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Energy performance assessment in terms of primary energy and exergy analyses of the nursing home and rehabilitation center

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Abstract

This paper concerns with the energy analysis (based on primary energy) and exergy analysis of Narlıdere Nursing Home and Rehabilitation Center (NNHRC) in İzmir, Turkey that was chosen as a sample public building. The Center services as a nursing and rehabilitation center for the aged and it also includes a geriatric division operating as a hospital. The Center was analyzed using the actual energy consumption data derived from several energy audits. Energy efficiency (according to the primary energy ratio) and exergy efficiency of the facility were calculated to be 59% and 14%, respectively. The results have indicated that the exergy efficiencies of space heating and cooling have the lowest values compared with the other units of facility. Specific primary energy consumption and specific exergy consumption of the facility were found to be 271.91 kWh/m^2 year and 290.23 kWh/m^2 year, respectively. Sustainability index value of the overall NNHRC was found to be 1.621.

Keywords

Public building, primary energy ratio, exergy efficiency, specific primary energy consumption, specific exergy consumption

Introduction

Nursing home (NH) is a home for older adults where they receive necessary care for their health providing a social environment at the same time.[1] The world population is rapidly

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aging and older adults who live in long-term care facilities are drastically increasing in number.[2–4] People aged 65 and over constituted 5.1% of the world population in 1950 and 8.7% in 2017. This proportion is expected to reach 15.8% for those aged 65 and over by 2050.[5–7] Similarly, in Turkey, while the proportion of people population aged 65 and over was 3.3% in 1950, this proportion had increased to 8.5% in 2017. According to population projections, this ratio is estimated to increase to 10.2% in 2023, 20.8% in 2050, and 27.7% in 2075.[8–10]

Energy is one of the most critical resources for human survival and is the power driving economic development to promote social progress,[11] but at the same time the rising level of global warming, which has increasing effects and is sourced by climate change, indicates danger alert for the common future of mankind.[12] Hence, reducing the electricity generation becomes more and more important. On the other hand, according to the International Energy Outlook 2013, the energy consumption around the world is set to grow by 56% between 2010 and 2040, mostly in developing countries. In response to concerns about climate change and in line with legislation in other developed countries, the UK Climate Change Act (2008) mandates an 80% reduction of greenhouse gas emissions by 2050 compared to the 1990 baseline.[13] Therefore, the increased growth in demand for electricity and emissions concerns about the improvement of energy production[14,15] as well as using energy efficiently. Energy efficiency is the quickest, cheapest, and the most direct way to reduce energy demand and CO_2 emissions.[16] Energy efficiency is the reduction of energy consumption per service quantity without reducing one's standard of living or the quality in the service. It is also possible to make a major contribution to the economy of the country and to protect the environment. The increase in the effective use of energy resources and the prevention of wasted energy is of great importance for ensuring the security of energy supply. Approximately 40% of the emission reduction required by 2050 to limit global temperature increase to less than 2°C would potentially come from energy efficiency.[17] The need to control atmospheric emissions of greenhouse and other gases will increasingly have to focus on the efficiency in energy production, transmission, distribution, and consumption in the world.[18,19]

In the European Union (EU), the largest share of the total energy consumption is in the residential sector, which is 45%.[20–22] In a similar way, about 31% of the energy demand in Turkey is associated with residential houses. Buildings have come into the spotlight as an area where significant energy savings can be achieved; existing buildings in particular present the largest potential.[23,24] The potential for saving energy was determined to be 30% in buildings and 20% in the industrial sector in Turkey.[25]

Energy saving is one of the main elements of the Europe 2020 flagship initiative for a resource-efficient Europe. It is described as the most cost-effective and fastest way to increase security in the supply of energy and as an effective way to reduce greenhouse gas emissions.[26,27] In line with the Energy Efficiency Directive, the EU aims to achieve energy savings of 20% or more in 2020 and 30% in 2030.[28] One of the strategic purposes published in the Turkish Energy Efficiency Strategy Document (prepared by General Directorate of Renewable Energy (GDRE)[29] in 2012) is to use energy efficiently. As stated in this document, in public buildings, the annual energy consumption has been aimed to decrease by 10% until 2015 and 20% until 2023. In this context, it has been envisaged to prepare projects improving the effective usage of energy by doing energy audit in public buildings and facilities. According to the results of Public Building Energy Efficiency Study Implementation Monitoring Report-1 by GDRE, required rehabilitation building rate in the total stock was found to about 20%.[30] The buildings open to the public have great importance in this sense because their proportion in the energy consumption is large in Turkey. It has been found that there are potential savings of approximately 27.3% in the total energy consumption, including 13% of electricity consumption and 35.5% of fuel consumption in the completed energy efficiency study of 166 public buildings by GDRE.[31]

