system from different countries markets are collected as following. They are averaged for Afghanistan or Kabul city market. The average cost is chosen for this building. The average initial/capital cost of coal-fired central heating systems is found form the Table 2. The cost of chosen building coal-fired central heating system can be found with the obtained above found heating load of the chosen building in Table 2. The ranges A, B, C and D is divided according to the coal-fired central heating system size and there is a specific initial or capital cost for each range. For more information about the Table 2 is in Appendix B.

**Table-2.**
Coal-fired central heating system size and initial or capital cost [5].

| **Range** | **System size** | **Initial or capital cost (€/kWth)** |
|---|---|---|
| Range A | <25 $kW_{th}$ | 219.7 |
| Range B | 25 to 100 $kW_{th}$ | 112.3 |
| Range C | 101 to 250 $kW_{th}$ | 81.2 |
| Range D | 251 to 350 $kW_{th}$ | 36.3 |

From the above data, the initial/capital cost of needed or required coal-fired central heating system can be found by Equation 2.

Coal-fired central heating system capital cost = heating load ($kw_{th}$) × initial or capital cost per demand (€/$kw_{th}$) (2)

The range C is chosen from the Table 2 for finding the initial/capital cost of coal-fired central heating system for the needed or required heating load. As conclusion, from the above calculations, it is found that 10524 € is needed to provide the initial/capital cost of coal-fired central heating system. In the operation/running cost finding section for the coal-fired central heating system, some analytical formulas of thermodynamics and other sciences are used. First the amount of water to provide the above building daily demand. Then the amount of coal to heat the found amount of water is obtained from the Equation 3 [12].

$$m = Q \div [c \times (T_{out}-T_{in})] \quad (3)$$

The Q is the daily heating demand, m is the mass of water which is heated per day, c is the specific heat of water at 50ºC, $T_{out}$ is the temperature of water which is exited from boiler to flow into radiators (temperature of hot water) and $T_{in}$ is the temperature of water which entered into boiler (temperature of cold water) to be heated in boiler. To provide the building daily load, 51025 kg of water must be heated per day. Form this value, the amount of coal to be used per day for heating can be found. 7464957.5 kJ of energy is required in a day to rise the water temperature from 25ºC to 60ºC of 51025 kg of water mass. If this required energy is divided on energy content of these different types of coals, the amount of required coal per day is found. It is assumed that in Kabul city, the anthracite is not used for heating applications due to existence of different reasons such as lack of anthracite in market. As the best option and selection, it is assumed here that the bituminous coal is used for heating the water of this building for the existence of various reasons in Afghanistan market and it has a higher heat content or energy content value which is 32.5 MJ/kg Equation 4.

Coal required amount per day = required energy per day ÷ coal energy content of per kilogram (4)

Where CA/D stands for coal amount per day which is the required amount of coal in a day to heat the required amount of water. If the found values are calculated for cold season of winter, the total amount of using coal during the cold season of winter is found Equation.5.

CA/S = CA/D × 360 Days × (1 Ton ÷ 1000 kg) (5)

Where CA/S stands for coal amount per season which is the required amount of coal in a coal season of winter to heat the required amount of water. The price of 1 ton of bituminous coal is Afghanistan market is 168 €. If the found above amount of bituminous coal is multiplied by this value, the yearly (seasonal) or total operation/running cost of coal-fired central heating system is found Equation 6.

Coal-fired system yearly operation cost = required amount of coal per year (Ton/Year) × Coal of Coal (€/Ton (6)

From the above calculations and descriptions, finally it is concluded that 46368 € is required for operating/running of a coal-fired central heating system yearly. In every system the maintenance cost of the system is a percentage of its initial/capital cost in a specific time. This value is 2 to 5 % for coal-fired central heating system per year. If this value is averaged 3.5 % of the initial/capital cost of coal-fired central heating system is needed for the maintenance of the system per year. It is calculated by Equation 7.

