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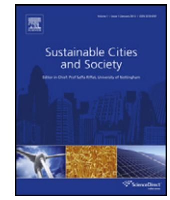

Development of sustainable energy options for buildings in a sustainable society

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A R T I C L E   I N F O

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A B S T R A C T

In this study, a building with a volume of 392 m^3 and a net floor area of 140 m^2 is considered as a case study with the indoor and exterior air temperatures of 20 °C and −15 °C, respectively. For heating applications, seven options are studied, namely (i) electric boiler, (ii) cogeneration, (iii) biomass/wood, (iv) ground heat pump water–water (v) heat pump borehole/glycol, (vi) standard boiler and (vii) solar collector as driven by renewable and non-renewable energy sources. Energy and exergy analyses are conducted to assess their performances and compare them through energy and exergy efficiencies and sustainability index. Energy and exergy flows are studied and illustrated accordingly. Also, the energetic and exergetic renewability ratios are employed here along with sustainability index. The results show that overall exergy efficiencies of heating systems are found to be 2.8%, 5.5%, 6.0%, 6.4%, 6.1%, 5.4% and 25.3%, while the sustainability index values for the seven cases considered are calculated to be 1.029, 1.058, 1.063, 1.069, 1.065, 1.057 and 1.338 for options 1 through 7, respectively. So, solar collector-based heating system gives the highest efficiency and sustainability index values.

1. Introduction

The world's primary energy demand has increased rapidly due to the increase of the industrialization and population. More than one third of the world's primary energy demand use in residential sector. Space heating, cooling and lightening in the residential sector are considered one of the main parts of the energy consumption in buildings. Worldwide energy consumption by HVAC equipment in buildings ranges 16% to 50% of total energy consumption (IEA, 2004; Saidur, Masjuki, & Jamaluddin, 2007), depending on the countries and their sectoral energy use patterns, as given in Fig. 1. In residential sector, most of the energy is used for maintaining the room temperatures at about 20 °C. In most cases energy demand of the buildings supplied by high quality energy sources, such as fossil fuels or using electricity (Baehr, 1980; ECBCS, 2002). However, fossil fuels and low efficient equipment are still extensively used in many developing and some developed countries, particularly for HVAC applications. Therefore, energy utilization in an efficient way for space heating and cooling is very important for the development of the energy systems. Also, excess usage of fossil fuels causes several environmental and energy problems such as global warming beside of the depletion of fossil fuels.

The aim of this study is how to make buildings energetically sustainable? Exergy as a thermodynamic analysis tool can help achieve this objective. The low exergy approach is one of these approaches, which may be used in sustainable building design. The scope of this approach is the main object to constitute a sustainable built environment. Low exergy heating and cooling systems use low valued energy also easily obtained by sustainable energy sources (e.g. by using heat pumps, solar collectors, etc.), instead of high valued energy (Balta, Dincer, & Hepbasli, 2010).

Nowadays, the assessment of space heating and/or cooling loads of buildings estimated by temperature calculations, the so-called energy balances. Energy balance is based on the first law of thermodynamics, which states that energy is neither destroyed nor created under this conservation law. To better understand the nature of energy flows in systems, we need to use the concept of exergy in addition to the energy (Balta et al., 2010; Balta, Kalinci, & Hepbasli, 2008; Schmidt, 2003). Simply, exergy can be defined as potential or quality of energy. Exergy is one of the most important tool for optimizing the building energy demand, since the exergy consumption can, to a certain extend, be minimized (Caliskan & Hepbasli, 2010; Sakulpipatsin, Van Der Kooi, Boleman, Itard, & Luscuere, 2009). Furthermore, for comparing various types of energy carriers on the equivalent basis, this analysis seems to a very useful tool (Boelman & Asada, 2002; Caliskan & Hepbasli, 2010). Exergy analysis is a method that uses the conservation of mass and conservation of

Abbreviations: COP, coefficient of performance; DHW, domestic hot water; ECBCS, Energy Conservation in Buildings and Community Systems Programme; IEA, International Energy Agency; Lowex, low exergy.