Exergy analysis is a very effective method, which can be successfully used in the design of an energy system and provides information to choose the appropriate component design and operation procedure. This information is much more effective in determining the plant and operation cost, energy conservation, fuel versatility, and pollution.[32] Bejan[33] pointed out that the minimization of lost work in the system would provide the most efficient system. By using exergy analysis method, magnitudes and locations of exergy destructions (irreversibilities) in the whole system are identified, while potential for energy efficiency improvements is introduced.[34]

There are many articles on energy and exergy analyses in the open literature. The majority of these studies are based on the energy consumption and the compatibility of the standards on energy efficiency.[13,35–45] There are also specific articles on air circulation, electric drivers, and so on,[46,50] and on renewable energy.[35,51] Due to the lack of studies on NHs, this work mainly focused on these energy efficiencies-related topics in public buildings and hospitals.

Narlıdere Nursing Home and Rehabilitation Center (NNHRC) in İzmir, Turkey was built by the State Retirement Fund and it has the biggest capacity in its field in Turkey and Europe.[52] The purpose of energy and exergy efficiencies feasibility project in NNHRC is (i) to apply the energy and exergy analyses for improving the overall system and (ii) to show the energy consumption of building from the point of primary energy. In this study, the differences between the overall efficiency have been attempted to show holistically while drawing attention to primary energy consumption in the NH as an example of a public building.

Building description

In this study, NNHRC in İzmir, Turkey has been examined. The center has been active since 2001 and it is the biggest facility serving in its field in Turkey. The total land area of the facility is 114.517 m^2; total building area is 74.616 m^2. The facility consists of one building for management, 34 blocks for old people without disabilities, two blocks with nine floors for geriatric care center where old people with disabilities are taken care of professionally, two conference rooms, six cafes, one kitchen, two laundry rooms, one kindergarten, a 32-floor building used for dormitory purpose, one amphitheater, and one greenhouse (Figure 1).[52] The facility is designed for 1061 people. There are 480 rooms for old people without disabilities and the capacity of geriatric care center is 271.

In the facility as the main central heating system, natural gas boilers are utilized for heating and domestic hot water (DHW) production. A steam generator (SG) operating with natural gas is used to provide steam for laundry. The chillers for cooling are driven by electricity.

Figure 1. The view from the top of Narlıdere Nursing Home and Rehabilitation Center.

Method

Initially, the etude information form taken from GDRE,[31] which includes technical information regarding the building was filled. Natural gas and electricity bills concerning six years' time period were gathered and evaluated. The information about the building structure, installed systems and equipment, and monthly electric counter data were provided by the facility's personnel. Also, deficient values were completed with the fieldwork.

Boiler efficiency was measured by flue gas device. Based on these measurements, the boiler (heat generator) thermal efficiency was calculated to be 88%. The coefficient of performance (COP) of chiller used in the center has 4.5 catalog value. In general, COP of these systems decreases to a value of around 3.5 and so for this study it was assumed to be 3.5 in calculations. The hot/cold water distribution and emission losses were estimated as 15%.

The energy use was divided into five main groups: space heating and cooling, DHW, steam production, and electric equipment (including lighting). It should be noted that in NNHRC, the ambient temperature is maintained at 24°C for old people without disabilities and on the other hand geriatric care center is kept at 28°C, since this center is occupied with people who cannot look after themselves, mostly confined to bed and need greater physical, psychological, and social care. The other operating temperatures of the facility for each unit are also shown separately in Table 1.

In exergy calculations, the required quality factor was calculated for each unit due to the reference state (or dead state). In this study, the monthly average outdoor temperatures for Izmir derived from Turkish State Meteorological Service[53] were used for the dead-state air temperature for heating, cooling, and steam generation (Table 2). For the DHW, water dead

Table 1. Average temperatures in NNHRC.

