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Green building design solution for a kindergarten in Amman

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ABSTRACT

Buildings in Jordan consume a significant amount of energy for heating, cooling and lighting purposes. Therefore, improving energy performance of the existing building in Jordan will significantly reduce national electrical consumption. In this work, an existed kindergarten in Amman was redesigned moving toward low energy performance, in doing so, the proposed design studied the use of applying lighting saving lamps, adding thermal insulation for walls, solar water heater for domestic hot water, on grid photovoltaic system as a source of electrical power to generate free solar electricity to cover the electrical load demand of the kindergarten, and finally a heat recovery system for the exhaust air in air conditioning and ventilation. Also, a suitable economic evaluation criterion was used to estimate the payback period of all systems applied. The results showed energy saving fluorescent lamps can reduce the energy use by about 15%, and reduce the heating load up to 10%, achieved by using thermal insulation and 61.3% by using exhaust air heat recovery system. Furthermore, suitable energy conversion using solar systems were sufficient to cover the domestic hot water heating demand to reach zero of domestic hot water heating energy during sunshine days. The annual reduction achieved in carbon dioxide (CO_2) emission was 11.7 ton.

1. Introduction

Buildings in Jordan consume a significant amount of energy for heating, cooling and lighting purposes. In the building sector, most energy is consumed by existing buildings while the replacement rate of existing buildings by the new-build is only around 1.0–3.0% per annum as reported by Barlow and Filala [1]. Therefore, rapid enhancement of energy efficiency in existing buildings is essential for a timely reduction in global energy use and promotion of environmental sustainability. Accordingly, improving energy performance of existing building in Jordan will significantly reduce national electrical consumption. Studies have shown that the value of a house can increase anywhere from 10 to 15% if it was eco-friendly [2]. The energy demand in Jordan has doubled during the last 20 years, and is expected to continue at the same rate. Hence all recent energy forecast scenarios have shown that national energy consumption might double between 2015 and 2020 [3]. Due to economic growth and increasing population, energy demand is expected to go up by at least 50% over the next 20 years. This state forces Jordan to adopt a number of policies that enhance energy efficiency and support the sustainable development by using clean and environmentally friendly resources and apply baseline parameters in harmony with international standards.

Previous work by researchers was highlighted in the open literature in order to identify the progress and development on existing green buildings. Asadi et al. [4] and Flourentzou and Roulet [5] investigated different energy efficiency opportunities in order to improve energy performance of existing buildings. The results have showed that energy use in existing buildings can be reduced significantly through proper retrofitting or refurbishment. Jaggs and Palmer [6] stated that the potential retrofit opportunities can be identified based on the information collected during the energy audit. Zhenjun et al. [7] presented a systematic methodology to proper selection and identification of the best retrofit option of existing buildings for energy efficiency and sustainability. They concluded that building retrofit with comprehensive energy simulation, economic analysis and risk assessment is an effective approach to identifying the best retrofit solutions.

In literature, there are a number of studies focused on existed commercial and residential buildings retrofits. Among these, studies reported by Chidiac et al. [8], Flourentzou et al. [9], Juan et al. [10], and Doukas et al. [11] have demonstrated that energy and environmental performance of existing commercial office buildings can be improved greatly if the retrofit measures are selected and

