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Optimization of an envelope retrofit strategy for an existing office building

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ABSTRACT

Energy-efficient retrofits include improvement of building envelope via insulation, employment of building integrated renewable energy technologies, and climate control strategies. Building envelope improvements with insulation is a common approach, yet decision-making plays an important role in determining the most appropriate envelope retrofit strategy. In this study, main objective is to evaluate and optimize envelope retrofit strategies through a calibrated simulation approach. Based on an energy performance audit and monitoring, an existing building is evaluated on performance levels and improvement potentials with basic energy conservation measures (ECMs). The existing building is monitored for a full year and monitoring data is used in calibrating the simulation model. In order to obtain a better-performing building envelope three retrofit strategies including several ECMs are proposed. Retrofit strategies are simulated through calibrated base-case model, and results are evaluated according to changes in indoor environmental parameters and annual energy consumption measures. The analysis of results indicated that pre-assessed strategies yield close results. Therefore, a more comprehensive evaluation based on different decisive criteria is used in optimization of the final retrofit strategy, with the intention to evaluate the effect of individual ECMs on annual end-use energy consumption and investment.

1. Introduction

Rapid technological and industrial growth of last decades caused fossil fuel consumption to present an increasing trend. Overall energy consumption, largely founded on non-renewable energy sources, became threatening for the environment, thus global focus on reduction of non-renewable energy consumption increased [1,2]. Necessity to reduce fossil fuel consumption and CO_2 emissions led energy-efficient improvements of existing buildings and regulations for new building designs. These efforts developed into research areas such as monitoring and assessment of energy performance of existing buildings, further into retrofit of existing buildings due to implementation of possible energy conservation measures [3–5].

Approximately 40% of world energy consumption is in buildings. Building stock significantly contributes to consumption of non-renewable energy sources due to services such as space heating, cooling and air handling, water heating, lighting, and utilities [6]. Therefore, consumption measures become important for reducing environmental impact of the built environment. Different initiatives launched programs and regulations with the aim to increase energy-efficiency for the built environment. Most distinguished regulation is the EU Legislation of 2002, “Directive on Energy Performance of Buildings” (EPBD). Particularly, the directive asserts the necessity to increase energy-efficiency for new and existing buildings. In addition, the directive emphasizes the need to develop certain methodologies to determine energy performance of buildings and to prepare energy certificates. National methodologies, consistent with the structure of the directive, are mandatory for EU and candidate countries [7].

Turkey announced Energy Performance of Buildings Directive in 2005 based on the former Turkish Standard 825 – Thermal Insulation in Buildings [8,9]. The directive became mandatory only in 2010 and adopted static monthly calculation methodology to assess building energy performance and to determine energy performance of new buildings. In addition, it mandates energy certificates for existing building stock before 2014. As a result, it is possible to state that Turkey has potentials in terms of energy-efficient retrofit of existing buildings, where considerable percentage of the building stock dates prior to the standard. Nevertheless, monthly methodologies based on steady-state calculations yield less precise results in predicting both new and existing building energy performances [10,11]. It is essential to assess energy performance of existing buildings through use of dynamic models, preferably by calibrated simulation approach [12,13]. This research aims to demonstrate a systematic approach for optimization of an energy-efficient retrofit strategy. A case building in the campus area of Izmir Institute of Technology is monitored for a full year, including on site climatic

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Table 1
Building information.

Location	38°19′15.91″ latitude 26°38′26.86″ longitude
Orientation	8.09° (CW normal angle of north façade)
Environment	Open land, no shadow effect of close structures, landscape, etc.
Floor area (m^2)	5540
Floor height (m)	3.60
Volume (m^3)	19,944
Façade surface area (m^2)	3515
Roof area (m^2)	2824
Glazing area (m^2)	816.20
Glazing ratio (%)	23.20
Compactness (A_{tot}/V_{tot})	0.32

data, indoor temperature and humidity, energy consumption, efficiency of active systems and CO_2 emissions. The research aims to utilize a building energy simulation tool in order to replicate the base-case energy performance of the existing building and propose ECMs (energy conservation measures) targeting the improvement of the building envelope.

2. Methodology

Buildings are complex and unique systems, composed of physical, functional, and environmental characteristics. Considering this level of complexity, a holistic approach is essential, which employs methodologies combined with national and international standards [4,14,15]. In Turkey, despite the ongoing accreditation of regulations to EPBD, methodological approaches for energy-efficient improvement of buildings are insufficient. In this framework, for Turkish building stock, even basic envelope retrofits may contribute significantly to decrease heating and cooling energy consumption. Yet, pre-assessed measures do not always provide expected results. Discrepancies between assessed and actual performance of retrofit measures commonly depend on environmental, physical, and functional characteristics of a building [16]. In order to obtain close results to actual performance levels, it is essential to validate any assessment methodology with real data.