Space heating				
Blocks	Geriatric care	Space cooling	Steam generation	Domestic hot water
24	28	25	150	60

Table 2. An average monthly temperature for Izmir.[48]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8.8	9.4	11.7	15.9	20.9	25.7	28	27.6	23.6	18.9	14.1	10.6

state temperature was accepted as 10°C. The quality factors for each task were calculated by equation (10). For electric-powered equipment (except for heating and cooling applications), the quality factor of the electric work was equal to the unit.[54]

Energy analysis

The primary energy demand ($E_{p,i}$) is given by equation (1)

$$E_{p,i} = E_{f,i} + \frac{W_{el,i}}{n_{eg}} \tag{1}$$

where i is the final user, E_f is the annual fossil fuel demand (assumed as direct primary energy), W_{el} is the annual electricity input, and n_{eg} is the overall energy efficiency of the electric grid. The conversion factors for primary energy taken from SAP 2005[55] are 1.15 for gas fuels and 2.8 for electricity.

The specific primary energy (SPEC) or energy performance (EP) indicator is calculated in equation (2). Here, A_f is the building floor area

$$SPEC = \sum_i \frac{E_{p,i}}{A_f} \tag{2}$$

Primary energy ratio (PER) is determined from equation (3)

$$PER_i = \frac{E_{u,i}}{E_{p,i}} \tag{3}$$

where $E_{u,i}$ is the useful energy.

General relation of $E_{u,h}$ for heating system and DHW is given by equation (4)

$$E_{u,h} = \sum E_{f,h} n_b n_d + \sum W_{el,aux} \tag{4}$$

where $E_{f,h}$ is the fuel input of the boiler, n_b is the thermal efficiency of the boiler, and n_d is the efficiency of distribution network. $W_{el,aux}$ is the electricity load required for the auxiliaries of space heating process (e.g. pumps, fans).

For the cooling units (c), a chiller is used. The formulation is given by

$$E_{u,c} = W_{el,ch} COP_{ch} n_d + \sum W_{el,aux} \tag{5}$$

$W_{el,ch}$ and COP_{ch} are the supplied electricity and the averaged coefficient of performance for the chiller; $W_{el,aux}$ is the electricity load required for the auxiliaries of space cooling process (e.g. pumps, fans).

For electricity-powered equipment (*el*) (excluding heating and cooling equipment), such as lighting, ventilation, and other NNHRC's electric equipment, the useful energy is given by equation (6)

$$E_{u,el} = \sum W_{el} \tag{6}$$

Exergy efficiency

The exergy efficiency (ε_i) is expressed by equation (7), and in a similar way, exergy efficiency is defined as the ratio of the total exergy output to the total exergy input, i.e.

$$\varepsilon = \frac{Ex_{out,i}}{Ex_{in,i}} \tag{7}$$

where "out" stands for "net out" or "product" or "desired value" or "benefit", and "in" stands for "given" or "used" or "fuel".

The exergy input is obtained as follows

$$Ex_{in,i} = F_{q,f} E_{f,i} + \sum_k F_{q,f,k} \frac{W_{el,k}}{n_{eg,k}} \tag{8}$$

where $F_{q,f}$ is the quality factor of the fuel and $E_{f,i}$ is the fuel energy supplied for task *i*. $F_{q,f,k}$ is the quality factor of the fuel source, *k* for the electricity production $W_{el,k}$. The quality factor $F_{q,f}$ used was 1.04.[56] In the same way, the output exergy, $Ex_{out,i}$ is calculated by equation (9)

$$Ex_{out,i} = F_{q,i} E_{u,i} \tag{9}$$

where $F_{q,i}$ is the quality factor for the output task *i* and $E_{u,i}$ is the useful energy. $F_{q,i}$ was taken to be 1 for electric applications.[54] For thermal-based applications, such as space heating and cooling, DHW, or steam generation (SG), $F_{q,i}$ was calculated by using equation (10), where T_0 is the dead state temperature and T_i is the ambient temperature for task i.