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Nomenclature

A_C	solar collector area (m^2)
A_{array}	area required by the PV panel (m^2)
A_{module}	area required by the PV module (m^2)
$A_{spacing}$	area spacing between required PV panel (m^2)
C_P	specific heat capacity at constant pressure (kJ/kg K)
F_R	removal heat transfer factor
h_i	indoor air enthalpy (kJ/kg)
h_0	outdoor air enthalpy (kJ/kg)
h_1	indoor convection heat transfer coefficient (W/m^2 K)
h_2	outdoor convection heat transfer coefficient (W/m^2 K)
$h_{1,i}$	inlet convection heat transfer coefficient from supply of fresh air (W/m^2 K)
$h_{1,0}$	outlet convection heat transfer coefficient from supply of fresh air (W/m^2 K)
I	total intensity of solar radiation (MJ/m^2)
K	thermal conductivity (W/m^2 °C)
L	material thickness (m)
L_T	temperature loss factor
L_C	cable loss factor
m	hot water demand (kg)
N	number of daylight hours
n	number of working days in a month
n_C	number of collector panels
n_S	number of days where there is no sunlight
$(P_{in})_C$	power inout for cooling (W)
$(P_{in})_H$	power inout for heating (W)
$P_{\max}$	maximum rated power of PV module (W_p)
$P_{\max,actual}$	actual rated DC power of a single PV module (W)
P_{in}	electric water heater power consumption (kWh)
$P_{inv,output}$	inverter AC power output (kW)
$P_{inv,in}$	inverter AC power input (kW)/power input of the inverter (kW)
Q	monthly water heating demand (GJ)
Q_t	actual solar collector thermal loss per unit area (MJ/m^2)
Q_u	actual solar collector useful gain of energy (MJ)
Q_{ayx}	auxiliary energy of electric solar heater (GJ)
Q_{ERV}	actual heat transfer by ERV (kW)
$Q_{\max}$	maximum heat transfer by ERV (kW)
R_{fi}	the inner film thermal resistance (m^2 °C/W)
R_{f0}	the outer film thermal resistance (m^2 °C/W)
R_{wall}	wall thermal resistance (W/m^2 °C)
R_{th}	thermal resistance (m^2 °C/W)
S	absorbed solar radiation per unit area (MJ/m^2)
T_i	collector inlet temperature (°C)
T_0	solar heater collector set temperature (°C)
T_{an}	annular average temperature (°C)
T_{am}	monthly average temperature (°C)
T_a	ambient temperature (°C)
T_m	average module temperature (°C)
T_a	average ambient temperature (°C)
t	time needed to heat the water to the desired temperature (h)
$T_{1,i}$	inlet temperature of supply of fresh air of ERV (°C)
$T_{2,i}$	inlet temperature of exhaust air of ERV (°C)
$T_{1,0}$	outlet temperature of fresh air of ERV (°C)
$T_{2,0}$	outlet temperature of exhaust air of ERV (°C)
U	overall heat coefficient (W/m^2 °C)
U_L	solar heater overall heat coefficient (W/m^2 °C)
V	operating voltage (V_{DC})
V_{MP}	maximum DC power voltage of PV module (V_{DC})
$\dot{V}$	air volume flow rate of ERV (CFM)
$v_{1,0}$	specific volume for the outside condition (m^3/kg)
$v_{2,i}$	specific volume of the exhaust air (m^3/kg)
W_P	Watt peak (W)
X	height of titled PV panel (m)
Y	shading distance (m)

Greek letters

ρ	density
γ	azimuth angle
β	tilt angle
α	solar altitude at certain solar time
$(\tau\alpha)_e$	effective transmittance – absorptance
$\eta_{inv,CEC}$	CEC weighted efficiency of inverter
ε_h	exchanger heat transfer coefficient or enthalpy efficiency for ERV
ε_T	temperature exchange efficiency for ERV

Abbreviations

ASHRAE	American Society of Heating, Refrigeration and Air conditioning Engineers
AIA	American Institute of Architects
AC	alternating current
COP	coefficient of performance for heating load
CFM	cubic feet per minute
D/M	day per year
DR	demand reduction
EER	energy efficiency ratio for cooling load
ERV	energy recovery ventilation
EAT	energy audit team
GDP	gross domestic product
HAP	hourly analysis program
HVAC	heating, ventilating and air conditioning
H/D	hour per day
GoJ	Government of Jordan
kW	kilo-Watt
KWh	kilo-Watt hour
LCC	life cycle cost
LEED	leadership in energy and environmental design
M/Y	month per year
PBP	pay back period
PV	photovoltaic
US$	United State dollar
W	Watt

implemented properly. Retrofit studies on residential buildings by Cohen et al. [12], Al-Ragom [13], Gustasson [14], Hens [15], Mahlia et al. [16] and Zavadskas et al. [17] have showed that appropriate selection of retrofit technologies is very important in building retrofits to achieve maximum energy and environmental performance, and methods developed for residential buildings can also be used in other types of buildings.

Jaber [18] studied a prototype of the Jordanian "future houses", thermally designed of a class of energy conservation plus passive and active solar systems. Paul and Taylor [19] studied and argued that green buildings have a better indoor environmental quality as measured by the comfort perceptions of occupants than conventional buildings and that this translated into a more satisfying workplace for the building's occupants and, in turn, a more productive workforce. More work by Badarneh and Kiwan [20] on renewable energy systems such as PV, wind and using thermal