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Energy Efficiency in Ports: Comparative Performance and Cost Analysis of Heat Demand in Port Facilities Using Solar Energy

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Abstract. Energy efficiency for less energy consumption, as well as using eco-friendly and sustainable energy to provide port services in a most efficient way play a key role in the competitiveness of ports both at national and at international level. Port facilities are complex systems with various energy demands for different functions and applications. Renewable energy systems are applications that have been handled in recent years, especially for energy efficiency and sustainable energy management. These preferences are valuable choices not only for energy efficiency but also for reducing CO_2 emissions. This study is based on the audit for evaluation of the energy consumption of a port building and saving potential with use of a concentrated solar system. Besides, CO2 emission saving potential with this preference was also examined. The energy demand of the port buildings, which uses heat and electric energy during whole year, were examined affordability of consumption with solar-powered systems. The research results indicated that the solar aided system preference provides 44.31% saving potential. At the end of the work, recommendations were given on energy efficiency and management.
Keywords: Port, Solar energy, Demand management, efficiency, Sustainability

1. Introduction

Logistics management plays an important role for sustainable development and related sustainability issues are the priority areas of societies as a social necessity. In this process, in particular the growing international trade potential has made it more important in the maritime transportation. Energy demand is constantly increasing in the maritime sector, which currently carries about 90% of international trade [1,2]. The market demand and operations of maritime transport have increased energy demand directly and indirectly, while raising environmental pollution and emissions. In shipping applications, ports are an important key player and energy costs are a parameter that must be taken into account in operating processes. In this context, it is a criterion based on reducing costs for management elements [3]. In view of environmental sustainability and marine environment protection, green shipping and green port initiatives will play an important role to reduce emissions.

Ports are composed of integrated systems and structures where energy is used continuously and intensively. In this context, sustainability of energy is a structural management requirement. In this process, planning for holistic approaches such as energy efficiency, effective energy management, operational initiatives and using alternative resources need to be evaluated to emphasize the process efficiency and efficient use of energy as well as the success of an effective energy management system. However, management of environmental pollution and emissions related to inefficiency and loss as well as consumption inefficiency evaluated as priority issue in system analysis and preferences.

Energy has been evaluated quantity wise until the recent years and this approach has always been taken as basis in determining efficiency strategies as well as efficiency calculations. New studies have shown that the energy quality instead of the quantity for the rational management of energy, is more valid parameter in the evaluation of energy efficiency [4]. In studies aiming to keep environment sustainable and reducing carbon emissions, considering the quality of energy has been accepted as a more realistic approach. Today, as in all public structures, ports need growth paradigms that will support their economic development needs and also provide climate and environmental sustainability. Economic activities and environmental protection are related to processes that negatively affect each other in traditional approaches. However, effective energy management and sustainable energy efficiency are both key players for sustainable development. Main activities based on energy management at the ports are as follows.

- Sustainable energy efficiency and use of renewable or clean energy instead of fossil fuels
- Organizing sustainable energy management that adds value to all building processes in the port operations (e.g., low carbon technologies, operational control and energy efficiency, smart networks and management, waste management, renewable energy)

Many studies are carried out for renewable energy preferences and low temperature heating systems under the International Energy Agency's (IEA) public and building systems program (LowEx). International low temperature heating systems research program (Annex 37); use of renewable energy and hybrid technology in heating and cooling preferences, encourage the use of low carbon technologies in energy system preferences, which will contribute to the rational use of energy as well as effective energy management in ports [5,6]. Considering these studies, the sustainable environment; along with alternative source solutions such as solar and wind energy, created an environment for low energy approaches to be molded in active and passive system applications. Thus, it highlighted the preferences of low-energy systems with renewable energy support in building heating and cooling system applications [6]. This study examined the energy management framework in a port application and evaluated the heating system preference developed as an alternative. The environmental effects of meeting the heat demand of a selected port with a hybrid application with solar support were also evaluated.

2. Ports and Holistic Energy Management Framework

Ports are structures with intense activities for various operations. Only container ship movement is around 1000 port calls weekly which includes handling of average 9000 containers. This involves more than 10000 ship movement around the world. [7]

Energy efficiency in ports is a managerial action that needs to be evaluated from multiple perspectives. Ports are institutional structures that have operational continuity together with intense energy consumption when their operational processes are taken into account. However, considering consumption behaviors, ports are a problematic area not only economically but also in terms of environmental impacts. In this context, for energy continuity and corporate manageability, it is essential to develop an effective energy management system and actions that will support the related improvement processes. There are many studies in the literature to be evaluated in this context. However, strategic approaches such as the green port concept point to an institutional transformation based on the protection of the ecosystem and the environment in ports and sustainable change in ports [8]. Some studies highlight key indicators such as greenhouse gas emissions from ports, waste from processes, and versatile energy consumption behaviors to improve energy and environmental sustainability [9]. However, for all these processes, port managements should develop the energy management culture in their corporate strategies and define behaviors and actions based on energy efficiency as a strategic goal.