$$F_{q,i} = 1 - \frac{T_0}{T_i} \tag{10}$$

Specific annual exergy consumption associated primary energy is calculated with equation (11)

$$SExC = \sum_i \frac{Ex_{in,i}}{A_f} \tag{11}$$

Sustainability index

The sustainable supply of clean and affordable energy resources as well as their efficient usage are vital for sustainable development. Exergy analysis has a big potential to improve efficiency by maximizing the benefits and efficient using of resources as well as minimizing the detrimental effects such as environmental damages. Therefore, the exergy analysis can be applied to amend the efficiency and sustainability of thermal systems. The relation between exergy efficiency and the sustainability index (SI) can be expressed as follows[57]

$$SI = \frac{1}{1 - \varepsilon} \tag{12}$$

Results and discussion

Energy consumption of NNHRC

In this study, energy consumption for heating and cooling, DHW, SG, and electrical equipment (including lighting) in NNHRC were investigated.

Energy consumption share of NNHRC was examined considering utility bills for six years. As a result, annual natural gas and electricity consumption were found to be 9,289,451 kWh (73%) and 3,430,815 kWh (27%), respectively.

Natural gas was used mainly for space heating, DHW, and SG. Annual natural gas consumption was 5,229,767 kWh (56%) for space heating, 3,810,708 kWh (41%) for DHW, and 248,976 kWh (3%) for SG, respectively. Monthly natural gas consumption is shown in Figure 2. Unlike space heating, natural gas was used for DHW and SG throughout the year.

Electricity was used for space heating/cooling, hot/cold water pumping, steam pumping, lighting, computers, and other electrical appliances. Monthly electricity consumption is summarized in Figure 3.

The annual energy consumption for natural gas and electricity is shown in Figure 4. It demonstrates that the NNHRC's DHW was the major primary energy consumers, followed by space heating and cooling applications.

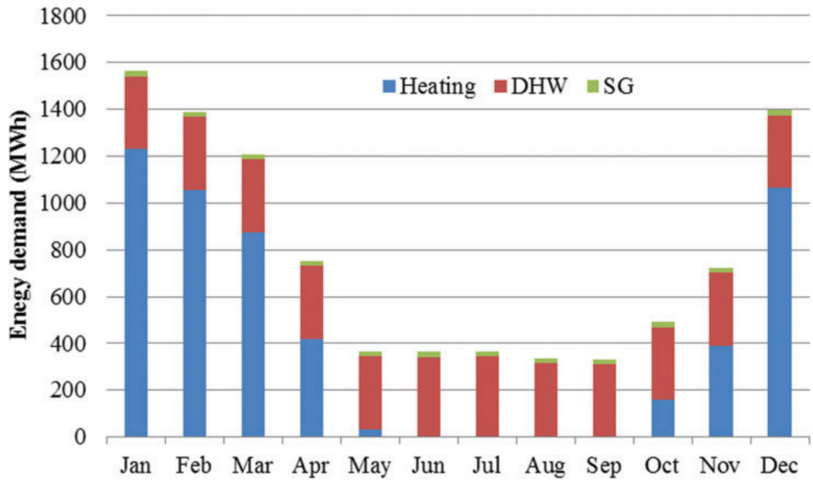

Figure 2. Monthly natural gas consumption.

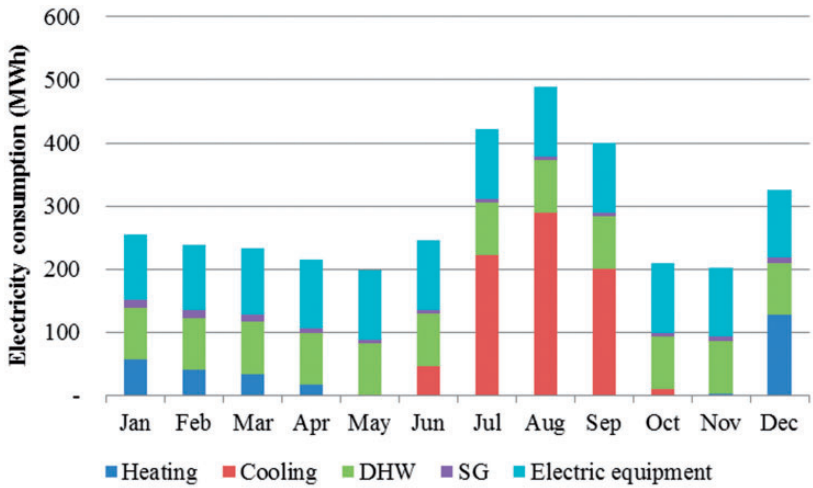

Figure 3. Monthly electricity consumption.

