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Integrated dynamic modeling for energy optimization in the building: Part 1: The development of the model

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Abstract

Considering the magnitude of energy loss in Iran's buildings, development of energy saving and energy optimization methods appears to be essential. To date, many energy saving methods, such as energy auditing, have been developed in this area, though none of them enjoyed high accuracy and efficiency. Optimization methods aided by energy modeling are the most useful tools for energy saving as well as energy loss reduction. In this study, a new model has been developed based on mathematical equations of mass and energy balance between different parts of a building and its surrounding area. Generally, this model integrates two methods of load and heating, ventilation and air conditioning modeling. Furthermore, the presented model allows for simulation of energy-efficient scenarios and their optimization based on life cycle cost analysis method. In this part, capabilities of the model have been closely analyzed based on historical records of existing models. The relations covering boundary conditions at external–internal surfaces; energy equations for building systems; interzone airflow and infiltration; heating, ventilation, and air conditioning models and economic models; and their optimization method and possible solutions have been explained in detail. Complete details about the application of this model for the XYZ case study building will be given in the second part of this article.

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Integrated dynamic modeling, building energy simulation, optimization, life cycle cost analysis

Introduction

As compared to other developing countries, Iran has higher energy consumption in building and construction sector since over 40% of energy consumption belongs to this sector (Iranian Fuel Conservation Organization (IFCO), 2012; Iranian Ministry of Energy, 2012). This is in fact sixfold greater than the average consumption rate in European countries. In Iran, the average gas consumption rate is 30 m^3 per cubic meter of building space, while in Europe that is 5 m^3 per cubic meter of building space (Iranian Institute for International Energy Studies, Ministry of Petroleum, 2012). According to the studies carried out in Iran, energy saving potential in new buildings has been reported to be approximately 43% (IFCO, 2012). Nowadays, energy auditing methods along with technical solutions for energy saving extracted from them, if applied independently, fail to make desirable reduction in energy loss. It should be noted that the criteria for adopting energy saving solutions as well as energy auditing methods are determined based on energy conservation building codes (Ministry of Housing and Urban Development IRI, 2012). Taking into account the necessity of reducing energy loss and existence of high potential for energy saving in the country, energy loss can be predicted by energy efficient measures and ideally reduced to the lowest level by using energy modeling tools. In building energy modeling, the building's physical behavior is identified and simulated by integrating the factors involved in reduction of energy consumption. Subsequently, the simulated building can be optimized using energy optimization methods. Normally, a building energy system model is composed of different parts of building's sub-models, so that the energy loss can be dynamically analyzed in a study period and then optimized by integrating the energy variants pertaining to each part. These variants include measures that enhance energy efficiency and lead to reduction in wasted energy in buildings. In the past 50 years, many studies have been conducted regarding buildings, in which the energy demand, temperature, humidity, and energy costs have been mainly assessed by Building Energy Simulation Tools (BEST) (Crawley et al., 2008). Nowadays, vast variety of programs have been developed for energy simulation in buildings, some of which calculate the cooling and heating loads of the building based on weighting factor method. Through this method, the ratio of convective heat transfer to total incoming energy on a building element in a time period is calculated. Weighting factor is the simplest method for building energy modeling devoid of intricate and detailed calculations. This method was widely used during the 1970s when computer programs were very limited. Sets of software utilizing this method are NESCAP, DOE-1, DOE-2, and VisualDOE-3 (Birdsall et al., 1985; Hunn et al.,1977; Henninger et al., 1975; Green Design Tools, 2001).

Energy balance method is another type of energy modeling method applied to building's zone air and enclosure elements. This method is chiefly applied to calculation of load and energy demand of heating, ventilation, and air conditioning (HVAC) systems. Sets of energy software that model the building on mentioned basis are Building Loads Analysis and System Thermodynamics (BLAST), ACCURACY, ESP-r and EnergyPlus (Chen and Kooi, 1988; Clarke, 1985; Crawley et al., 2000; Hittle, 1979).

Another type of energy modeling software has been designed based on indoor airflow simulations. By this software, indoor airflow speed, thermal comfort, and air quality prediction are calculated as variants of model. The relevant initial models were first presented by Jackman (1970) in the name of multizone method. Through this method, large volume of the room air is considered as single nodes, and the flow through discrete paths such as doors and cracks can be calculated. In the same year, another method called zonal method was introduced by Lebrun (1970) for room airflow simulations. Through this method, a room was divided into different zones with variable characteristics, and the temperature distribution in the room could be predicted and calculated. Sets of software functioning based on multizone method are CONTAM and COMIS (Dols and Walton, 2003; Feustel, 1998).

Generally, various studies have been conducted toward energy modeling using simulation software. Kim et al. (2005) applied the ESP-r software as a modeling tool for a case study of hybrid renewable energy systems for residential building in Korea. In this model, the feasibility of using new technologies for a simulated building was evaluated. Eskin and Turkmen (2007) used the EnergyPlus software for office buildings located in four major climatic zones in Turkey in order to assess the interactions between their different climatic conditions, estimate the cooling/heating loads, and evaluate the control strategies.

Griffith et al. (2003) employed the DOE-2.1E software for predesigning and simulation of an energy efficient model for a new building in Teterboro airport. Tavares and Martins (2007) simulated a building located at the center of a town in Portugal with the help of VisualDOE software. Using this model and aiming at a thermally comfortable and energy efficient building, they could run sensitivity analysis on some parts such as wall structure and materials, window frames, and HVAC system. Al-Rabghi and Hittle (2001) studied the open-source types of simulation programs used in buildings. Using the BLAST software as an open-source simulation program, they managed to model a three-story typical school in Jeddah and identify some of the problems encountered by new users of this type of software and to comment on new trends. Ren and Stewart (2003) modified the COMIS software for modeling airflow inside the building. Using the improved software, they compared the modeling results with the published experimental measurements and subsequently evaluated the capability of predicting temperature distribution as well as inside airflow.

Costola et al. (2009) modified and compared the wind pressure coefficient (Cp) data utilized in some types of software including building energy simulation (BES) and airflow network (AFN). In addition, they evaluated the Cp by means of COMIS and CONTAMW 2.4b software belonging to BES and AFN categories, respectively. Finally, they came to the conclusion that Cp values are quite independent of the source adopted.

Nowadays, energy modeling has found a widespread application in energy conservation, choosing optimum HVAC energy systems and building energy management; thereby, the majority of studies have particularly focused on it. For instance, in a study carried out by Nassif et al. (2008) using energy modeling, estimation of zone temperature, return air enthalpy/humidity, and CO_2 concentration and also general design of cooling–heating coil and fan were improved in line with energy management and control in HVAC systems.