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Nomenclature

A	area (m^2)
c_p	specific heat at constant pressure (kJ/kg K)
$\dot{E}$	energy rate (W)
$\dot{E}x$	exergy rate (W)
f	approximation factor
F	factor
g	total transmittance
I	radiation intensity (W/m^2)
l	length (m)
N	percentage of equipment resistance
n_d	air exchange rate (1/h)
no	number
P	power (W)
p	specific power, pressure (W/m^2, N/m^2)
$\dot{Q}$	heat transfer rate (kW)
R	pressure drop of the pipe (Pa/m)
R_R	renewability ratio
SI	sustainability index
T	temperature (K)
U	thermal transmittance (W/m^2 K)
$\dot{v}$	volumetric flow rate (m^3/s)
V	volume (m^3)

Greek letters

η	energy efficiency
ψ	exergy efficiency
ρ	density (kg/m^3)
Δ	difference

Subscripts

air	indoor air
aux	auxiliary energy requirement
circ	circulation
dest	destruction
dis	distribution system
dt	design temperature
En	energetic
Ex	exergetic
e	equipment
el	electricity
env	environment
ex	external
f	window frame, parameter
flex	flexibility
HP	heat production system
HPP	heat production system position
HS	heating system
h	heat
heat	heater
i	indoor, counting variable
in	input, inlet
ins	insulation
j	counting variable
l	lighting
loss	thermal losses
max	maximum
N	netto
no	effect of non-orthogonal radiation
o	outdoor, occupants
p	primary energy
pa	per area
plant	plant
pv	per volume
q	quality
R	renewable energy
ref	reference
ret	return
S	solar,
s	source
sh	shading effects
sys	system
T	transmission
td	temperature drop
tot	total
usf	useful
V	ventilation
w	window, water
x	part *x*

Superscript

over dot	rate

energy principles together with the second law of thermodynamics for the design and analysis of energy systems. Therefore, exergy analysis can reveal whether or not, and by how much, it is possible to design more efficient energy systems by reducing the inefficiencies in existing systems (Rosen & Dincer, 1999). Rosen et al. (2008) recommended that this approach should be applied by engineers and scientists, as well as decision and policy makers, involved in green energy and technologies. In this regard, exergy analysis approach for buildings, which is so-called "Lowex (low exergy)" analysis approach, aims to understand the exergy flows in buildings, while it indicates the potential for further improvements in the energy utilization (Schmidt & Juusela, 2004).

In the last few years, also due to the increasing interest in low temperature heating and high temperature cooling systems, a research co-operation in a working group of the International Energy Agency (IEA) has been formed within the Energy Conservation in Buildings and Community Systems Programme (ECBCSP): "Low Exergy Systems for Heating and Cooling of Buildings" (IEA, 2008).

Recently, a considerable number of studies have been conducted on the exergetic analysis of Lowex heating and cooling systems. Based on reviewing the recent literature, the number of studies on Lowex approach shows an increase in the literature but still it is not adequate. Some recent studies on low exergy heating and cooling

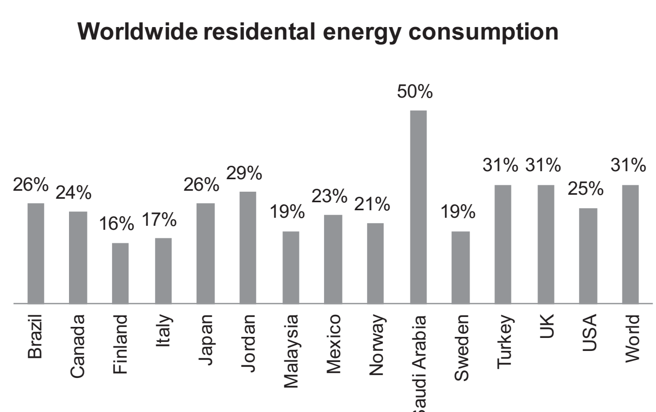

Fig. 1. Worldwide residential energy consumption.
Adapted from Saidur et al. (2007).