Energy and exergy analyses

PER and exergy efficiency indicators were calculated by using the results derived from Energy Consumption of NNHRC section, the field work measurements, and making necessary assumptions. The results for natural gas, electricity and related primary energy input, the useful energy and PER indicator for the tasks: heating, cooling, DHW, SG, and NNHRC electric equipment (lighting, elevators, personal computers, and others) are presented in Table 3. In this table, the overall PER of the facility and PER of each unit were also included. Lower PER value was found for the electricity-powered equipment (except for chillers) due to the usage of low overall electric grid efficiency. The higher

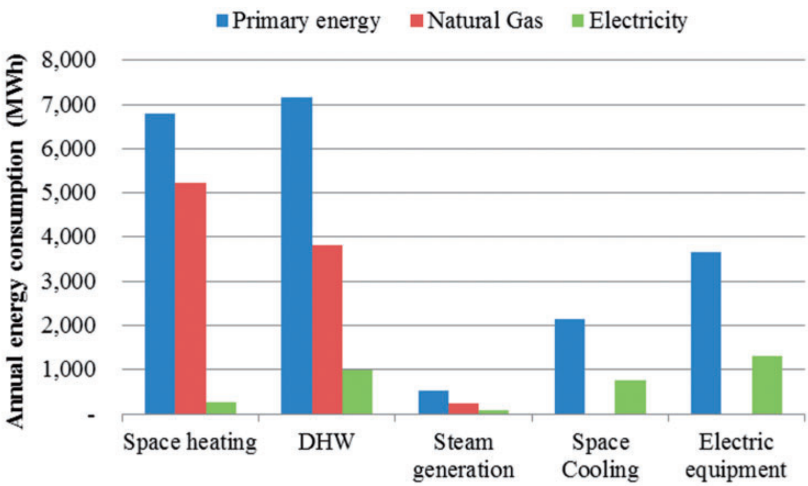

Figure 4. Annual energy consumption for natural gas, electricity and primary energy.

Table 3. Estimated annual energy values and PER indicators.

Unit	Primary energy (kWh/year)	Natural Gas (kWh/year)	Electricity (kWh/year)	Useful energy (kWh)	PER
Heating (boiler)	6,014,233	5,229,767	n.a.	3,911,866	0.65
Heating (auxiliaries)	769,810	n.a.	274,932	274,932	0.36
DHW	4,382,314	3,810,708	n.a.	2,850,409	0.65
DHW (auxiliaries)	2,780,736	n.a.	993,120	993,120	0.36
Steam generation (SG)	286,322	248,976	n.a.	186,234	0.65
Steam generation (SG) (auxiliaries)	249,088	n.a.	88,960	88,960	0.36
Cooling (chiller)	1,735,062	n.a.	619,665	2,168,828	1.25
Cooling (auxiliaries)	416,980	n.a.	148,922	148,922	0.36
Electric equipment	3,654,607	n.a.	1,305,217	1,305,217	0.36
Total	20,289,152	9,289,451	3,430,815	11,928,488	0.59

PER: primary energy ratio; DHW: domestic hot water.

PER value obtained was associated with the chiller, since it has a high COP value. The electric equipment of NNHRCs had the lowest PER, so they could be considered as the biggest contributors for the decrease of the overall PER value.

Significant differences were shown between PER and the exergy efficiency values of the units in Figure 5. When PER and exergy efficiencies of electricity-powered equipment were examined, high exergy efficiency and low PER values were observed. On the other hand, low exergy efficiencies of space cooling and heating unit were obtained while their PER values were high. Both DHW and SG had similar exergy efficiency values. As can be seen