Trčka and Hensen (2010) have also studied the HVAC system modeling. They analyzed all solution techniques used for modeling HVAC components, HVAC control, and HVAC general systems. Raftery et al. (2011) studied the evidence-based methodology for calibrating general building energy models and used it for investigating energy conservation measures when a model is calibrated.

Rysanek and Choudhary (2012) analyzed a mixed-use office building and a primary school in the United Kingdom in terms of all salient types of energy- and carbon-reducing retrofit options by simulating energy supply systems.

Having in mind the mentioned studies and the efficiency of methods employed through different energy models, a model was introduced for energy optimization in a typical building in Iran. Using this model, capability of highly accurate, dynamic and integrated simulation can be obtained. This model can be also employed as a building energy modeling software in Iran and widely in other countries. The overall procedures followed in this study are as follows:

1. Providing a new modeling method and identifying the correlation of its deferent components.
2. Describing set of equations dominating energy model for the whole building.
3. Discussing the prominent functions of each part of the model.
4. Modeling a 10-story high-rise case study in the north of Tehran.
5. Model verification using statistical method of paired sample *t*-test of monthly electric and natural gas energy consumption data obtained for the case study during 2011.
6. Evaluation of energy efficiency scenarios for the simulated case study.
7. Optimization of energy scenarios considering distinct types of scenarios using life cycle cost analysis (LCCA) methodology.
8. Integration of all optimized energy scenarios into an optimized integrated multienergy system models and analyzing the results.

Model description

From energy viewpoint, buildings can be considered as dynamic systems whose different components having constant mass and energy exchange with the surrounding area. Most of the common whole-building simulation models have limited functionality as they are performed merely based on the input data and may bear very low accuracy due to data deficiency. Thus, calculation and integrate programming of energy and mass equations of building system, surrounding area, and building system components can be relatively difficult.

The accuracy of model is always in direct connection with relation to building energy elements, equipment, and HVAC system components. This relation needs to be established as integrated and based on mass and energy equations in different time steps among the whole-building components. The marked advantage of the model developed in this study, as compared with other energy models, is dynamic, such as simulation of sub-models in weather and climate zones and economic, load, and HVAC systems in simultaneous and integrated form. Therefore, the logical dynamic relation of the sub-models' components leads to a drastic accuracy increase in model variables. Climate condition of all towns of Iran and the world has been included in this novel and well-developed model.

Normally, only one type of appropriate simulation for the user is done in the conventional models. For instance, in some types of models such as HAP v4.5 (Carrier Corporation, 2012) and Energy Express (Hearne Scientific Software, 2012), HVAC is simulated, while in some other types such as ENER-WIN (Degelman Engineering Group, Inc., 2007) and BLAST (Hittle, 1979), load model is simulated. In other types such as TRACE 700 (Trane, 2012) and DOE-2.1E (Simulation Research Group, 2012), simulation of economic model is carried out in sequential steps based on results from former energy modeling; thereby, relation of such model with results from other parts of it would not be integrated and simultaneous. Particularly, in models like DeST (Feng and Yi, 1999), weather data are used as input data while no simultaneous simulation and integration are rendered between weather/climate models and other parts of the model. Overall, the mentioned integrated and dynamic model has been designed as multipurpose energy software that can simultaneously render the dynamic and integrated modeling for energy optimization in the building. The correlation of its different parts' sub-models and all steps of modeling, making scenarios, energy optimization to the selection, and simulation of an optimized integrated multienergy system models for the buildings can be described in Figure 1.

At the first stage, weather and climate modeling of urban stands is done as a boundary condition model. Hourly dry bulb temperature, dew point temperature or relative humidity, wind speed and direction, and horizontal solar radiation can be mentioned as variables of this model. Using the website of US Department of Energy (DOE) (2012), the mentioned model's input data can be obtained hourly in the form of EnergyPlus Weather (EPW) file from the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) International Weather

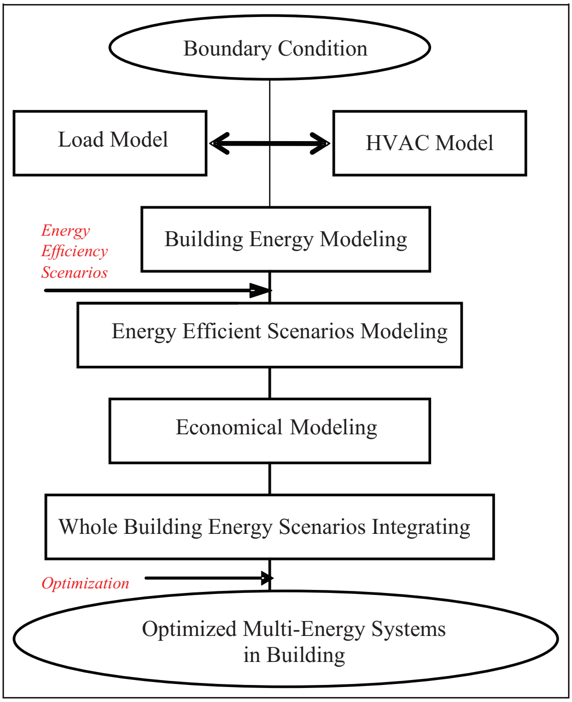

Figure 1. Flow diagram of the comprehensive and dynamic model designed for energy optimization in the building.
HVAC: heating, ventilation, and air conditioning.

for particular zones of the world. Considering the fact that sets of building energy modeling software have been designed based on load model (Clarke, 1985) and HVAC model (Crawley et al., 2000) methods, this study attempts to employ both methods simultaneously. In HVAC system model, rate of mass and energy flow conservation for various components of electric, cooling, and heating energy demand systems can be calculated. These components include types of chillers, boilers, humidifiers, pumps, mixing boxes, fans, coils, ducts, and other HVAC systems. In load model, heating and cooling loads are calculated for the study period, and the obtained results are assumed as set of boundary conditions of HVAC systems' mass and energy balance equations, which can be directly solved for sparse linear systems. The models in which simulation is rendered based on either load model (Degelman Engineering Group, Inc., 2007) or HVAC model (Carrier Corporation, 2012) will not be so accurate. The reason is that energy simulation merely based on load model cannot accurately simulate energy supply in the building. Likewise, the simulation merely based on HVAC model fails to simulate energy demand accurately (Crawley et al., 2008). In the event that load model is simulated simultaneously and in integration with HVAC model, then the effective variables dominating energy consumption control can be instantaneously exchanged between them. Thus, in HVAC system, energy supply is balanced in accordance with required cooling/heating loads of energy demand. This, in fact, enhances the accuracy of energy modeling in building (Zhai and Chen, 2003, 2005, 2006). In some models, load model is integrated with HVAC model to enhance the accuracy of energy modeling. However, such integration is done in sequential steps rather than simultaneously. In these models, especially in DOE-2 (Birdsall et al., 1985), cooling/heating loads are initially simulated using assumptive boundary conditions chosen by the user. In the next step, the required energy consumption is predicted and calculated. Finally, in the last step, the proper energy plant is chosen based on the results from the second step.