The International Maritime Organization (IMO) has developed many regulations or regulations that will improve energy and environmental sustainability. However, environmental sustainability, especially in port and maritime operations, is defined by the International MARPOL Convention and refers to the regulations for the prevention of pollution from ships. Indeed, under MARPOL Annex VI, ship-based emissions have emerged as both global requirements and strict requirements applicable to ships located in Emission Control areas in the Baltic and North Sea [10]. In recent years, especially the sustainability of ports, energy management, de-carbonization and green port studies have become prominent issues. It is based on green growth, energy and environmental sustainability, as well as effective economic growth and sectoral sustainable development. In this development and growth process, it aims to develop energy efficiency actions together with effective energy management. This envisages the widespread use of low carbon technology, priority to the use of renewable energy sources and efficient use of solar energy as basic approaches in sectoral applications. Energy-related sustainability in ports is a dynamic process and actually needs support from many disciplines. An example of a plan is shared in Figure 1. The institutional character of energy management in ports is related to the disciplinary process developed by the port authorities [11].

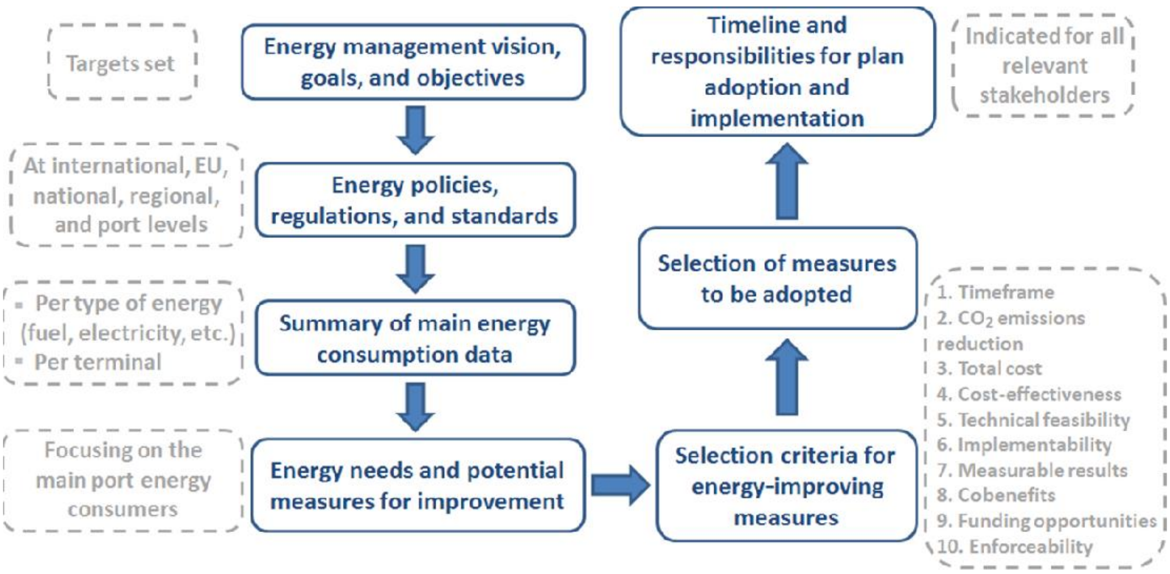

Fig.1. Energy management plan example [11]

Ports have to develop sustainable energy management indicators. It is valuable in terms of economic sustainability and environmental management effects in these ports. In energy management processes, improving energy efficiency, reducing energy costs, increasing the use of low-carbon technologies in operational processes and, above all, developing an energy efficiency behavior culture in ports can be considered as fundamental steps. In order to develop effective actions in all these processes, the basic requirement is to define important energy users by port managements. This allows direct analysis of users' energy consumption behavior and a holistic assessment together with resource adequacy and port operations. An example of a model study showing the operational processes and energy consumption distributions for this purpose is given in Figure 2.

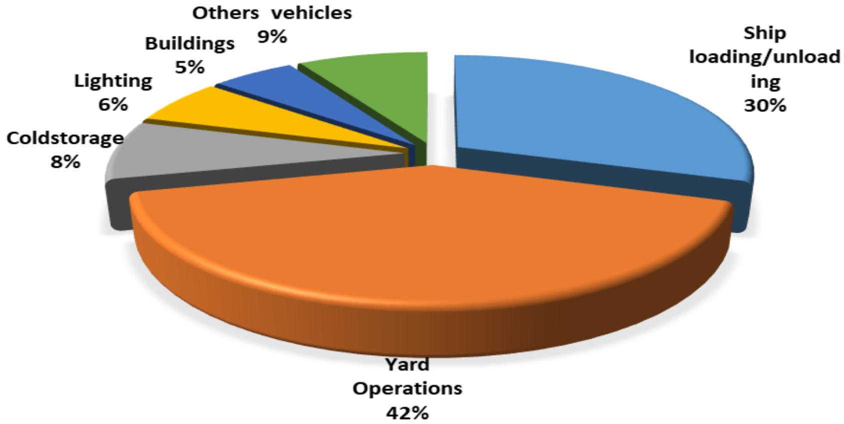

Fig.2. Energy Consumption versus Operations [12]