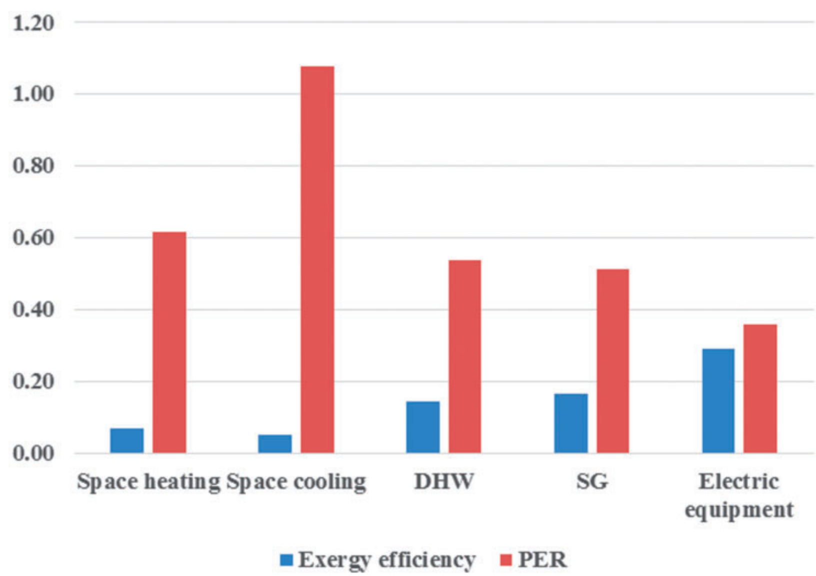

Figure 5. PER and exergy efficiency for NNHRC.

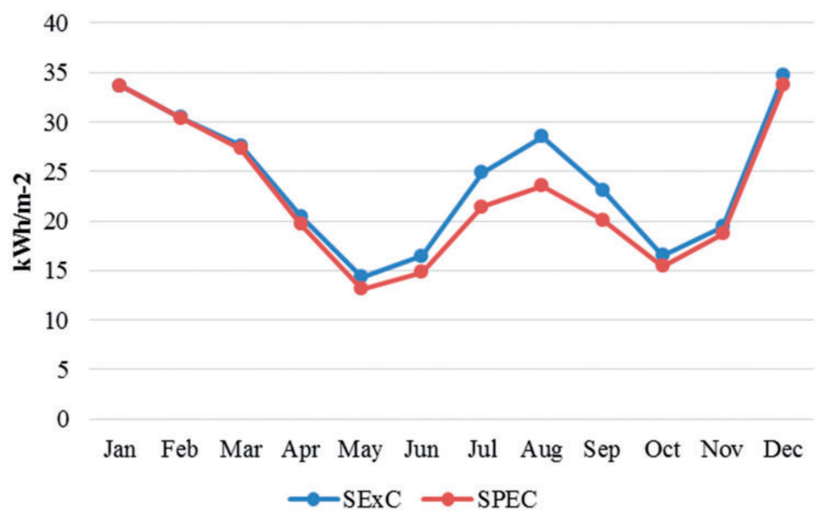

Figure 6. SExC and SPEC for NNHRC.

previously from Figure 4, even though DHW had the highest consumption rate, it had higher exergy efficiency compared to space heating and cooling. These results indicate inadequate insulation of the building shell and pipeline and it may be advisable to prioritize insulation in the improvement process.

The differences between SPEC and SExC in terms of monthly change are illustrated in Figure 6. It should be noted that the primary energy was taken into account for

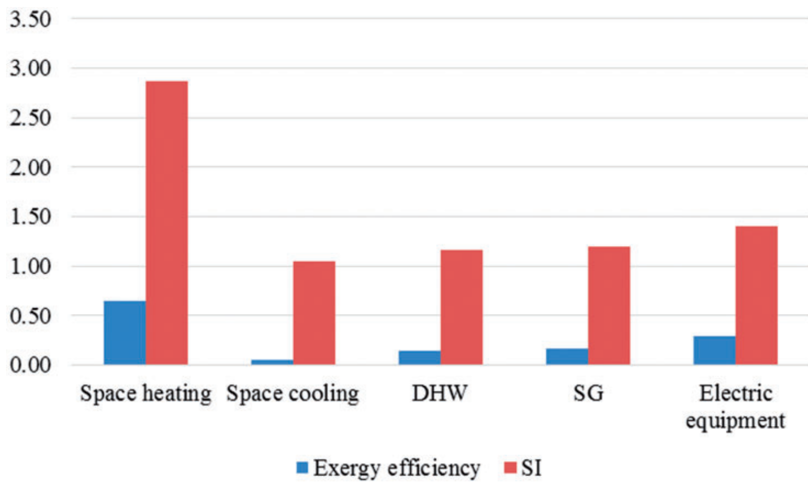

Figure 7. Exergy efficiency and SI for NNHRC.