The disadvantages of this method are as follows: (a) solving mass and energy balance equations describing the HVAC systems without iterations and (b) extracting the data—for key variables involved in energy calculation—from previous step and using them for predicting thermal comfort condition (Birdsall et al., 1985).

This method does not provide the feedback information from HVAC systems to the cooling/heating load calculation. Due to lack of feedback on control variables in aforementioned models, thermal comfort predictions can be calculated inaccurately; thereby, the demand for cooling/heating load in the next time steps will be calculated unrealistically.

To analyze the results from these models, for instance, when a central plant fails to supply the required heating demand of a building exceeding its production capacity, air temperature will drop below the set point. In this procedure, it is always assumed that the central plants bear enough capacity for supplying the temperature required at set point. This assumption, however, leads to error and inaccuracy in the mentioned modeling method. Zhai and Chen (2003, 2005, 2006) reported the high accuracy of integrated dynamic methods for HVAC models through simultaneous solution of computational fluid dynamics (CFD) and load models compared with other integrated methods for these models.

In HVAC system modeling through CFD method, the problems such as occurred irregularities in simulation of turbulent flows and also complexity of calculating diffusivity, large Reynolds numbers, three-dimensional vorticity fluctuations, dissipation and continuum of these currents make it difficult to apply the aforementioned methods (Tennekes and Lumley, 1972).

In ESP-r model (Clarke, 1985), HVAC equations are integrated into load matrix to form HVAC–load matrix. In this method, all equations use sparse linear system solver directly. HVAC system equation matrix should be connected to the load matrix through some coefficients (matrix elements) in order to be solved. This, in fact, leads to irregularity, complexity, and time-consuming solutions. Moreover, HVAC model equations need to be linearized, which makes their solving more difficult (Clarke, 1985).

In EnergyPlus (2001) model, difficulties in solving HVAC–load matrix and linearization of equations by iterative solutions for HVAC model have been settled. In this model, integration of HVAC model and load model is done based on

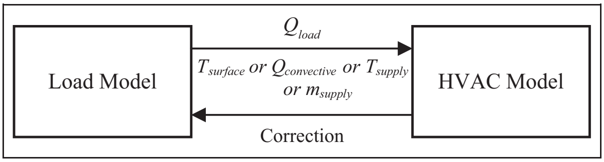

Figure 2. Schematic of an integrated simultaneous solution scheme implemented into the designed model.
HVAC: heating, ventilation, and air conditioning.

information exchange, several times during the calculation procedure, which is called simultaneous solution using predictor–corrector method to integrate HVAC system model and cooling/heating load model (EnergyPlus, 2001). This method can be applied for correction of zone air temperature where central plant fails to satisfy the required cooling/heating loads. The disadvantage of predictor–corrector solution is that it can only correct the air temperature (T_{air}) as a control variable but not the temperature of enclosure and building's other elements.

However, in the designed model, deficiencies of EnergyPlus model have been improved, so that the method of integrated and simultaneous solution for HVAC and load models can correct temperature of the whole building, including air temperature, enclosure temperature, and temperature of all building elements in which thermal energy is stored.

The new method of simultaneous solution for HVAC and load models, which has been applied in the designed model, includes the following steps:

1. Calculating thermal device surface temperature (T_{HVAC}) and required cooling/heating loads (Q_{HVAC}) to supply air temperature (T_{air}) at set point condition.
2. Modeling HVAC based on two parameters of (T_{HVAC}) and (Q_{HVAC}) and outdoor weather data in order to enable the designed model to provide the capacity of cooling/heating conditions required for the building.
3. Returning Q_{HVAC} to the load model if capacity of a thermal plant is not sufficient (Figure 2). When the load model identifies the insufficiency of HVAC system's actual capacity, a completely new temperature distribution appropriate to its capacity is calculated for all building elements. This way, simulation of performance and function of HVAC model will be intelligently corrected by load model.

The advantage of this model to other energy simulation models is that relying on the new method of integrated simultaneous solution for HVAC and load models, it can eliminate thermal capacity constraints of HVAC systems in order to provide the real thermal comfort condition and better air quality. Elimination of these constraints also contributes to control parameters ($T_{surface}$, $Q_{convective}$, T_{supply}, and

m_{supply}) exchanged between HVAC–load models. The designed model performs energy simulation for the following four HVAC configurations:

1. HVAC systems that control the room temperature, using the HVAC device's surface temperature ($T_{surface}$), are represented by the radiant panel system.
2. Pure convection HVAC systems, which have negligible radiative heat exchange with room surfaces and exchange energy with air directly by convection heat flux ($Q_{convective}$), are represented by baseboard heater and fan–coil systems.
3. HVAC systems that use variable supply air temperature (T_{supply}) for control are represented by the constant air volume (CAV) system.
4. HVAC systems that use mass flow rate of supply air (m_{supply}) to control the room temperature are presented by the variable air volume (VAV) system.

The cooling/heating loads produced by HVAC systems (Q_{HVAC}) are instantaneously corrected by control parameters of four HVAC configurations defined above. Therefore, the designed model allows for linking of Q_{HVAC} and Q_{load}, which is essential for integrated and simultaneous solution of equations of HVAC and load models in order to achieve the energy balance between supply and demand sections. Considering the configurations of HVAC system, this link is defined as follows:

1. Cooling/heating loads (Q_{load}) and surface temperature ($T_{surface}$) in HVAC system, with $T_{surface}$ as control parameter.
2. Cooling/heating loads (Q_{load}) and convective heat flux (Q_{supply}) in HVAC system, with Q_{supply} as control parameter.
3. Cooling/heating loads (Q_{load}) and supply air temperature (T_{supply}) in HVAC system, with T_{supply} as control parameter.
4. Cooling/heating loads (Q_{load}) and supply air mass flow rate (m_{supply}) in HVAC system, with m_{supply} as control parameter.

Energy optimization in building is considered as another function of energy modeling software. Various applications and software have been designed for energy optimization in buildings. Currently, there are many methods for energy optimization. These methods can be classified into two main groups: (a) methods for optimization of load models and (b) methods for optimization of HVAC models.

Most of the current methods for optimization of load models are based on minimization of capital and operation costs through placing a set of constraints. Wilson and Templeman (1976), in their study, optimized thermal model in an office building based on minimizing initial and operation costs to employ appropriate thermal insulation processes. Radford and Gero (1980) used the concept of "pareto optimality" as a criterion for optimization of peak summer internal environmental temperature and daylight factors in building spaces. Kumar et al. (1989)

used the maximized net energy savings—raised from applying insulation as objective function—for optimization of load model in the intended building.