Coal-fired system annual maintenance cost =3.5 (%/Year) × system capital cos ( 7)

From the above calculations, it is concluded that 368 € is needed for the maintenance of coal-fired central heating system per year. To sum up, 46736 € is needed to operate and maintain the selected coal-fired central heating system annually. The environmental considerations (emissions) section of a heating system is a basic part of a heating system. For it is costly for the society health and can be counted as an important factor and parameter to compare different heating systems. The coal is a fuel which is the most active producer of $CO_2$ among all fuels. In this part, with the usage of online calculator of the amount of $CO_2$ emissions from the combustion of different types of coal, the $CO_2$ emission of using all above mentioned coal types and using type of coal for coal-fired central heating system is calculated as following. From the above conclusions, when 276 tons of bituminous coal is used in this coal-fired central heating system, it emits 740 tons $CO_2$ to environment yearly (seasonal). One question is raised here that in spite of less emissions of sub-bituminous coal, why it is not used in the system. This can be answered easily and briefly that sub-bituminous coal in spite of having less emissions, it has lower heat content or energy content which increase the amount of coal and finally increase the operation/running cost. To sum up, the above discussed issues and calculations of needed initial/capital cost for investment, needed operation/running cost for working, needed maintenance cost for protection and efficient working and environmental consideration (emissions) of the coal-fired central heating system can be concluded in Table 3.

**Table-3.**
Results of Coal-fired Central Heating System Analysis.

| **Coal-fired Central Heating System Costs** | **Costs (€)** |
|---|---|
| Capital Cost | 10524 |
| Operation and Maintenance Cost | 46736 Per Year |
| Environmental Considerations (Emissions) | 740 Ton Per Season |

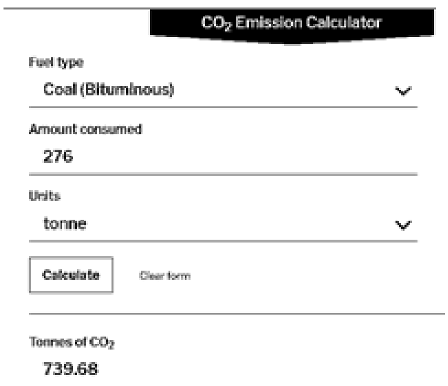


**Figure-2.**
Bituminous coal $CO_2$ emissions [13].

The initial or capital cost, operating or running cost and maintenance cost of central heating by seasonal sensible heat storage of solar thermal energy is found as below and the environmental consideration (emissions analysis) of this system is also performed. Finally, the results are presented. In this part, the initial/capital cost central heating by seasonal sensible heat storage of solar thermal energy is calculated by some following analytical formulas. For this purpose, the water equivalent can be found by Equation 8 and Equation 9 [14].

$$Q = m \times c \times (T_{Sin} - T_{Sout}) \qquad (8)$$

$$Q/V = \rho \times c \times (T_{Sin} - T_{Sout}) \qquad (9)$$

Where Q is the water equivalent or the heat energy which is stored by 1 $m^3$ of water, m is the mass of water, c is the specific heat of water at 80°C, ρ is the density of water at 80°C, V is the volume of water, $T_{Sin}$ and $T_{Sout}$ is the temperature of water entering and exiting from the storage tank respectively. When the required seasonal amount of needed energy for heating of the building is divided by the above found number, the storage volume (SV) in water equivalent (WE) is found. It is mentionable, when the volume is found, it is used to find the initial/capital cost of central heating by seasonal sensible heat storage of solar thermal energy Equatin 10.

$$SV\ (WE) = \text{Cold Season Needed Energy (kJ)} \div \text{Water Equivalent (kJ/m}^3\text{)} \qquad (10)$$

From the Equatin 10, the initial/capital cost per cubic meter water equivalent of the central heating by seasonal sensible heat storage of solar thermal energy is found. The investment cost of 1 $m^3$ of water equivalent for found volume is 150 euro per $m^3$ of water equivalent as it is seen in Figure 2.