In energy planning, conducting a study according to consumption behaviors and controlling resource continuity is a managerial responsibility in energy management processes. It is a correct approach to plan actions in a limited way, especially for port authorities to support cost-effective solutions and to support the right feasibility at solution points. In this context, consumption needs and their scope areas are evaluated together with demand control in energy management. As exemplified in Figure 3 in ports, priority can be considered as a step in architectural evaluation and defining structure distributions.

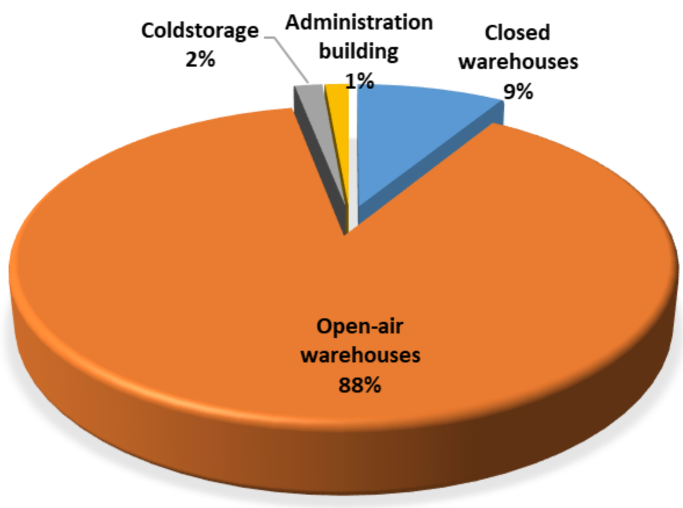

Fig.3. Structural Distribution of a Model Port [12]

2.1. Energy Demand Management

Energy is evaluated in two forms: heat and work. In structural needs, fuel-based consumption is used to meet the heat demand directly. Especially in ports with integrated building concept, heat requirement is the type of energy used for different purposes. This need, which mostly originates from fossil fuels, is generally evaluated over peak requirement. However, in effective energy management processes, this need is defined by demand management based on degree/day values.

Demand management is the primary target of reducing the carbonization pollution originating from fossil fuels in the control of energy demand for integrated structures. In this context, resource demand should be handled holistically for the relevant building components. Capacity management should be shaped directly with energy demand, especially in system preferences. While this will directly control fossil fuel consumption, it will also define technology management based on system preference. Different energy usage in conventional systems or process needs will find value especially with low carbon approach. In addition to sustainable fuel control, management of structural demands can be seen within this integrity. In this context, reduction of primary fuel consumption in enterprises or buildings, together with low carbon technologies, is a result of demand management. Demand management has an approach methodology given in Fig.4.

Fig.4. Concept map of demand control and management

In demand management, needs should be provided with sustainable resources and technologies, independent of conventional approaches. However, the use of an effective resource such as the sun provides a significant advantage in holistic system management. Especially the evaluation of solar energy with seasonal potentials is an important advantage in reducing fossil fuel consumption with technology and energy management. However, this system preference should be handled with actions planned within the energy management discipline. In this context, this study has revealed an approach in which energy demand management is evaluated in direct system selection with system preference. The developed work has shown that system preference, operation control and management in energy control provide significant energy and cost savings.

2.2. Technology Management and Solar Systems

One of the main goals of energy demand management in ports is sustainable and manageable energy efficient model development. In this context, it is a priority to reduce the energy consumption of the port or to increase the use of low carbon energy technology during off-peak periods. Thus, while consumption and energy usage habits are managed in port processes, general energy consumption is reduced. In energy demand management, the use of renewable energy generation should be increased for network operators in ports.

Solar systems can play an important role in reducing energy consumption in ports, especially with conventional heating systems (space heating, water heating) and PV technologies. However, in both conditions, together with a demand management, sustainable feasibility studies should be handled. Solar technologies can provide significant advantages in terms of emission control at all ports and reducing energy costs depending on the requirements. Fig.5 shows application of PVT technologies developed in recent years.