Al-Homoud (2005) introduced a new method, called system approach, for optimization of office and residential buildings' envelopes. Using minimum thermal discomfort criteria and minimum annual source energy use level as objective functions, he conducted optimization procedure. In this method, objective functions and their constraints are cyclically linked to different parts of structural systems and materials according to logical and systematic procedures, which leads to data correction and better solution of energy optimization. To solve thermal model optimization, search method, developed by Nelder and Mead (1965) and Himmelblau (1972), was used. In this method, difficulties in calculating nonlinear equations in objective functions have been resolved. In another study, Al-Homoud (2009) optimized thermal comfort conditions for a mosque in two climatic zones using system approach optimization procedure.

In some of the methods for optimization of HVAC models, energy consumption, as an objective function, is formulated within different parts of energy distributor systems and also minimized based on constraints of input variables. However, in recent studies, solution of mentioned methods has been considerably improved owing to nonlinearity of energy consumption relations among model components. Kusiak et al. (2010), in an approach to optimize air handling unit (AHU) model, formulated the variables affecting main model's energy consumption as separated into sub-models in the objective function. In this approach, total energy consumption, as a single objective function, was minimized as a result of temperature and desirable pressure constraints. In another approach, Eisenhower et al. (2012) used the balance between energy consumption and thermal comfort rate to reduce the time required for solving optimization calculations. In this approach, function of costs, as an objective function, is optimized once for thermal comfort and another time for energy consumption, and at the final step, its combined optimized model is obtained by balancing these two items. They named this approach "meta model." Sometimes, several optimization criteria are applied for optimization of a building. In this case, multiobjective functions are used. Because of excessive variables, parameters and constraints in such models as well as complexity rooted in nonlinearity of their relations, a method entitled evolutionary optimization technique was presented aiming at optimal solution. In these types of methods, "pareto" concept is used as a criterion for optimal selection of a new population (Verbeeck and Hens, 2007). The variables affecting optimal conditions are codified in objective functions, and the intended model is optimized with the help of criterion of population's satisfaction growth (Enadi et al., 2010). Enadi et al. (2010) managed to optimize combined heat and power (CHP) plant model for domestic use through multiobjective function and genetic algorithm approach. In this approach, the quantity of people who are satisfied from HVAC system is regarded as an optimization criterion for objective function. Obviously, this can lead to simplification of the intended model's optimization solution and help to overcome the difficulties attributed to nonlinearity of objective function. The disadvantages of this approach are as follows: (a) modification of independent variables that have optimal value and (b) having no authentic criterion for optimization of variables that lack the information about their allowable conditions (Enadi et al., 2010).

In the designed model, considering the direct relation between energy consumption and its related costs, economic methods for optimization of energy consumption costs during the study period can be used instead of energy consumption optimization models. In this approach, energy optimization is considered as an outcome of economic optimization of costs pertaining to energy consumption. These costs cover the total present value (PV) for energy consumption costs including investment costs; capital costs; installation costs; energy costs; operation, maintenance, and repair costs; and disposal costs.

LCCA is one of the mentioned economic optimization procedures, which can identify cost optimal building design options. Based on economic analyses, these options can be accordingly selected and simulated as an optimal economic model from energy point of view.

The American Society for Testing and Materials (ASTM, 2012), Federal Energy Management Program (1990) of the DOE, and National Institute of Standards and Technology (NIST) (Fuller and Petersen, 1996) have approved this method as an energy optimization procedure based on relations of equations dominating energy costs and economic analyses. Thus, the mentioned method can be a substitute for other conventional energy optimization models that are based on direct relations of equations dominating energy. Also, the standards presented in this method have been properly developed and utilized. The advantages of using LCCA method for optimization of energy systems in building are as follows: (a) simplified calculations of design alternatives' energy optimization in a model using measures and economic optimal criteria, (b) possibility for comparing design alternatives optimized for a model in different times and spaces, (c) potential for economic analysis and assessment of a model from optimal energy consumption point of view in a long-term study period, and (d) possibility for predicting the energy optimal condition of simulated model in future (Korpi and Ala-Risku, 2008).

Models like eVALUator and building life cycle cost (BLCC) implement the economic optimization based on LCCA method. In these models, optimization is done with high accuracy and pace in an unlimited range of building life as focused on energy efficiency (Energy Design Resources, 2012; US Department of Energy, Federal Energy Management Program Home, 2012). The data required for economic energy optimization are provided by the user and fed to the software manually, which is known to be weakness of these models (Snodgrass and Technology & Development Program (US), 2008).

Considering the advantages of the designed model, LCCA has been used for optimization of the functions dominating economic models in a study period, in order to decrease energy consumption and optimally utilize energy in the building.

Comparing the existing software, tools, and methods, the adopted method for economic energy optimization in the designed model is advantageous because in the first step, it simulates the building as an energy system, and in the second step, it obtains the data required for economic energy optimization of the building from simulated model's output. Thus, in this method, unlike other conventional programs, the data are not entered manually.

Considering the fact that energy modeling is dynamically performed based on simultaneous integration of HVAC model and load model, in the first step, the data required for economic energy optimization are corrected, and in the next step, they are used for optimization of the mentioned model. Possibility for simulation of various types of energy efficient building samples and optimization of them is another advantage of this method. In fact, this model is able to first use the intended building's corrected data for optimization and second allow for optimization of various scenarios suggested for a simulated building before being designed and constructed. According to Figure 1, the designed model has the potential for inputting various energy-efficient scenarios into the model, so that for every single scenario, one energy model can be simulated. However, these models may not be optimal in terms of economic energy. Thereby, only one of the suggested scenarios would be chosen as an optimized economic energy model after being passed through the optimization step. Some of the current energy programs model energy focusing on energy analyses, whereas some others are responsible for energy optimization in the building according to the data provided by the user. Nonsimultaneous capabilities of such programs make it difficult to precisely optimize the suggested scenarios in a simulated building before being designed and constructed (Crawley et al., 2008).

Other capabilities of the designed model are integration of all types of single scenarios that are optimized for the whole building, simultaneous optimization of them using LCCA method, and finally presenting the general model of optimized multienergy systems for the simulated building.

Set of energy equations' model

The designed software comprises two main parts: energy modeling and energy optimization. In energy modeling, all mathematical equations dominating the whole system and the building surrounding area are modeled for its different energy-effective components in a dynamic and integrated form.