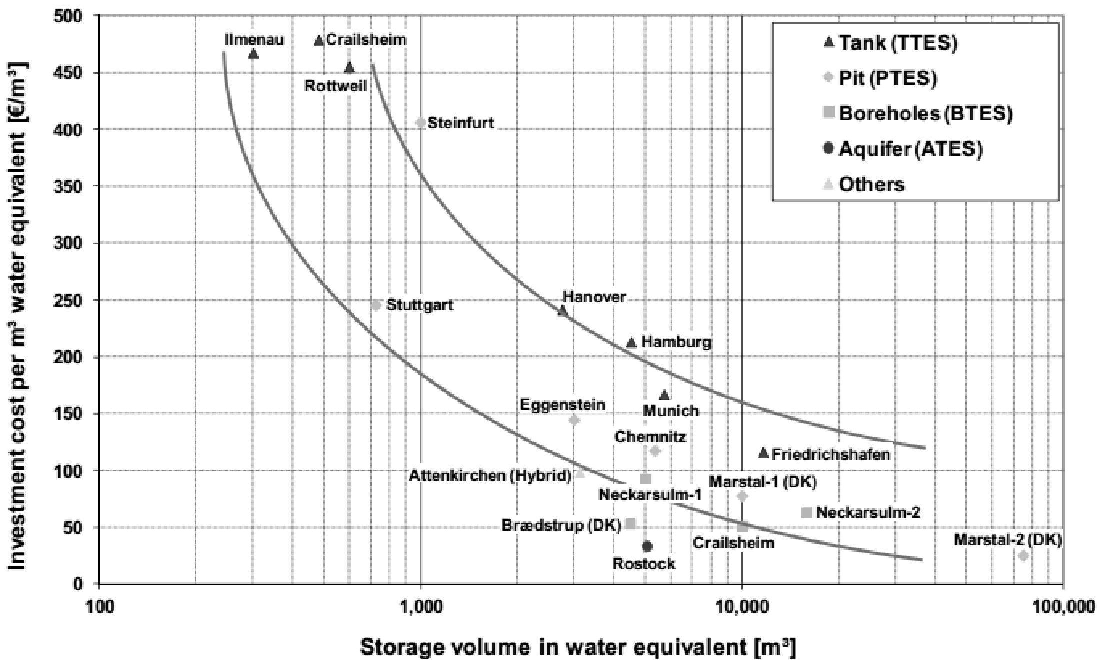


**Figure-3.**
Specific storage cost [15].

$$\text{Alternative System Capital Cost} = \text{Storage Volume in WE (m}^3\text{)} \times \text{Investment Cost in WE (€/m3)} \qquad (11)$$

From the above calculations and descriptions Equation 11, it is concluded that 1644600 € is needed to provide a central heating system by seasonal sensible heat storage of solar thermal energy for the selected and chosen building. In this part, operation/running and maintenance cost of central heating by seasonal sensible heat storage of solar thermal energy is calculated and found. The operation and maintenance (O & M) cost of this system can be calculated together by the found constant rate of 108 euro per kilowatt per year. This is found as below Equation 12.

$$\text{Alternative System Operation \& Maintenance Cost} = \text{Heating Load (kW)} \times \text{Constant Rate (€/kW/Year)} \qquad (12)$$

From the above calculations, it is concluded that 13997 € is needed to operate/run and maintain the central heating by seasonal sensible heat storage of solar thermal energy system yearly to provide the required heating demand of the selected building. In this part, the environmental consideration or emissions of central heating system by seasonal sensible heat storage of solar thermal energy is discussed. As it is clear solar any part of this system is environmentally friendly and do not produce $CO_2$ or do not emit any hazardous and dangerous gas. If it produces something, it is as much as it can be negligible. Therefore, it is concluded that central heating by seasonal sensible heat storage of solar thermal energy is zero emitting To sum up, the above discussed issues, descriptions and calculations of needed and required initial or capital cost for investment, needed operation or running cost for working, needed maintenance cost for protection and efficient working and environmental consideration (emissions) of the central heating by seasonal sensible heat storage of solar thermal energy can be concluded in Table 4.

**Table-4**.
Results of alternative system analysis.

| Alternative central heating system costs | Costs (€) |
|---|---|
| Capital Cost | 1644600 |
| Operation and Maintenance Cost | 13997 Per Year |
| Environmental Considerations (Emissions) | 0 |

## 4. Results

As it is seen in below Figure 4, the initial/capital cost of central heating by seasonal sensible heat storage of solar thermal energy system is much higher than coal-fired central heating system which cannot be comparable. The payback period for the alternative system is found by Equation13.