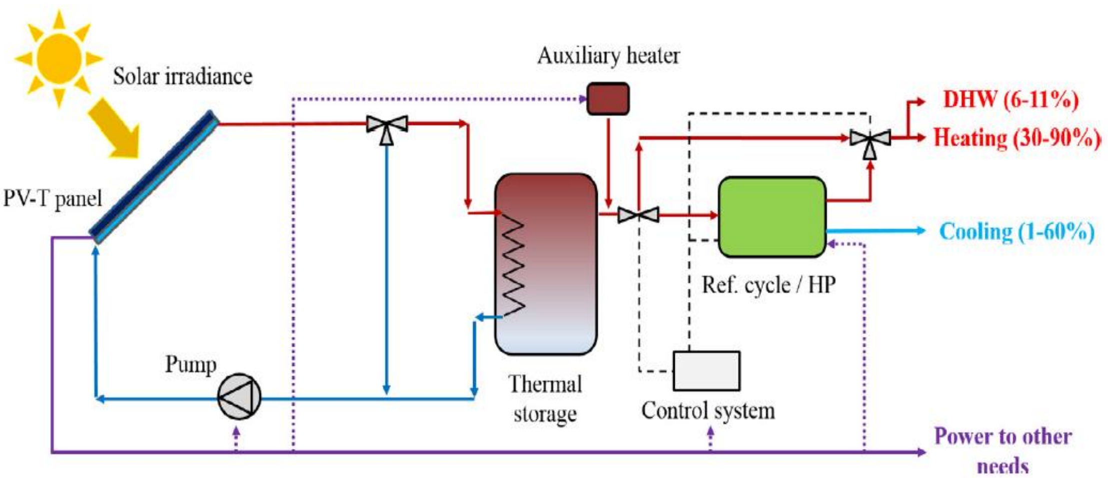

Fig.5. PVT system and components [13]

These technologies increase 10-15% efficiency in PVs to 25-30% range with thermal energy. However, another solution in solar technologies is Parabolic dish applications. In solar energy systems, parabolic collection collectors (PTC) have completed the R&D process and are commercial collectors. The system diagram can be seen in Fig.6.

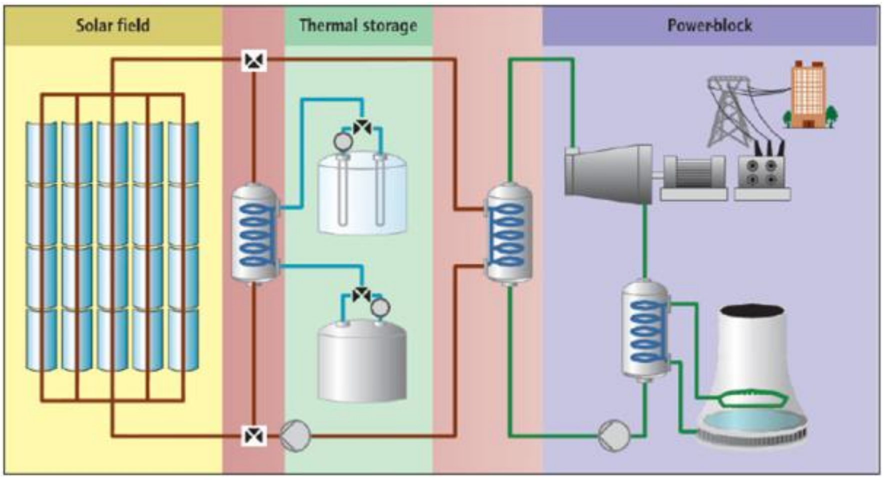

Fig.6. Parabolic concentrated solar technologies [14]

In these technologies, the average efficiency is in the range of 15-25% and the efficiency average of the system together with the heat recovery units is 40%. The energy transfer is provided through a secondary fluid. It is an important advantage especially for processes where more than one type of energy is needed.

Especially administration offices and closed areas have been evaluated as manageable elements for solar energy preferences in ports. In this context, a model was developed through concentrated parabolic solar technologies as defined in Fig.7.