Considering the structure of these models, mathematical equations of mass and energy balance, types of heat transfer, and indoor and outdoor airflow dominate the whole-building system. In this part, the mathematical equations dominating the building's energy are designed as energy equations' model. A set of energy equations' model includes relation of boundary conditions at external–internal surface, energy equations for building systems, interzone airflow and infiltration, and HVAC models.

The boundary conditions at external–internal surface model can be expressed through equations (1) and (2)

$$B_{ex} = \left[b^{A}_{c.h}, b^{B}_{s.r}, b^{C}_{sh}, b^{D}_{e.l.w.r}, b^{E}_{c.g} \right]_{t=0}^{t=n} \tag{1}$$

$$B_{in} = \left[b_c^F, b_{i.l.w.r}^G, b_{s.w.r}^H \right]_{t=0}^{t=n} \tag{2}$$

In this model, b refers to heat transfer equations concerning boundary conditions at external–internal surface. Superscripts A, B, C, D, E, F, G, and H represent type and location of building elements' surfaces. Subscripts *c.h, s.r, sh, e.l.w.r, c.g, c, i.l.w.r*, and *s.w.r* refer to the types of energy phenomena on external–internal surfaces, which include convective heat flux, solar radiation, shading, external longwave radiation, conduction to the ground, convection, internal longwave radiation, and shortwave radiation, respectively. This model is dynamically implemented at time steps of 0–n.

In the designed model, the convective heat flux generated by each external surface is determined according to calculation of external convection coefficient (h). Referring to equations (3) to (5), wind velocity and direction are required for calculation of convection coefficient (Kimura, 1977). The software extracts these data from weather database and receives them as inputs, and then considering wind velocity and direction, it chooses the related equation and calculates the external surface convection coefficient.

For surfaces that are windward

$$u = \begin{cases} 0.5 & \text{for } U < 2\,\text{m/s} \\ 0.25 \cdot U & \text{for } U > 2\,\text{m/s} \end{cases} \tag{3}$$

For surface that are leeward

$$u = 0.3 + 0.05 \cdot U \tag{4}$$

$$h = 3.5 + 5.6 \cdot u \tag{5}$$

where u is the local velocity in the vicinity of the surface, U is the wind speed on a façade surface, and h is the external convection coefficient.

To calculate direct solar radiation (I_{DIR}) and diffuse solar radiation (I_{dif}) in external surfaces with assumption that sky diffuse is uniform, equations (6) and (7) (Duffie and Beckman, 1991) have been used in the software

$$I_{DIR} = I_{DNR} \cdot \cos\theta \tag{6}$$

$$I_{dif} = \frac{(I_{GHR} - I_{DNR} \sin\alpha) \cdot (1 + \cos\beta)}{2} \tag{7}$$

where I_{DNR} is the direct normal radiation, I_{DIR} is the direct solar radiation, θ is the incident angle, I_{dif} is the diffuse solar radiation, I_{GHR} is the global horizontal radiation, α is the solar altitude, and β is the surface slope (90° for vertical surface).

Shading in external surfaces is calculated through equations (8) to (10) (Duffie and Beckman, 1991)

$$q_{absorbed\_s} = \alpha_{shortwave} \cdot [I_{DIR} \cdot (1 - \frac{A_{shaded}}{A_{total}}) + I_{dif}] \tag{8}$$

$$q_{transm\_DIR} = \tau_{DIR} \cdot I_{DIR} \cdot (1 - \frac{A_{shaded}}{A_{total}}) \tag{9}$$

$$q_{transm\_dif} = \tau_{dif} \cdot I_{dif} \tag{10}$$

where $q_{absorbed\_s}$ is the absorbed solar radiation; q_{transm_DIR} is the direct solar radiation transmitted through windows; q_{transm_dif} is the windows' -transmitted diffuse radiation; I_{dif} is the diffuse solar radiation; I_{DIR} is the direct solar radiation; A_{shaded}/A_{total} is the shaded portion of the considered surface based on geometry data for the surface, geometry data for horizontal and vertical shading devices, sun azimuth and altitude, and surface azimuth; $\alpha_{shortwave}$ is the absorption coefficient for shortwave radiation; τ_{DIR} is the window transmittance coefficient for direct solar radiation; and τ_{dif} is the window transmittance coefficient for diffuse solar radiation.

External longwave radiation between external surfaces and space is calculated with equations (11) and (12)

$$q_{surf\_ground} = h_{rad\_ground}(T_{surf} - T_{ground}) \tag{11}$$

$$q_{surf\_sky} = h_{rad\_sky}(T_{surf} - T_{sky}) \tag{12}$$

where T_{surf} is the external surface temprature, q_{surf_ground} is the external surface heat exchange with the ground by radiation, h_{rad_ground} is the radiative convection coefficient with the ground, T_{ground} is the ground temperature, q_{surf_sky} is the external surface heat exchange with the sky, h_{rad_sky} is the radiative convection coefficient with the sky and T_{sky} is the sky temperature (Kimura, 1977).

Conduction to the ground can be calculated by equation (13)

$$q_{cond\_ground} = \frac{k_{ground}}{L \cdot (T_s - T_{ground})} \tag{13}$$

where q_{cond_ground} is the external surface heat exchange with the ground by conduction, k_{ground} is the ground conductivity, T_s is the surface temperature, T_{ground} is the ground temperature, and L is the distance.

Convection correlation (Beausoleil-Morrison, 2000) is used for calculation of convective heat transfer formed within building's internal surfaces in the designed model. This correlation is formed by combination of natural convection (Alamdari and Hammond, 1983) and forced convection (Fisher, 1995).

Equation (14) can be used for calculation of internal longwave radiation among surfaces in the room. This equation relies on radiative heat exchange factors ($\psi_{i,j}$) (Hoornstra, 1986)

$$Q_{i,j} = \varepsilon_i \psi_{i,j} A_i \sigma (T_i^4 - T_j^4) \tag{14}$$

where $Q_{i,j}$ is the radiative heat exchange in between surfaces "i" and "j" that include reflection from other surfaces, ε_i is the reflectivity of surface "i," $\psi_{i,j}$ is the radiative heat exchange factors, A_i is the surface "i" area, σ is the Boltzmann constant, T_i is the temperature of surface "i," and T_j is the temperature of surface "j."

Shortwave radiation among surfaces in the room, which was introduced by Judkoff and Neymark (1995), can be calculated according to equation (15)

$$SF_i = A1_i + A2_i + A3_i + AR_i \tag{15}$$

where SF_i is the transmitted direct solar radiation that surface "i" absorbs, $A1_i$ is the absorbed energy at the first "strike" of the transmitted direct solar radiation, $A2_i$ is the absorbed energy of surface "i" at the second "strike" that follows after first reflection, $A3_i$ is the absorbed portion of the direct solar radiation that is transmitted by surface "i" at the third "strike," and AR_i is the distribution of all remaining (after the third "strike") nonabsorbed energy based on the distribution of fractions from the calculations for $A3_i$.

