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Assessment of residential building performances for the different climate zones of Turkey in terms of life cycle energy and cost efficiency

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ABSTRACT

In residential buildings, the usage of non-renewable resources, which are scarce and exhaustible, the negative impacts of resource usage on the environment and the high energy costs require the evaluation of residential energy performance on a life cycle basis. Therefore, in the framework of this study, it is intended that the measures effective in the improvement of residential energy performance aimed at providing optimum use for the country sources and the decision makers are developed for the different climate zones. Regarding these measures, the energy, economic and environmental performances of residential buildings are evaluated on the basis of life cycle. The effects of the approach developed in accordance with this purpose and the considered improvement measures on life cycle energy consumption, CO_2 emissions and the costs are evaluated within the framework of "life cycle assessment" (LCA) and "life cycle cost" (LCC) methods. So, in the design of new residential buildings or the improvement of the existing residentials, the results which generate data for the regulations concerning the optimisation of energy, and economic and environmental performances regarding the life cycle of residential building, can be enabled.

1. Introduction

Today, the speed and cost-effective solutions for globalised energy and environment problems constitute the basis of energy policies in all over the world. The improvement of energy efficiency levels in terms of establishing a sustainable and resource-efficient economy containing transformation and growth also serves as a base. Energy efficiency keeps the balance between environmental development and economic growth against great environmental problems. Therefore, it considerably determines producing policies of economy and environment and their maintainability.

It is also acknowledged that residential buildings in Turkey, just as all over the world, are highly responsible for the energy consumption and CO_2 emissions due to energy consumption. In the design of new residential buildings or the improvement of existing residentials, it is obvious that energy and cost efficiency and environmental impact assessment have not been taken into consideration. However, the improvement of energy and cost efficiency levels of residential buildings plays a significant role in solving the energy, economic and environmental problems encountered within the framework of the sustainable development goals of Turkey. For the improvement of energy and cost efficiency levels of residential buildings, it is necessary to minimise energy consumption, increase energy efficiency by integrating energy producing systems, thereby improving the building's energy performance. It is well known that in this way, a considerable amount of energy savings can be provided in the residential buildings which can then be turned into high-performance buildings which have fewer CO_2 emissions and energy expenses.

In this context, studies related to the improvement of building energy performance all over the world aim to evaluate the cost efficiency of the buildings in the context of their life cycle from raw material extraction and material production to the stages of design, construction, use and maintenance, and reuse or destruction of buildings. In the framework of these evaluation studies, it is necessary to define the integrated processes considering the economic and environmental impact performances; and in the framework of the defined processes the appropriate methods enabling the solving of the complex interactions between the buildings' sub-systems differing from one to another building should be used.

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Nomenclature

Abbreviations and acronyms

BOS	balance of system
CO_2-eq	carbon dioxide equivalent
CBRT	Central Bank of Turkish Republic
CEN TC	Technical Committee of European Standardisation Committee
DPP	discounted payback period
EC	embodied carbon dioxide emission
EE	embodied energy
EPR	energy payback ratio
EPT	energy payback time
GHG	greenhouse gas
ICE	inventory of energy and carbon
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle assessment
LCC	life cycle cost
$LCCO_2$	life cycle carbon dioxide
LCE	life cycle energy
LCEC	life cycle energy consumption
Low-E	low emissivity
NPV	net present value
OC	operational carbon
OE	operational energy
PR_{CO_2}	CO_2 emission payback ratio
PT_{CO_2}	CO_2 emission payback time
PV	photovoltaic
SA	sensitivity analysis
SHGC	solar heat gain coefficient
tCO_2	tonne carbon dioxide
TEUR	Thousand euros
TOKI	Housing Development Administration of Turkey
TS	Turkish Standard
UNDP	United Nations Development Programme

