Applied Energy 179 (2016) 626–637

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A hybrid Genetic Algorithm and Monte Carlo simulation approach to predict hourly energy consumption and generation by a cluster of Net Zero Energy Buildings

Samira Garshasbi [a], Jarek Kurnitski [b,d,*], Yousef Mohammadi [a,c]

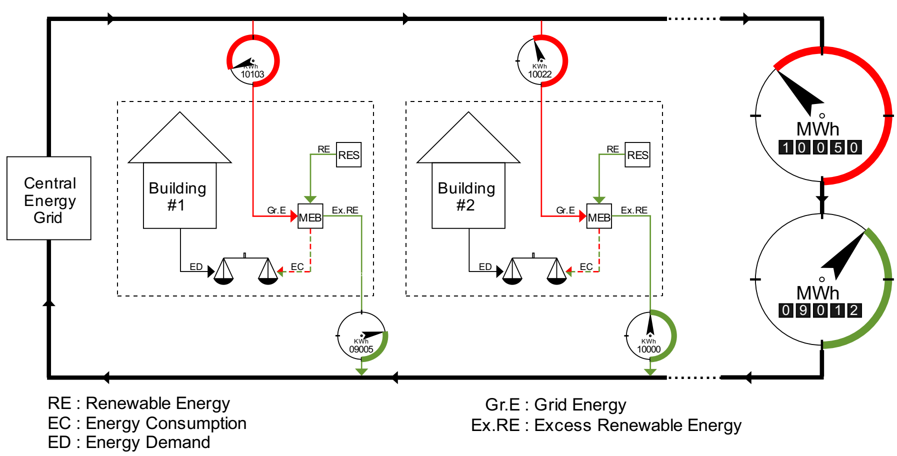
[a] Islamic Azad University, Central Tehran Branch, Young Researchers and Elites Club, P.O. Box 13185-768, Tehran, Iran
[b] Tallinn University of Technology, Faculty of Civil Engineering, Tallinn, Estonia
[c] Petrochemical Research and Technology Company (NPC-rt), National Petrochemical Company (NPC), P.O. Box 14358-84711, Tehran, Iran
[d] Aalto University, School of Engineering, Espoo, Finland

HIGHLIGHTS

- Hourly energy consumption and generation by a cluster of NZEBs was simulated.
- Genetic Algorithm and Monte Carlo simulation approach were employed.
- Dampening effect of energy used by a cluster of buildings was demonstrated.
- Hourly amount of energy taken from and supplied to the grid was simulated.
- Results showed that NZEB cluster was 63.5% grid dependant on annual bases.

GRAPHICAL ABSTRACT

The energy consumption and renewable generation in a cluster of NZEBs are modeled by a novel hybrid Genetic Algorithm and Monte Carlo simulation approach and used for the prediction of instantaneous and cumulative net energy balances and hourly amount of energy taken from and supplied to the central energy grid.



ARTICLE INFO

Article history:
Received 3 March 2015
Received in revised form 20 June 2016
Accepted 10 July 2016

Keywords:
Monte Carlo simulation
Genetic Algorithm
Renewable energy

ABSTRACT

Employing a hybrid Genetic Algorithm (GA) and Monte Carlo (MC) simulation approach, energy consumption and renewable energy generation in a cluster of Net Zero Energy Buildings (NZEBs) was thoroughly investigated with hourly simulation. Moreover, the cumulative energy consumption and generation of the whole cluster and each individual building within the simulation space were accurately monitored and reported. The results indicate that the developed simulation algorithm is able to predict the total instantaneous and cumulative amount of energy taken from and supplied to the central energy grid over any time period. During the course of simulation, about 60–100% of total daily generated renewable energy was consumed by NZEBs and up to 40% of that was fed back into the central energy grid as surplus energy. The minimum grid dependency of the cluster was observed in June and July where

* Corresponding author at: Ehitajate tee 5, 19086 Tallinn, Estonia.
E-mail address: jarek.kurnitski@ttu.ee (J. Kurnitski).

http://dx.doi.org/10.1016/j.apenergy.2016.07.033
0306-2619/

NZEBs
Sustainable design

11.2% and 9.9% of the required electricity was supplied from the central energy grid, respectively. On the other hand, the NZEB cluster was strongly grid dependant in January and December by importing 70.7% and 76.1% of its required energy demand via the central energy grid, in the order given. Simulation results revealed that the cluster was 63.5% grid dependant on annual bases. In general, this stochastic algorithm is a self-learning one, i.e., at the end of each year, it utilizes the instantaneous energy consumption and generation data of each building to predict its energy balance in subsequent years. Hence, the accuracy and validity of the predictions increase over time. The simulation results are capable of modifying and readjusting the energy consumption patterns of buildings via appropriate predefined policies and well-designed monitoring systems.