The model of energy balance for building system can be presented as

$$E_{b.s} = \left[e^{I}_{b.e}, e^{J}_{a}, e^{K}_{w}, e^{L}_{i.h.s}, e^{M}_{l}\right]^{t=n}_{t=0} \tag{16}$$

where e refers to the energy balance equations for building system; superscripts I, J, K, L, and M represent type and location of building system elements; and subscripts $b.e$, a, w, $i.h.s$, and l indicate the type of energy balance for specific building components, which are building elements, air, window, internal heat source, and lighting systems (lamps), respectively. This model is dynamically implemented at time steps of t in the range of 0–n.

Heat transfer equation (17) has been used for calculation of energy balance among building elements such as walls, ceiling, floor, and windows. To make this equation simple and one-dimensional, width and height (length) of building elements have been assumed much greater than their thickness. The designed model solves the mentioned equation through numerical discretization method

$$\frac{\partial(\theta)}{\partial t} = \frac{k}{\rho c_p}\left[\frac{\partial^2\theta}{\partial x^2}\right] + q_{source} \tag{17}$$

where θ is the temperature, t is the time, k is the thermal conductivity, ρ is the mass density of the material, c_p is the specific capacity for air, x is the thickness of building elements, and q_{source} is the internal heat flux source.

Attributing T_{air} to room air with homogeneous temperature, ρ to physical characteristics as density, and c_p to specific capacity, equation (18) can be considered as energy balance for room air.

In this equation, the first term represents convective heat flux of surface; the second term stands for heat transfer originated from supplied air, infiltration, and interzone air mixing; and the last term shows the sum of convective heat sources in the room

$$\frac{\partial (V_{room}\rho c_p T_{air})}{\partial t} = \sum_{i=1}^{n} h_i A_i (T_{s,i} - T_{air}) + \sum_{i=1}^{n} mc_{pi}(T_{ext\_air,i} - T_{air}) + \sum Q_{source} \tag{18}$$

where ρ is the mass density of air, c_p is the specific capacity for air, V_{room} is the volume of room space, h_i is the surface "i" convection coefficient, A_i is the surface "i" area, $T_{s,i}$ is the surface "i" temperature, T_{air} is the air temperature, T_{ext_air} is the external air temperature, t is the time, m is the mass flow rate, and Q_{source} is the convective heat sources in the room.

Energy balance attributed to conductive heat flux for a single glazed window is achieved based on equation (17). For the double glazed windows and over, in addition to energy balance for heat flux conduction, energy balances for convection in windows cavity and longwave radiation in between glazing surfaces are achieved through equations (19) and (20).

$$q_{i,j} = h_{ri,j}(T_i - T_j) \tag{19}$$

$$h_{ri,j} = \varepsilon_i \psi_{i,j} \sigma (T_i^2 + T_j^2)(T_i + T_j) \tag{20}$$

where $q_{i,j}$ is the longwave radiation in between glazing surfaces, $h_{ri,j}$ is the radiation convection coefficient, T_i is the temperature of surface "i," T_j is the temperature of surface "j," ε_i is the surface "i" emissivity, $\psi_{i,j}$ is the radiative heat exchange factors from surface "i" to surface "j," and σ is the Boltzmann constant.

The insulated glazing unit (IGU) model, which is used by Curcija, (1992), has been applied to calculate convective heat flux in between two glazing surfaces (equations (21) and (22))

$$q_{IGU} = Nu \frac{k_{air-cavity}}{e_{IGU}} \Delta t \tag{21}$$

$$Nu = 0.21 \cdot Gr^{0.269} \left(\frac{l}{e_{IGU}} \right)^{-0.131} \tag{22}$$

where q_{IGU} is the convective heat flux, Nu is the Nusselt number, $k_{air\text{-}cavity}$ is the air-cavity conductivity, e_{IGU} is the thickness of the cavity, Δt is the temperature difference, Gr is the Grashof number, and l is the cavity height.

Internal heat sources when producing building heat loads for occupants, computers, tools, lighting devices, machines, and so on would release convective and radiative heat fluxes from their surface as a reaction. Precise calculation of convective and radiative heat fluxes based on the surface temperature of the heat source is impractical because the exact position and surface temperature of the source are unknown. Thus, values for this heat sources can be extracted from experimental measurements of existing literature in the form of convection/radiation portions for internal heat sources as model inputs during simulation (ASHRAE, 2001; Kimura, 1977).

In the designed model, convective parts of internal heat sources ($Q_{source\_convection}$) directly affect room air temperature, which can be calculated as a heat source by equation (18). In radiative part of internal heat sources ($Q_{source\_radiation}$), the generated convective flux appropriate for each room surface is distributed according to equation (23)

$$q_{source_i} = \frac{1}{Area_i} \cdot [\frac{Area_i \cdot \lambda_i}{\sum (Area_i \cdot \lambda_i)}] \cdot Q_{source\_radiation} \tag{23}$$

where q_{source_i} is the radiative internal heat source for room surface "i," $Area_i$ is the surface "i" area, $Q_{source\_radiation}$ is the radiative internal heat sources, and λ_i is the surface "i" absorptivity.

Total power of lighting system includes longwave, shortwave, and convective radiative heat flux, and energy balance between light and interzone spaces can be calculated using equations (14), (15), and (18), respectively.

Equations of infiltration and interzone airflow models can be expressed as

$$A_{in} = \left[a_{i.z.f}^{N}, a_{i}^{O}\right]_{t=0}^{t=n} \tag{24}$$

where a refers to mass and energy flow equations; superscripts N and O refer to location of building internal zones; and subscripts $i.z.f$ and i dynamically express the equations of interzone airflow and infiltration, respectively, at time steps (0–n).

To calculate interzone airflow as well as plenum above the room, equation (25) is used (Deru and Burns, 2003)

$$m_{in-zone} = C_d A \sqrt{2\rho \Delta P} \tag{25}$$

where $m_{in-zone}$ is the interzone airflow rate, C_d is the discharge coefficient of an opening (dimensionless), A is the free area of an opening, ρ is the air density, and ΔP is the pressure difference across the opening.

Most of the whole BES programs use very simplified models for calculating infiltration. Since the heat transfer due to infiltration has the smallest effect on building load calculations, the whole-building space can be taken as a single zone (Deru and Burns, 2003). Doing this and considering the effects of wind and stack superposition obtained by equation (26), infiltration can be simulated as a simple model (ASHRAE, 2001). The stack and wind coefficients are provided by the user based on building height and shelter class information (ASHRAE, 2001)

$$m_{\mathrm{inf}} = \rho \frac{a_l}{1000} \sqrt{C_S \Delta T + C_w U^2} \tag{26}$$

where m_{inf} is the infiltration mass flow rate, ρ is the mass density of air, a_l is the effective air leakage area, C_S is the stack coefficient, ΔT is the temperature difference between the room and outdoor air, C_w is the wind coefficient, and U is the wind speed.