Symbols

cf_t	cash flow at time t
C_{inv}	initial investment cost of energy retrofit strategy (€)
C_{opt}	optimum improvement combination
C_{PV}	energy cover factor (%)
ΔC_{op}	the saving value obtained in the usage cost (€)
$E_{cons,e}$	electrical energy consumption of the reference residential building (kWh/a)
$E_{cons,fuel}$	energy consumption per fuel type (kWh/a)
E_{PV}	energy generated by the PV system (kWh/a)
$f_{co_2,yakut}$	country specific emission factor per fuel type ($kgCO_2$/kWh)
$f_{co_2,PV}$	conversion factor for the CO_2 emissions avoided concerning the electrical energy generated by PV system ($kgCO_2$/kWh)
$f_{p,fuel}$	primary energy conversion factor for each fuel type
$f_{p,PV}$	primary energy conversion factor for electrical energy generated by the PV system
i	discount rate
U	U-value (W/m^2 K)
T	calculation period (years)

There are a good number of studies based on the improvement and implementation of the appropriate method and measures related to the evaluation of residential building performances. Cohen et al. [1] assessed the energy savings and cost-effectiveness of individual retrofit options and packages of measures in single-family buildings, based on the analysis of metered energy consumption and actual installation costs. Poel et al. [2] presented an overview of the method and software that can be used to perform building energy audits and assess buildings in a uniform way, and perform demand and savings calculations. Ouyang et al. [3] developed methodology to assist decision makers to design energy-efficient renovation plans in the early stage of the design stage for upgrading existing residential buildings in China. Sadineni et al. [4] identified several potential efficiency improvements for the production of residential buildings in the desert southwest region of the USA, and evaluated each building component by using building energy simulation software to develop cost benefit data to be used by a local electric utility in defining a rebate program. Morissey and Horne [5] applied an integrated thermal modelling, life cycle costing approach to an extensive sample of dominant residential building designs to investigate the life cycle costs in the cool temperate climate of Melbourne, Australia. They stated that the most cost-effective building design is always more energy efficient than the current energy code requirements, for the full time horizon considered. The life cycle energy (LCE) demand of ten residential building designs with energy saving features, e.g. thermal insulation on wall and roof, double pane glass for windows, in the Indian context, was evaluated by Ramesh et al. [6]. One of these buildings was further examined to assess LCE performance with an on-site power generation. Life cycle energy and greenhouse gas (GHG) analyses of three representative residential building types in Lisbon were presented by Bastos et al. [7]. The life cycle model focused on building construction, retrofit and use stages, applied an econometric model to estimate energy use in Portuguese households, and considered two functional units. Famuyibo et al. [8] developed a hybrid model for assessing the life cycle energy and GHG emission impacts of retrofitting residential building stocks comprising a process based approach. The representative archetypes were used to estimate the performance along retrofitting, operation, maintenance and disassembly stages of the three selected house retrofit scenarios. To minimise the life cycle cost (LCC) and carbon dioxide equivalent (CO_2-eq) emissions of the buildings, a multi-objective optimisation model based on harmony search algorithm was presented by Fesenghary et al. [9]. The performance of the model was tested on a typical single-family house, and several building envelope parameters were taken as the design variables to demonstrate the efficiency of the proposed approach. Wang et al. [10] presented a multi-objective optimisation model for life cycle cost analysis and retrofitting planning of buildings. A net present value (NPV) based on the economic analysis taking life cycle cost into account was introduced to formulate the objective functions.

When analysing the studies regarding the evaluation of residential building performances, it is observed that there are differences between the evaluation methods because many different variables and interactions are effective on the energy, cost and environmental effectiveness levels of residential buildings. However, the fact that residential buildings have a complicated structure from the viewpoint of either architectural and mechanical, or environmental and social necessitate ranging the priorities when determining the effective measures to improve the building performance. Therefore, although determining the appropriate method regarding the evaluation of energy, economic and environmental performances of residential buildings in terms of life cycle energy and cost efficiency is still an important issue, it differs based on the variables and regulations related to the climatic conditions, user needs and artificial environment. Thus, each country determines the obligations within the framework of its own conditions by the legal regulations arranged for the improvement of residential building performance. There are ongoing studies in Turkey. In the framework of these studies, offering energy and cost effective solutions in a residential building, when considering growing energy demand and energy prices, they have a great importance in terms of energy economy of