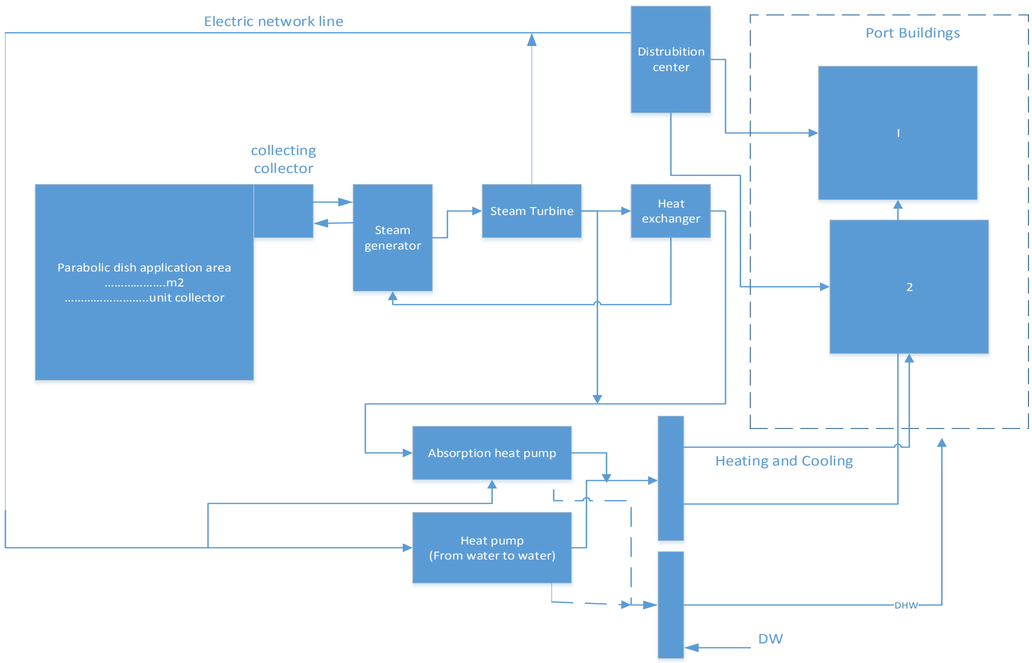

Fig.7. Concentrated solar model modified for port building

This model study is based on the use and evaluation of solar technology for a selected port in İzmir/Turkey. In Turkey, the average annual sunshine time is 2640 hours (7.2 hours per day total), and average total solar radiation is 1311 kWh /m^2/year (daily total of 3.6 kWh / m^2). Monthly solar energy potential and radiation values are given in Fig.8 [15].

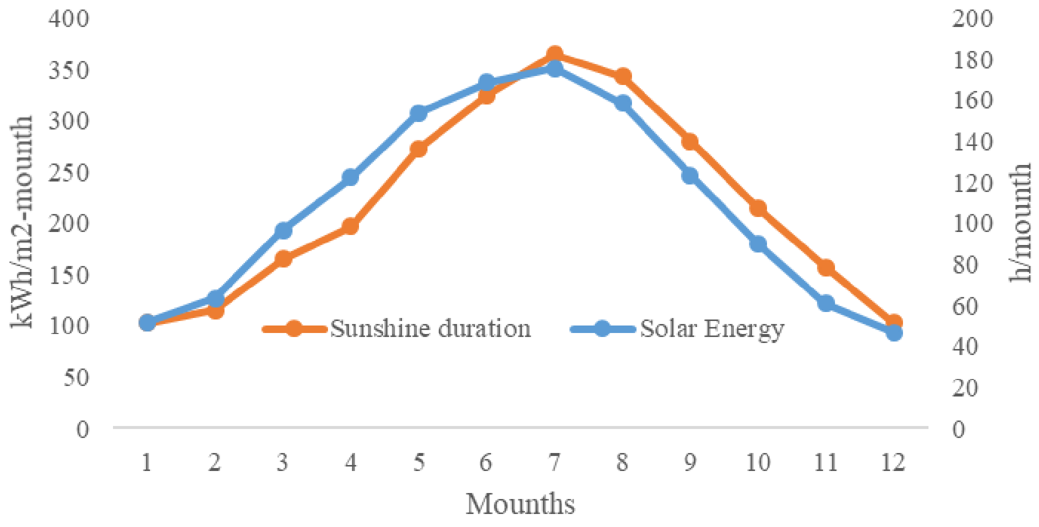

Fig.8. Solar energy in Turkey [15]

İzmir is a region with high potential for solar energy preference. Solar radiation values are above the average of Turkey. As a matter of fact, the radiation time for İzmir is 7. 8 hours / day and the average of solar radiation is 1500 kWh / m^2/year. Below, both sunshine time and solar radiation values are given in Fig.9 and Fig. 10 separately.

Fig.9. İzmir Sunshine Hours [16]

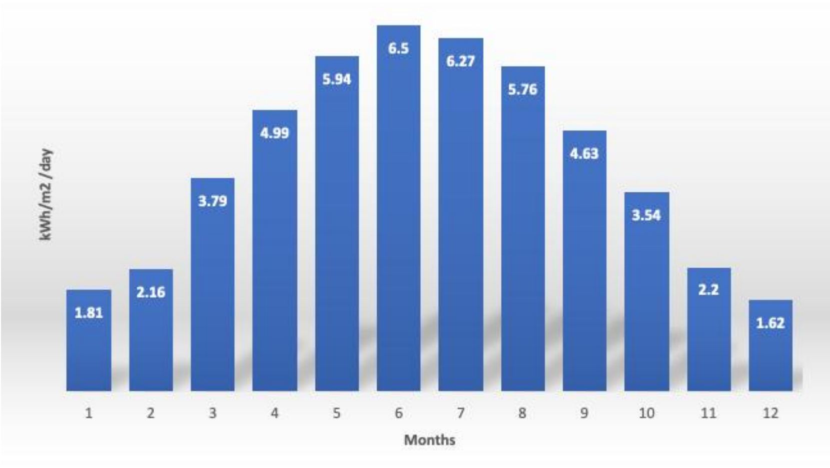

Fig.10. İzmir Radiation Values (kWh/m^2 /day) [16]

In line with the low carbon approach and sustainability concepts, it is possible to decrease the energy cost values by using solar energy in the public facilities with high energy consumption. For this purpose, a sample application model was studied in line with low carbon emission energy management approach by making thermo economic analyses on the annual energy consumption value of a public facility in İzmir.