Generally, the model designed based on single-zone modeling calculates equation (26). In the event that the user should calculate interzone airflow rate and infiltration using multizone models, the model will be able to couple with CONTAM (Dols and Walton, 2003) and COMIS (Feustel, 1998, 1999) programs.

In HVAC system model, h represents mass–energy balance and heat transfer equations. All four models, that is, pure convection, radiant panel, CAV, and VAV systems represented by subscripts *p.c, r.p, c.a.v*, and *v.a.v*, respectively, are dynamically expressed at time steps of t (0–n) through equation (27) in which superscripts *P, Q, R*, and *S* represent different sections of energy distribution by HVAC systems

$$HVAC = \left[h^P_{p.c}, h^Q_{r.p}, h^R_{c.a.v}, h^S_{v.a.v}\right]^{t=n}_{t=0} \tag{27}$$

To facilitate modeling procedure, the designed HVAC model has been simulated in a steady-state condition, and energy accumulation in HVAC components has been ignored as it is significantly smaller than energy accumulation in the building structure.

The implemented HVAC components are baseboard heaters, fan–coils, radiant panels, and elements of simple AHUs. Equation (28) is used in pure convective system of baseboard heater type, while equations (29) and (30) are used in pure convective system of fan–coil system type.

$$Q_{room} = Q_H \cdot \eta_{distribut\_system} \tag{28}$$

$$T_{fc\_surface} > T_{dp} \tag{29}$$

$$Q_{room} = m_w c_p (T_{w\_out} - T_{w\_in}) \tag{30}$$

where Q_{room} is the heating load for pure convective devices, Q_H is the load of the heating plant, $T_{fc\_surface}$ is the surface temperature of the fan–coil heat exchanger, T_{dp} is the room dew point temperature, m_w is the water flow rate, $\eta_{distribut\_system}$ is the heating distribution system efficiency, T_{w_in} is the inlet water temperatures, and T_{w_out} is the outlet water temperatures.

In radiant panel system model taken from solar collector (Duffie and Beckman, 1991), panel surface temperature complies with temperature of the fluid (water) passing through the radiant panel tubes. This system is the combination of steady airflow distribution systems and convective and radiative heat transfer due to energy-bearing fluid passing through the radiant panel tubes. In this model, equations (31) to (33) have been applied for calculations of energy balance for panel surrounding air and energy extracted by the panel within the room, respectively.

$$Q_{zone} = Q_{rad\_pan} + Q_{air} \tag{31}$$

$$Q_{rad\_pan} = Q_{radiation} + Q_{conv} \tag{32}$$

$$Q_{rad\_pan} = m_w c_{pw}(T_{w\_out} - T_{w\_in}) \tag{33}$$

where Q_{zone} is the total cooling/heating load in the room, Q_{rad_pan} is the energy extracted/added by the radiant panel, Q_{air} is the energy extracted/added by the air system, $Q_{radiation}$ is the radiative heat flux extracted/added by the radiant panel, Q_{conv} is the convective heat flux extracted/added by the radiant panel, m_w is the water flow rate, c_{pw} is the specific capacity for water, T_{w_in} is the inlet water temperatures, and T_{w_out} is the outlet water temperatures.

The designed model for AHU employs two types of CAV and VAV systems, so that equations (34) and (35) can be used for energy and air humidity balances in the intended room, equations (36) and (37) can be used for energy and air humidity balances in AHU mixing box, and equations (38) and (39) can be used for energy balance in heating and cooling coils. Provided that supply airflow rate (m_S) is considered as input data and supply air temperature (T_S) is calculated based on the cooling/heating load in the room ($Q_{room\_sensible}$), then AHU will be of CAV type. On the contrary, if supply air temperature (T_S) is considered as input data while sensible cooling/heating load in the room ($Q_{room\_sensible}$) is calculated by equations that define the energy balance in the room for certain air temperatures (T_R). The supply airflow rate (m_S) is calculated by equation (34), and then AHU will be of VAV type

$$Q_{room\_sensible} = m_S c_p(T_R - T_S) \tag{34}$$

$$Q_{room\_latent} = m_S(w_R - w_S) \cdot i_{phase\_change} \tag{35}$$

$$T_M = (1 - r) \cdot T_O + r \cdot T_R \tag{36}$$

$$w_M = (1 - r) \cdot w_O + r \cdot w_R \tag{37}$$

$$Q_H = m_S c_p(T_S - T_M) \tag{38}$$

$$Q_C = m_S c_p(T_S - T_M) + m_S(w_S - w_M) \cdot i_{phase\_change} \tag{39}$$

where $Q_{room\_sensible}$ is the sensible cooling load, m_S is the supply air mass flow rate, c_p is the specific capacity for air, T_S is the supply air temperature, T_R is the room temperature, Q_{room_latent} is the latent cooling load, w_R is the room humidity ratios, w_S is the supply humidity ratios, i_{phase_change} is the energy for phase change of water into vapor, T_M is the temperature of the air after the mixing box, r is the recirculated air fraction, T_O is the outdoor air temperature, w_M is the humidity ratio after the mixing box, w_O is the outdoor air humidity ratio, Q_H is the energy extracted/added by the heating coil, and Q_C is the energy extracted/added by the cooling coil.

The energy modeling part simultaneously involves all equations from (1) to (39) as mathematical models, so that all energy-effective factors of a building are finally simulated and correlated in an integrated and dynamic form. The energy optimization part of the designed software optimizes the integrated and dynamic building energy model based on economic modeling and through the LCCA method. In this

Table 1. Optimization procedure used in the model that has been designed based on LCCA

	Minimum LCC or maximum LCS subject to
1	SPB $>$ 0
2	SIR $>$ 1
3	AIRR $\geqslant$ MARR
4	AIRR $<$ 50%

LCCA: life cycle cost analysis; LCC: life cycle cost; SPB: simple payback; SIR: savings-to-investment ratio; AIRR: adjusted internal rate of return; MARR: minimum acceptable rate of return.

method, all economic measures, such as adjusted internal rate of return (AIRR), savings-to-investment ratio (SIR), simple payback (SPB), minimum acceptable rate of return (MARR), life cycle cost (LCC), and life cycle saving (LCS), are calculated in a specific study period (typically 15–25 years) for each scenario.