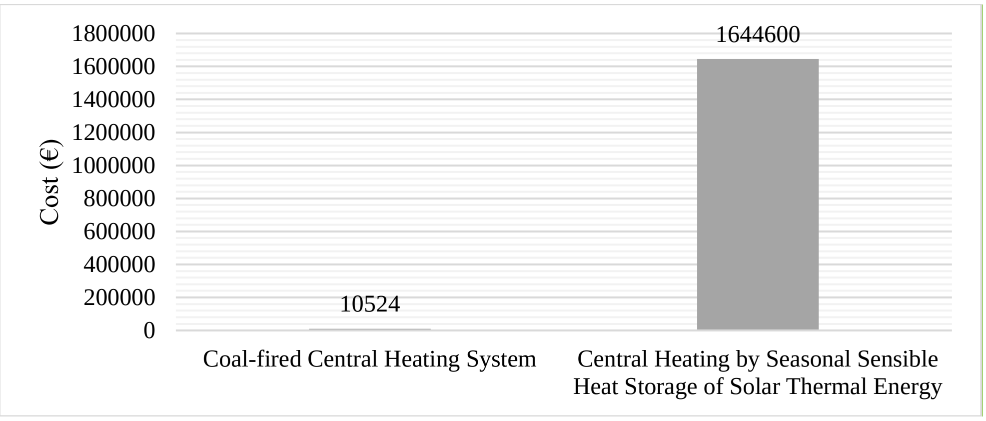


**Figure-4.**
Systems initial or capital cost comparison

Payback Period = ([Alternative System Capital Cost (€)] ÷ [Coal-fired System O & M Cost (€/Year) – Alternative System O & M Cost (€/Year)]) (13)

The life time of alternative system of central heating by seasonal sensible heat storage of solar thermal energy is between 40 to 50 year depending on the storage cycles and other factors. The payback period is longer than life time. It means that the alternative system cannot provide beneficial amount. It just can fill its initial cost in its life time. Therefore, it is concluded that system is not economically feasible and viable to install and to be used in this manner. The operation or running and maintenance total cost of the two system is compared in Figure 5. As it is seen in Fig. 6 the operation/running and operation cost of coal-fired central heating system is as much as it can be compared. It is not like initial or capital cost of the system which is not comparable. The operation and maintenance cost of central heating by seasonal sensible heat storage of solar thermal energy is one third of coal-fired central heating system which is a comparable value.

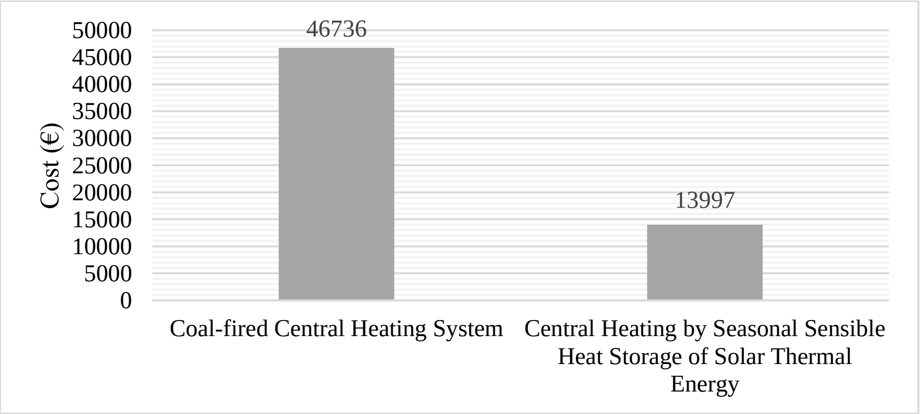


**Figure-5.**
Systems operation and maintenance cost comparison.

As it is seen in Figure 6, the coal-fired central heating system has $CO_2$ emissions while central heating by seasonal sensible heat storage of solar thermal energy does not have $CO_2$ emissions. Therefore, it is concluded from environmental considerations of the systems that the first system is much hazardous and dangerous to the environment while the second system is environmentally friendly with zero $CO_2$ emission.