3. Methodology: Thermoeconomic Analysis

In energy systems, performance criteria are handled directly by thermodynamic approaches. General energy efficiency in load evaluations regarding heat machines can be expressed as follows.

$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}} \quad (1)$$

Where η is thermal efficiency, $\dot{W}_{net}$ is network based on electric, $\dot{Q}_{in}$ is the net heat related to fuel.

In solar energy systems, besides electrical energy, which is defined as useful work, consumptions in power systems are also taken into consideration and evaluated as losses. Accordingly, the total energy of the system.

$$\dot{Q}_{in} = \dot{W}_{net} + \dot{Q}_{losses} \quad (2)$$

The $\dot{Q}$ loss in the formula refers to the losses in the systems. The energy delivered to the system depends directly on the amount of fuel. In this case, the energy given to the system can be expressed as follows.

$$\dot{Q}_{in} = \dot{m}_{fuel}.H_{LHW} \quad (3)$$

Where $\dot{m}_{fuel}$ is the total fuel, H_{LHW} is the low heat value. The amount of fuel (M_{fuel}) needed for the total energy load in a system can be calculated as follows.

$$M_{fuel} = \frac{\dot{Q}_{year}}{H_{LHV}\eta_{Boiler}} \quad (4)$$

Where η_{Boiler} is the efficiency of boiler [16]. The energy cost effect is a defined economic value for each type of fuel. The cost and value of energy obtained in a thermal system are mostly defined by the cost of resources.

$$C_{fuel} = \dot{m}_{fuel} \,.\, C_{unit\ cost} \qquad (5)$$

In this study, unit costs are derived directly from the purchasing costs of the enterprise.

All systems with fossil fuels and combustion processes cause direct or indirect environmental pollution due to combustion reactions. In particular, entropy production due to irreversibility is expressed by the greenhouse gas emissions of such processes. Especially the wastes produced after the combustion reaction are considered as the main source for both pollution and greenhouse gas emissions. In this context, this emission effects are defined as CO_2 equivalent emissions by the International Panel Climate Conference with an emission factor depending on the type of fuel. These results determine in an equivalent emission potential for each fuel type. (IPCC) [18]. Improvements in energy systems that can be achieved in such analyses indicate a reduction in process-induced emissions. In these analyses, emission potential is defined as a function of total fuel consumption and emission factor (F_{fuel}). Total emission related to fuel is;

$$C_{CO_2} = \dot{m}_{fuel} \,.\, F_{fuel} \qquad (6)$$

4. Results and Discussion

This study has aimed to calculate the energy demand of the closed areas and administrative buildings of a selected port facility which total closed area is 14250 m^2. The requirements for heat in winter and the hot water are provided by the natural gas boiler system. However, air conditioning is provided by air condition systems. Accordingly, annual heat requirements for closed volumes of the facility can be seen in Fig.11.

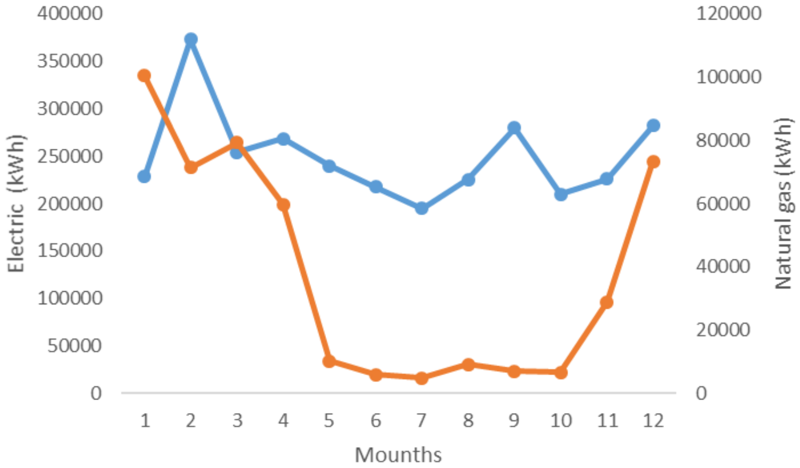

Fig.11. Heat demand of the port buildings

It is seen that electrical energy load is quite high in port energy demand. Especially in the summer months, the use of electricity has highlighted the solar energy system solutions. According to building demands, it is aimed to use concentrated solar technologies primarily for heat and electricity. Load analyses based on the annual energy demand described above have been accepted as reference values of the solar energy system to be installed. Absorption heat pump system for energy demand in the facility and especially for heat needs has also been added to the proposed model frame. The distribution of energy demanded in the port area is given in Fig.12.