1. Introduction

Today, world's energy resources are depleting fast and there is a growing concern about the increase in energy use and these issues have placed the world in the grip of energy crisis. In addition, increase in the amount of worldwide CO_2 emissions is damaging the ozone layer and changing our climate [1,2].

Sustainable design is a design approach put in place to promote the environmental quality and the quality of building indoor environment by reducing negative impacts on building and the natural environment. Also, it is a design philosophy that seeks to incorporate sustainable development concept in terms of initiatives and values into sustainable building envelope design [3–7]. The topic of NZEBs has received increasing attention in recent years, until becoming part of the energy policy in several countries. In the recast of the EU Directive on Energy Performance of Buildings (EPBD) it is specified that by the end of 2020 all new buildings shall be "nearly zero energy buildings" [8–17].

The design and construction of NZEBs are key factors in mitigating the impact of buildings on the environment. Emerging technology and advanced building techniques already enable the design and construction of NZEBs, but critical questions about what it is and how it can be achieved are warranted. What does Net Zero Energy mean? How does one build to net zero? Are these buildings sustainable (healthy, durable, resource efficient)? [18–21]. Furthermore, the life-cycle perspective should be included in the common concept and definition of NZEBs [22]. This certainly allows pointing out the relative importance of operating and embodied energies in NZEBs.

There are many definitions presented for the NZEBs. In the report written by Torcellini et al., authors used the general definition for ZEB given by the U.S. Department of Energy (DOE), Building Technologies Program: "A net zero-energy building is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies" [23]. There is a conceptual understanding of a ZEB as an energy efficient building able to generate electricity, or other energy carriers, from renewable sources in order to compensate for its energy demand. Therefore, it is implicit that there is a focus on buildings that are connected to an energy infrastructure and not on autonomous buildings. To this respect the term NZEB can be used to refer to buildings that are connected to the energy infrastructure, while the term ZEB is more general and may as well include autonomous buildings [8]. A ZEB can be off-grid or on-grid. The main difference between those two approaches is that the off-grid ZEB is not connected to the utility grid, and thus it does not purchase energy from the external sources. In other words, the building offset all required energy by producing energy from RES. The on-grid ZEB is also an energy producing building, but with the possibility of both purchasing energy from the grid and feeding excess energy production back to the grid to return as much energy to the utility as it uses on an annual basis [24].

Hence, NZEBs are buildings connected to the existing energy infrastructure that have a greatly reduced energy demand and are supplemented by renewable energy sources and produce as much energy as they consume annually. The first step for reaching the net zero energy balance is to construct an energy efficient building with a low-energy demand. Hereafter, energy supply is added to achieve the net zero energy balance. Since the net zero balance is reached annually, sometimes NZEBs produce more than they consume, and at other times, they consume more than they produce [8,25,26].

The technologies, which convert renewable sources, are generally divided into two groups. The first group encompasses the systems installed either on/in the building or on the ground directly attached to the building. The second group includes the systems placed outside the boundaries of the building site, which either are the property of the building owner or the building owner just purchases the generated energy in order to reach the zero energy goal. The first group is often labeled as on-site renewable energy source (on-site RES), and the latter as off-site renewable energy source (off-site RES) [27].

One of the most important problems in cities comprised of a cluster of NZEBs is the buildings-grid interaction, i.e., the prediction of the total amount of energy taken from the central energy grid daily and the total amount of renewable energies fed daily back into the central energy grid via the cluster of NZEBs [28–32]. In other words, wide diffusion of distributed generation may give rise to some problems such as power stability and quality in today's grid structures, mainly at local distribution grid level [8]. So, it is important to manage the fluctuations originated from renewable energies fed into the central energy grid through on-site RESs at different times. In general, it is hard to anticipate the amount of daily renewable energies sporadically supplied to the central energy grid and the amount of daily energy imported from the central energy grid. Thus, precise determination of the instantaneous and cumulative energy consumption and generation by each individual NZEB and the whole cluster is of vital importance. This information makes it possible to accurately calculate the instantaneous and cumulative net energy balances for a cluster of NZEBs. So, taking these data into account, the central energy grid can easily evaluate the total daily energy demand of the cluster and the total daily surplus renewable energies exported by NZEBs. Undoubtedly, in such a way, the interaction between the central energy grid and the cluster of NZEBs can be properly coordinated. Among different mathematical modeling strategies, Monte Carlo simulation methods and artificial intelligence techniques seem to be powerful statistical tools in prediction of the amount of energy generated and consumed by a cluster of NZEBs at different operational and environmental conditions.

Literature review shows that the focus of the most of the works published on the modeling and simulation of NZEBs are the application of Building Information Modeling and well-developed commercial softwares to evaluate the energy balances of a