According to the optimization procedure presented in Table 1, LCC and/or LCS models pertaining to each suggested scenario are regarded objective functions. Next, other economic measures pertaining to the same scenario are considered as constraints of solving the given model. The suggested scenario will be optimum if its LCC and LCS, as a result of satisfying other economic measures, are of minimum and maximum, respectively.

SIR, which is a ratio that expresses the relationship between savings and increased investment cost (in PV), can be calculated as follows

$$SIR_{scen/base} = \frac{\Delta E + \Delta O\, and\, M}{\Delta I_0 + \Delta Repl - \Delta Res} \tag{40}$$

where $SIR_{scen/base}$ is the ratio of operational savings-to-investment-related additional costs, computed for the energy-efficient scenario relative to the base case; ΔE is the saving in energy costs (E) attributable to the energy-efficient scenario, $E_{base} - E_{scen}$; ΔO and M is the difference in operation and maintenance costs, O_{base} and $M_{base} - O_{scen}$ and M_{scen}; ΔI_0 is the incremental initial cost (I_0) attributable to the energy-efficient scenario, $I_{0scen} - I_{0base}$; $\Delta Repl$ is the difference in capital replacement costs, $Repl_{scen} - Repl_{base}$; and ΔRes is the difference in residual value, $Res_{scen} - Res_{base}$.

SPB period is a measure of the length of time required for the cumulative savings from an energy saving project to recover its initial investment cost and other accrued costs, without taking into account the time value of money.

This measure can be calculated as

$$\text{SPB} = \frac{\text{Incremental first cost(US\$)}}{\text{First year annual savings(US\$)}} \tag{41}$$

where SPB is the simple payback, incremental first cost = energy-efficient scenario first cost − baseline first cost, and first year annual savings = baseline first year utility cost − energy-efficient scenario first year utility cost.

AIRR is a measure of annual percentage yield from an energy saving project investment over the study period. It can be also calculated using the following equation in the model

$$\mathrm{AIRR} = (1 + r)(\mathrm{SIR})^{\frac{1}{N}} - 1 \tag{42}$$

where AIRR is the adjusted internal rate of return; r is the assumed reinvestment rate, that is, the MARR (the discount rate); SIR is the savings-to-investment ratio; and N is the number of years in the study period.

MARR is the minimum rate of return on an energy saving project, which is equal to discount rate. The most important economic measures in optimization process are those related to calculation of LCC and LCS, which can be obtained through equations (43) and (44)

$$\begin{aligned}\mathrm{LCC} = {} & \text{Initial investment costs} + \text{replacement costs} + \text{energy costs} \\ & - \text{residual value} + \text{operation and maintenance costs}\end{aligned} \tag{43}$$

In equation (43), initial investment costs, replacement costs, energy costs, and operation–maintenance costs carry a positive sign, while all future cash flows and income or residual value carry a negative sign.

According to equation (44), LCS is resulted from difference in LCCs for baseline and energy-efficient scenario

$$\mathrm{LCS} = \mathrm{LCC}_{\text{baseline}} - \mathrm{LCC}_{\text{energy-efficient scenario}} \tag{44}$$

LCCA requires that all costs be expressed in a common time frame, that is, the present. LCC convention is to discount future cash flows to PV.

By calculating the economic measures through equations (40) to (44), the designed software can select the most efficient scenario from the energy scenarios suggested for each part of the building. Finally, it can simulate and select the optimal multienergy systems for the whole building by integrating all energy-efficient scenarios.

The most energy-efficient scenario has been selected based on model optimization procedure presented in Table 1. This capability can be employed by the user either individually in one scenario or simultaneously in several scenarios.

Feasibility of building energy modeling program

Through the building energy modeling program, load and HVAC models are simulated simultaneously. Load model includes geometrical, space/structural, lighting, equipment, and occupant simulation modules, while HVAC model comprises air-side and water-side air conditioning and domestic hot water systems. In geometrical model, type of usage, area, number of floors, floor height, orientation, and building dimension are simulated. In space/structural model, mainly shell, zone, and infiltration type of models are simulated. Normally, building shell modeling is performed based on the data pertaining to envelope, windows, doors, and shading. Through zone modeling, three methods of perimeter and core; multiperimeter and core; perimeter and multicore; and zoned by activity area are proposed and finally selected for users. In infiltration modeling, amount of outdoor air infiltration to interzone room ratio is calculated in the form of air change per hour (ACH), CFM/ft^2 of floor area and/or CFM/ft^2 of exterior wall.

The program furnishes the user with possibility to choose between calculations of constant or variable infiltration. In lighting, equipment, and occupant load model, exterior and interior lighting; domestic hot water, cooking, and refrigeration equipments; heat gain from occupants; and miscellaneous are simulated. Air-side system model can be divided into cooling systems and heating systems. In cooling systems, types of direct expansion (DX) coils, chilled water, and evaporator coolers are simulated. In heating systems, types of DX applied to heat pump and hot water coils and also types of electrical resistance and furnace heaters are simulated. In water-side system model, types of the ground-source heat pump (GSHP) plant, water-source heat pump, chilled and hot water systems, and domestic hot water apt for the given condition are simulated.

The model is capable of constructing scenarios for building envelope, internal loads, HVAC systems, chilled water, and domestic hot water systems. In each section, the energy-efficient scenarios fitted with user's requirements are proposed, and then, the optimum scenario is simulated and finally selected after energy optimization with the help of LCCA method.

Using this software, the user, depending on his research type, can rely on a set of scenarios selected for the whole building and integrate them in order to simulate and optimize the new condition. Accordingly, if all the qualifications for optimization are obtained through the LCCA method, then the user can decide on the new model for the intended scenario and select and simulate the related optimized model.

The possibility to conduct technical–economical and energy analysis for the building in both baseline and optimized models has been provisioned in this software. Likewise, it would be possible to compare the results from energy modeling and optimization based on the economic measures pertaining to the studied models.

Conclusion

In this part of this article, to analyze and optimize energy consumption in buildings using energy modeling, capabilities of the designed model have been investigated entirely. To highlight these capabilities, strengths and weak points of the existing models have been compared with one another based on historical literature. The results revealed the unique and functional advantages of the designed model over the existing models as follows:

1. Possibility for simultaneous and dynamically integrated simulation of models for energy, economics, and weather boundary conditions of all geographical zones, especially Iran.
2. Potential for correction of control parameters necessary for simulation of HVAC model and load model in energy supply and demand systems, respectively, and also simplification of their simultaneous solution as compared to the existing models.
3. Possibility to make scenarios for different parts that are effectively involved in energy improvement and diminution in building.
4. Potential for economic optimization of suggested energy-efficient scenarios as individually and integrated in the whole building and developing a model for optimized multienergy systems.

In the second part of this article, application of the designed model for a case study residential building in Tehran will be evaluated technically and economically aiming at energy optimization and verification.

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