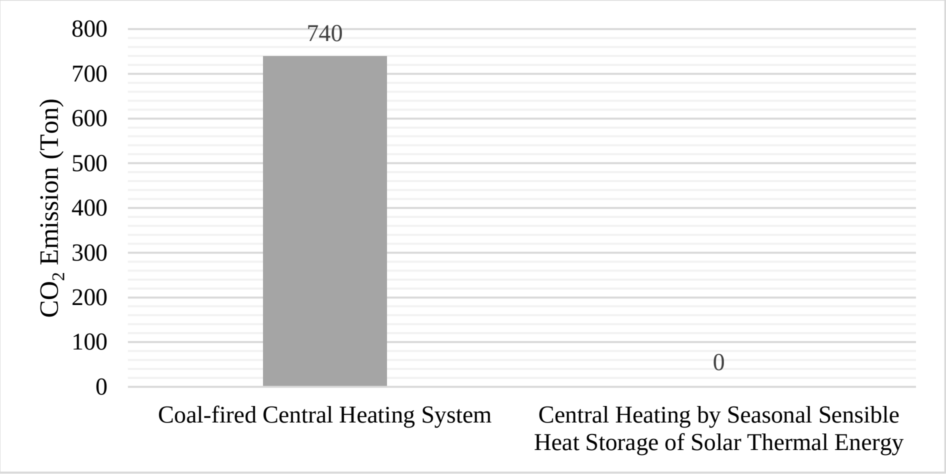


**Figure-7.**
Systems operation and maintenance cost comparison.

## 5. Discussions

As it is seen in the Figure 7., the following results are found. The initial or capital cost of the coal-fired central heating system is as much lower than central heating by seasonal sensible heat storage of solar thermal energy as it cannot be comparable with the initial or capital cost of central heating by seasonal sensible heat storage of solar thermal energy system.

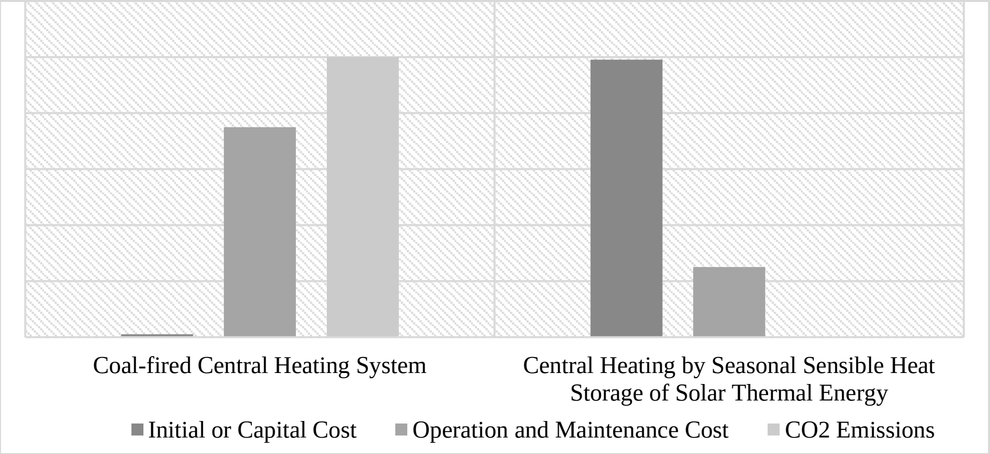


**Figure-8.**
Systems costs comparison.

- The operation or running and maintenance cost of the central heating by seasonal sensible heat storage of solar thermal energy system is one third of the coal-fired central heating system which shows comparable values.
- The central heating by seasonal sensible heat storage of solar thermal energy with zero emission is much environmentally friendly than coal-fired central heating system for it does not emit $CO_2$.
- The central heating by seasonal sensible heat storage of solar thermal energy is not an economically feasible central heating system. However, it can be useful and beneficent for the environment regarding to its no or zero $CO_2$ emissions.

The purposed system is in line with following Sustainable Development Goals (SDGs) [16]:

- Goal 3: Ensure Healthy Lives
- Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 8: Sustainable Economic Growth
- Goal 12: Ensure sustainable consumption and production patterns
- Goal 13: Take urgent action to combat climate change and its impacts

The central heating by seasonal sensible heat storage of solar thermal energy is a complex system which require multi-disciplinary design and analysis knowledge. In this study, the economic and environmental analyses of feasibility and viability of this system is performed. The baseline for this study is the using coal-fired central heating system. For the economic analysis, the initial or capital cost, operation or running and maintenance costs of the coal-fired central heating system and central heating by seasonal sensible heat storage of solar thermal energy are selected. For the environmental analysis, with the usage of online $CO_2$ emission calculator, the $CO_2$ emissions are selected as a baseline among different GHGs produced by coal.