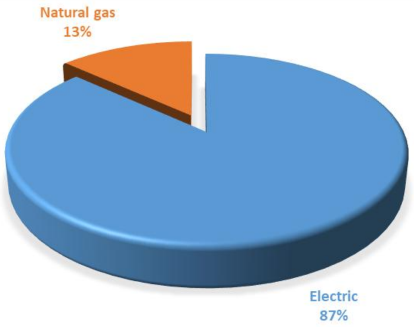

Fig.12. Heat demand of the port buildings

The analyses have shown that the main energy demand in the port area is electricity. In solar system preference, the priority is also for electricity demand. Parabolic bowl system was evaluated for the port and a system in the temperature range of 200-300 °C was planned. In practice, 200 kW steam turbine was based on, and 2 steam turbines with a total peak load of 2x700 kW were targeted for power needs. For the storage capacity of the facility, an analysis has been made for the conditions where the efficiency of the steam generator will be minimum at 250 ° C and 220 °C outlet conditions and the turbine outlet temperature 105 ° C for the conditions where the efficiency factor is 88% for the fluid temperature 250 ° C. Accordingly, 502 kWe value was taken as a reference for each turbine peak load generation. The 78.43% of the annual electricity requirement of the facility which is approximately 3 GWh can be met especially for the summer months. With this approach, energy system analyses are handled separately for each month and coverage rates are evaluated. The coverage rates and distributions are given in Fig.13.

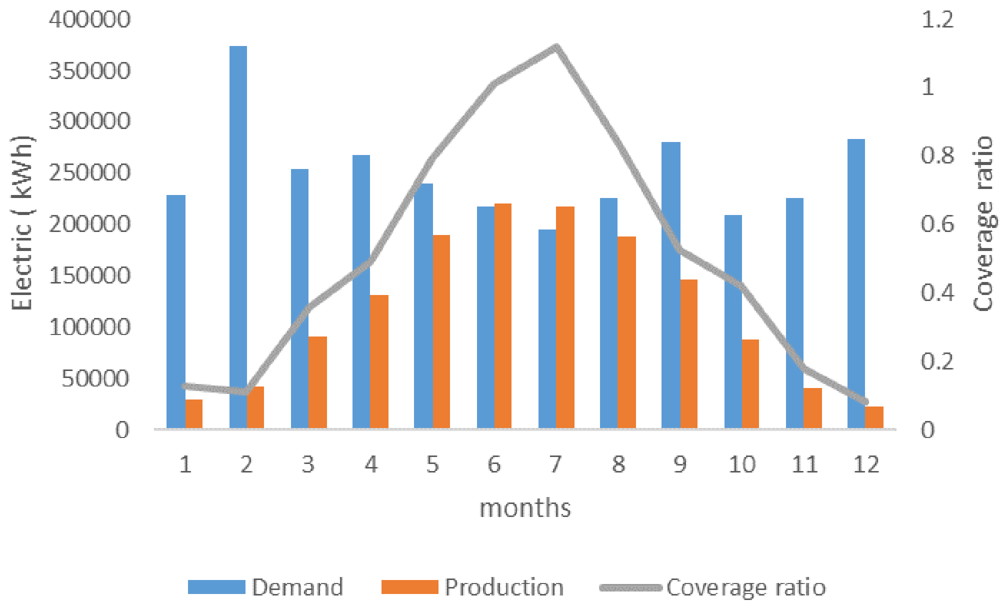

Fig.13. Coverage ratio of electric production for solar system

In this study, it was observed that the port buildings have a production potential of 933 kWh compared to 1353 kWh monthly consumption in peak load. It has been observed that the monthly consumption change varies between 373 MWh and 195 MWh. On the other hand, the load variation to be achieved in the Solar system is between 23 MWh and 220 MWh. Change interval rates of the proposed system vary between 8% and 100% in accordance with research results. The coverage rate for the whole year is found 50.39% in electricity and 64.73% in natural gas.

In condensed parabolic system solutions, both electricity and heat needs can be met from the system. The distribution of the coverage ratio in natural gas compared to the heat energy demand, is given in Fig.14.