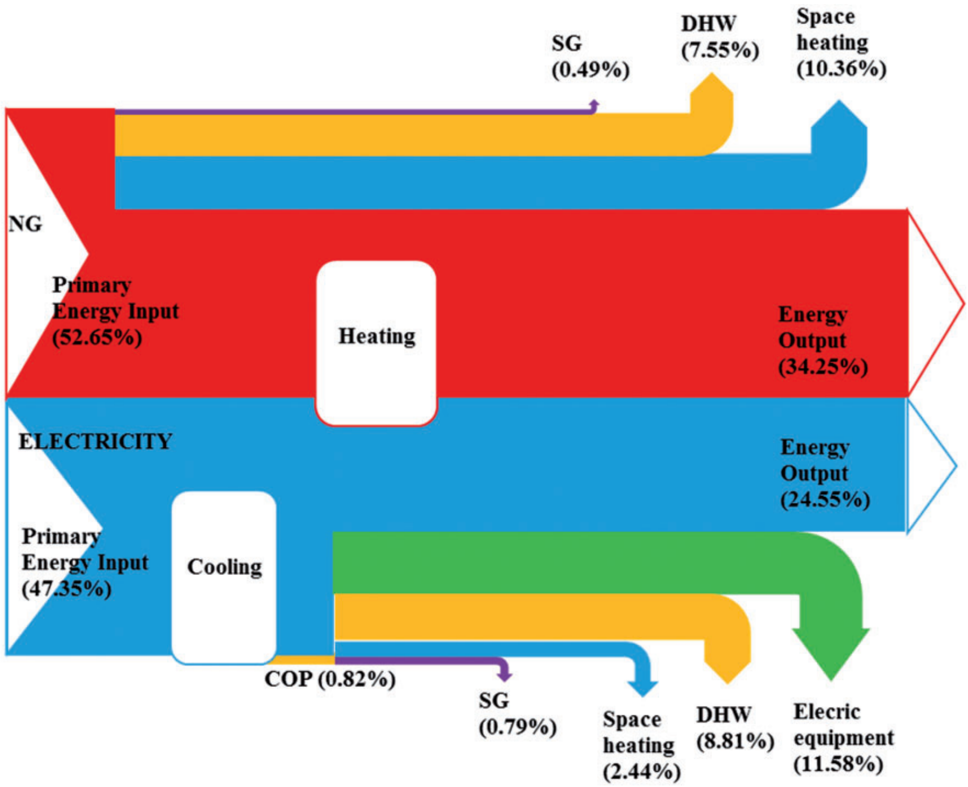

Figure 8. Sankey diagram with primary energy base.

SPEC calculations. Overall SPEC and SExC were determined as 271.91 kWh/m^2 and 290.23 kWh/m^2, respectively.

High SI values indicate high-efficiency values for a system or process, which in turn result in a low environmental impact. There is a direct relation between exergy efficiency and SI values (Figure 7). SI values of the overall NNHRC were calculated as 1.621.

The energy consumption for the whole system was quantified as percentage and illustrated in the Sankey diagram (Figure 8). In the considered system, while the percentage of the total energy input was 100, the percentage of the primary energy output was determined to be 58.8%.

Conclusions

In this study, results derived from an energy audit of NNHRC were used to evaluate energy and exergy performances of the building.

PER and exergy efficiencies for the whole facility were determined as 59% and 14%, respectively. Electrical equipment (including lighting) has the highest exergy efficiency and the lowest PER values due to the highest conversion factor. The exergy efficiency of the space heating and cooling has the lowest value. Depending on the results obtained, enhancement in space heating and cooling is suggested as a priority. Overall, SPEC and SExC were found to be 271.91 kWh/m^2 years and 290.23 kWh/m^2 years, respectively. The SI value of the total NNHRC was 1.621. Substantial improvement of the facility is recommended to increase the energy efficiency.

The application of renewable energy resources in the facility will cause the reduction of the energy consumption, which in turn will have a positive impact on the environment. Since the solar energy is the most suitable energy source for this region, further studies will be concentrated on this subject.

Declaration of conflicting interests

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