## 6. Conclusion

As the above analyses is performed, it is concluded that the central heating by seasonal sensible heat storage of solar thermal energy is not a good choice and option with the consideration of its economic feasibility and viability study due to much longer payback period than its life time. But this system is a good system according to environmental considerations with its no or zero $CO_2$ emissions. With the consideration of the above mentioned findings, results and conclusions, the following recommendations are given.

- The coal-fired central heating system must not be used anymore due to its harmful $CO_2$ emissions per year.
- The seasonal sensible heat storage of solar thermal energy must not be used as central heating systems source. For it is not economically viable and feasible due to its high initial or capital cost of investment. However, if further benefits are not needed, it can be used as central heating systems source.
- The seasonal sensible heat storage of solar thermal energy can be used as district heating systems source due to low initial or capital cost of investment for the large capacity of seasonal sensible heat storage. It is worth mentionable that as the storage capacity become higher, the low initial or capital cost of investment become lower.

In this writing, the central heating by seasonal sensible heat storage of solar thermal energy is studied with the consideration of economic and environmental factors. It is suggested that in first stage the issues related to the technical feasibility and viability of this central heating system is performed in the future. In the next future, it is suggested that seasons sensible heat storage of solar thermal energy for district heating is studied and wished that the studies of central heating and district heating by seasonal sensible, latent and thermochemical heat storage of solar and geothermal energies will be performed.

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**Appendix-A.**
Radiators Profile of Each Floor

| | Ground | First | Second | Third | Fourth | Fifth | Sixth |
|---|---|---|---|---|---|---|---|
| Radiator# 1 Load (kW) | 2.5 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Radiator# 2 Load (kW) | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 2.0 |
| Radiator# 3 Load (kW) | 2.0 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 2.0 |
| Radiator# 4 Load (kW) | 1.8 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 |
| Radiator# 5 Load (kW) | 1.8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.8 |
| Radiator# 6 Load (kW) | 1.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.8 |
| Radiator# 7 Load (kW) | 2.0 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 2.0 |
| Radiator# 8 Load (kW) | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.8 |
| Radiator# 9 Load (kW) | 2.0 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| Radiator# 10 Load (kW) | N/A | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 |
| Radiator# 11 Load (kW) | N/A | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 |

**Appendix-B.**
Specific Investment Costs in €/kWth of Coal Fired Central Systems [12]

| Country/Load | <25 $kW_{th}$ | 25 to 100 $kW_{th}$ | 101 to 250 $kW_{th}$ | 251 to 350 $kW_{th}$ |
|---|---|---|---|---|
| Austria | 300 | 151 | 109 | 49 |
| Belgium | 244 | 123 | 89 | 40 |
| Bulgaria | 112 | 56 | 41 | 18 |
| Cyprus | 184 | 92 | 67 | 30 |
| Czech | 163 | 82 | 59 | 26 |
| Denmark | 367 | 184 | 133 | 59 |
| Estonia | 176 | 88 | 64 | 28 |
| Finland | 269 | 135 | 98 | 44 |
| France | 294 | 148 | 107 | 48 |
| Germany | 283 | 196 | 140 | 65 |
| Greece | 179 | 90 | 65 | 29 |
| Hungry | 153 | 77 | 56 | 25 |
| Ireland | 254 | 127 | 92 | 41 |
| Italy | 195 | 98 | 71 | 32 |
| Latvia | 205 | 103 | 74 | 33 |
| Lithuania | 182 | 92 | 66 | 30 |
| Luxembourg | 253 | 127 | 92 | 41 |
| Malta | 159 | 80 | 58 | 26 |
| Netherlands | 318 | 160 | 115 | 51 |
| Poland | 176 | 88 | 64 | 28 |
| Portugal | 146 | 73 | 53 | 24 |
| Romania | 113 | 57 | 41 | 18 |

| | | | | |
|---|---|---|---|---|
| Slovakia | 172 | 86 | 62 | 28 |
| Slovenia | 188 | 94 | 68 | 30 |
| Spain | 202 | 102 | 74 | 33 |
| Sweden | 358 | 180 | 130 | 58 |
| United Kingdom | 287 | 144 | 104 | 47 |
| Average | 219.7 | 112.3 | 81.2 | 36.3 |