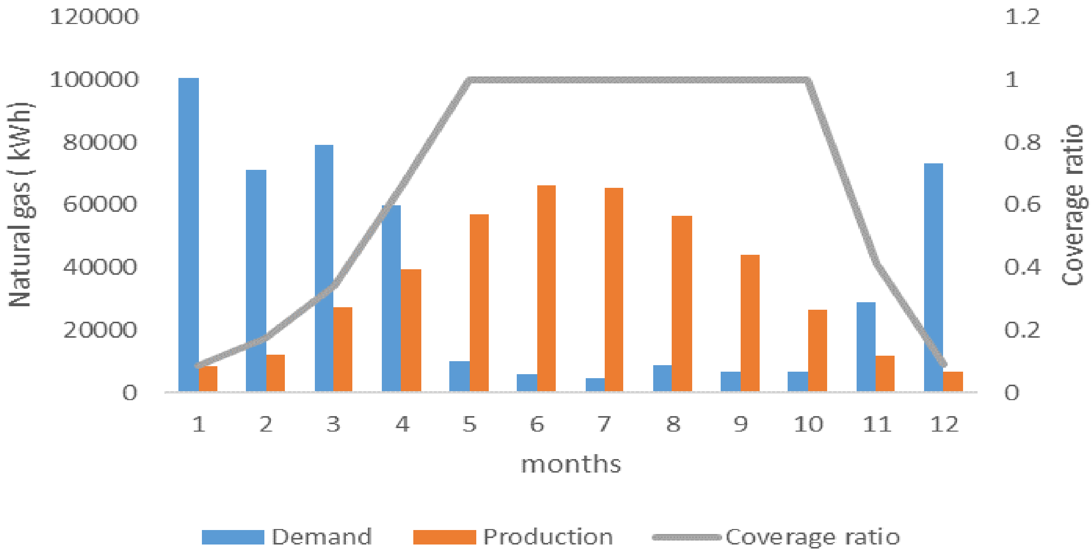

Fig.14. Coverage ratio of heat production for a solar system

In this study, the amount of savings to be achieved with the solar energy system compared to annual electricity consumption and natural gas consumption was evaluated. It has been observed that there is 32.88% saving in natural gas and 46.05% in electricity. It corresponds to a saving potential of 44.31% in total consumption.

The thermo economic potential of this savings to be achieved in the port facilities has been based over the fuel equivalency for natural gas and the consumption cost for electricity. Total saving amount in the study was found to be $ 160600 / year, including $ 4060 / year for natural gas and $ 1560000 / year for electricity. In the analyses made, not only the annual energy cost, but also the annual emission savings have an important potential. This distribution can be seen in Table 1.

Table 1 CO_2 emission distribution of port

Month	Natural Gas		Electric		Total Energy	
	Energy	CO_2	Energy	CO_2	Energy	CO_2
	kWh	Ton CO_2	kWh	Ton CO_2	kWh	Ton CO_2
1	8648	1.74	28825	15.94	37473	17.68
2	12443	2.50	41477	22.94	53921	25.44
3	27163	5.46	90544	50.07	117707	55.53
4	39391	7.92	131303	72.61	170694	80.53
5	10224	2.06	190169	105.16	200394	107.22
6	6027	1.21	217863	120.48	223890	121.69
7	4931	0.99	194928	107.80	199859	108.79
8	9122	1.83	188514	104.25	197636	106.08
9	6939	1.39	146713	81.13	153652	82.53
10	6716	1.35	88277	48.82	94993	50.17
11	12003	2.41	40011	22.13	52014	24.54
12	6800	1.37	22667	12.54	29468	13.90
Total	150408	30.23	1381292	763.85	1531700	794.09

5. Conclusions

The effectiveness of energy management in ports is primarily related to the development of energy efficiency depending on the choice of energy systems and operating parameters. In this process, the basic energy management include the evaluation of consumption related to direct energy demand and calculation of consumption-related emission threats. In this respect, this study has yielded important results in defining the impact of renewable energy sources, especially in energy system preferences in a port facility. Particularly the concentrated parabolic system preference attracts attention with a saving of approximately 44.31% in the efficiency potential of the system. In addition, supporting the systems with renewable energies such as solar energy in terms of sustainable environment has also been shown to affect the consumption costs of heating systems positively. However, it was seen that not only solar system preference, but also the proposed framework, heat pump preference is suitable for sustainable environment. For this purpose, besides the use of renewable energy sources such as solar technologies, low temperature heating in buildings, development of high temperature cooling systems will improve energy savings in all port buildings with operational parameters. Establishing effective energy management system for sustainability in ports should be perceived as an imperative.

Nomenclature

Abbreviations and symbols with subscripts and superscripts

C_{fuel} : Fuel cost
$C_{unit\ cost}$: Unit fuel cost
C_{CO_2} : Emission potential
F_{fuel} : Emission factor
H_{LHW} : Low heat value

$\dot{m}$: Unit mass flow rate
$\dot{m}_{fuel}$: Unit mass flow rate of fuel
M_{fuel} : Total mass flow rate
$\dot{Q}$: Heat flow
$\dot{Q}_{in}$: Heat flow for input process
$\dot{Q}_{year}$: Annual heat flow demand
$\dot{W}_{net}$: Net powe
η : Efficiency
η_{Boiler} : Boiler efficiency

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