Method of this study aims a systematic approach for optimization of an energy-efficient retrofit strategy composed of different ECMs (Fig. 1). In order to obtain close accuracy to actual performance levels, dynamic energy simulation approach is employed. Steps of the method start with building audit and energy performance monitoring of an existing building. Latter, audit data is transferred into a base-case simulation model and monitoring data is utilized in simulation model, in order to assess existing energy performance levels and obtain a calibrated model. Third step covers defining pre-assessed ECMs and retrofit strategies, testing through calibrated simulation model. To conclude, a single retrofit strategy is optimized via sensitivity of ECMs on annual consumption levels and investment payback analysis. The steps of the methodology are described, in this section.

2.1. Energy performance assessment: audit and monitoring

2.1.1. Building audit

Through building audit, information on building characteristics such as location, orientation, environmental factors, envelope characteristics, installation systems, comfort ranges, and schedules and occupancy are gathered [17–19]. Case building is located in Izmir Institute of Technology campus area, and predominantly accommodates office functions (Fig. 2). The building has a reinforced concrete structure with filled in brick walls. Detailed information of the building is presented in Table 1.

The building is non-insulated except the flat roof. Thermal characteristics of opaque building envelope components[1] are in Table 2. Glazing components consist of aluminum frames with thermal break and double-pane clear glass with air cavity. Glass surfaces occupy almost 90% of the whole window/door area and *U*-value for glazing is from Turkish Standard TS 2164, with a value of 3.0 W/m^2 K [20].

Heating, cooling, and ventilation systems are used to acclimatize the indoor environment and to maintain indoor air quality. Heating system includes two non-condensing boilers that use fuel as the energy source. Weather compensation system controls boiler temperatures according to exterior temperature and provides balanced indoor temperature profiles and values such as boiler water temperatures, return water temperature, and exterior air temperature are recorded with 5 min interval. Cooling installation is an air-cooled liquid chiller with heat recovery system and runs on electricity. Air handling unit functions both with heating and cooling installations and works via mixing outdoor air with returning air from indoors.

Comfort range temperatures for offices and classrooms are 22 °C and 24 °C, for storage spaces 20 °C and 24 °C and circulation spaces 20 °C and 26 °C, respectively, for heating and cooling periods. Laboratories are not conditioned for both periods. Approximate discrepancies of ±2 °C are observed in monitored indoor temperature data. Students, academic and administrative staff occupy the building in weekdays is between 08:00 and 18:00.

2.1.2. Energy performance monitoring

Detailed and continuous measurement of indoor and outdoor parameters is crucial to obtain accurate results to assess the indoor thermal profiles [21]. Temperature and humidity measurements of sample volumes, electricity consumption, fuel consumption, microclimatic data, and CO_2 emissions of the heating installation of the building are monitored for a full year in 2009. Table 3 presents measurement type, intervals, and equipments used throughout building energy performance monitoring.

Electricity consumption is monitored from cooling unit board with a power analyzer data logger with 15 min interval. Flow meters are installed on both boilers, between the pre-heater and the burner, to record fuel consumption on daily basis. Consumption is calculated according to its viscosity at the pre-heated temperatures of 50–60 °C. Outdoor temperature, outdoor humidity, global horizontal solar radiation, wind speed, and wind direction are monitored with 10 min interval with a microclimatic station. Cloudiness is retrieved from macro-climatic main weather station of Izmir.[2]

2.1.3. Monitoring results

Monitoring data retrieved from the case building is analyzed via percentage of hours outside comfort range for heating, cooling, and free-running periods. In order to formulate this evaluation, hourly temperature and humidity averages are calculated from monitoring data with 10 min interval, for the 2520 occupancy hours in a year. Ratio of hourly temperature averages to the total hours of occupancy is obtained. The analysis covers the months of heating season (January, February, March, and December 2009) and non-conditioned months (April and May 2009). It is noticeable that north oriented spaces distinctly have larger ratios of hours below comfort range (average 40–45%). Similar approach is applied to both ground and first floor for heating, cooling, and free-running periods. Results are presented in Table 4 [22]. It is possible to assert that north oriented spaces in the monitored building have poorer indoor temperature profiles during heating season due to lack of

[1] OCW (2009), Office of Construction Works, Izmir Institute of Technology.
[2] TSMS (2009), Turkish State Meteorological Service.