Building energy model validation and estimation using heating and cooling degree days (HDD–CDD) based on accurate base temperature

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Abstract
A great deal of energy used in buildings is directed toward heating, ventilation, and air-conditioning (HVAC). The key procedure in reducing heating and cooling loads is the creation of a baseline model that represents a theoretical version of the building. This allows multiple scenarios to balance the lowest retrofit cost with the lowest annual energy cost. This study emphasizes establishing an energy consumption model and energy benchmarks for a commercial building located in Shiraz, Iran. The energy-related data are gathered for 3 years based on real values from billing receipts. Herein, two distinct approaches are integrated; forward and inverse methods. In the forward method, building energy consumption is predicted based on building performance and specifications, geometry, location, and air conditioning system. In the reverse method, building energy consumption is evaluated using the building load coefficient and building base consumption according to effective factors such as weather data and appliance performance. Also, considering constant fixed temperatures as 18°C, and 21°C for calculating heating and cooling degree days is not correct. Thus, finding a proper and valid base temperature is the main aim of this study by examining this integrated method. The integrated application of these methods allowed determining the thermomechanical state of the building as a whole. To this end, base temperature boundaries are extracted from the energy consumption trend which grounds the need for cooling and heating. Eventually, the baseline for energy consumption of the building based on the proposed method is provided for calculating the development of methodological foundations for the design, construction, operation, and renovation of energy-efficient buildings. The results show that according to an acceptable thermal building comfort zone of 14–18.6°C, the building achieves a
1 | INTRODUCTION

The building sector accounts for 40% of total principal energy usage and is analogous to greenhouse gas (GHG) emissions, and therefore it is essential to lessen energy consumption in them to address energy and environmental issues and decrease costs. Opportunities for improving efficiency are assorted and high savings are possible technical-wise. To improve the complex system's performance designed to provide residents with a safe, comfortable, and attractive work and living environment, building efficiency must be taken into account. This necessitates efficient designs of architecture and engineering, construction practices with high quality, and smart structure operation. Consequently, there is a high potential for improving buildings' energy efficiency, since the present buildings' performance is far from efficacious.

The model and the prediction of the load profile are stratified in three ways. The first is the white-box model that is grounded on physical importance. The second model acknowledged as the black box, is based on empirical and statistical models. Finally, the third, the gray-box model, is founded on both physical and statistical methods. Black-box models are mostly grounded on artificial intelligence and methods based on statistical data.

A survey on short-term forecasting models was proposed by Gross and Galiana, and several studies have been reported on the use of neural networks to predict short-term energy consumption. Similar studies on the use of fuzzy logic and genetic algorithm were also applied. In addition, numerous methods have been employed for countries like Korea, China, and America. These methods are usually used when statistical data is not available from energy-consuming equipment. However, in cases where statistical and empirical data are available, extra methods can be utilized for load profile modeling. Another common technique is the bottom-up method, which provides a consumer behavior patterns study and the effects of demand response (DR). Various studies have been carried out on the modeling of electric energy consumption using this method and are corroborated as a reliable technique for electric energy consumption simulation. The basic idea of the bottom-up approach is constructing the entire consumption profile from the initial organization profiles that can be a home or even any home appliance. These can be found by examining the behavioral patterns of employing different equipment at home and their corresponding energy consumption, or with energy billing information and specific questionnaires. The method is grounded on precise statistical information that has high accurateness in buildings' energy demand analysis.

Some studies have used accurate household information and household equipment for modeling power consumption, while others have taken this information to obtain random models to mitigate the need for accurate information. The foremost traits of the bottom-up method are hitherto categorized by Kavgic et al. Thus, from top to bottom, it can be a suitable method for finding energy consumption specifications as it comprises the level of consumer activity, and behavioral patterns (the way residents carry out definite tasks).

A comprehensive bottom-up model was introduced to obtain consumer power consumption profiles by Paatero and Lund. In this model, real data were utilized for every kind of electrical appliance, and the probability of starting these devices was calculated based on hourly, daily, and seasonal effects. Navarro et al. employed a bottom-up approach using diverse resolutions for the electric charge model of a large group of home-grown consumers. Fischer et al. carried out a similar approach to model energy consumption in homes and calculated the load factor and correlation coefficient. Moreover, the pattern of Denmark's electricity consumption was modeled via a bottom-up tactic by Marszal-Pomianowska. In their model, daily and seasonal changes, different house groups, assorted steps of simulation, and various home appliances groups were also encompassed.

Ayodele et al. calculated each resident's average activity in a house to determine the residents' use of a particular device probability and employed the identical process to calculate the load in residential homes. Concerning engineering and statistical methods as the two main methods, the efficiency in each was associated with their integration by Shiraki et al. In their study, energy consumption depended on several factors.
including social and economic status, individual behavior, size, location, and type of the building, number of inhabitants, number and characteristics of different equipment, and environmental conditions. The study denoted that daily load behavior at the annual level is influenced by external variables such as ambient temperature, which seeks for a specific pattern in a season as the seasonal effect.

In retrospect, in this study, a 10-story under-insulated commercial building in Shiraz, Fars, Iran, with 500 occupants on average, 12,600 m² area, UA-value of 10,348 W/K, 1038 m² window surface, U-value of 3.7 W/m²K, and 17,988 m³ mass of air is assessed. The central heating and cooling system consist of two 6170 lb/h steam boilers and two 210 TR absorption chillers, which provide hot and cold water of 150 thermal terminals (fan-coils), respectively during heating and cooling periods. In this building, owing to the core expenses of natural gas and electricity, the energy consumption of the building is monitored. To address this, the paper presents a combined inverse and forward method to prepare information for the building energy simulation process, from identifying the buildings' thermal properties, geometry, and the type of heating, ventilation, and air-conditioning (HVAC) system in the designing stage. At large, the present building information is grounded on finding exact indoor and outdoor temperatures which are meticulously assessed, and future development trends are delineated. Furthermore, by finding the exact comfort temperature, the energy management system setpoint can be set efficiently and the systems operate in a better condition with lower energy consumption.

This study reveals that using reverse and forward methods simultaneously can be effective, not only in calculating the base building temperature instead of considering constant fixed comfort temperatures such as 18°C and 21°C for the day of heating and cooling but also in renovating stage to choose better materials to mitigate energy usage and achieve better energy performance. Also, thermal comfort can be achieved by implementing a smart building energy management system using base temperature as an input set-point to start-up/down the system. These issues are presented comprehensively in this paper as main contributions and novelties.

2 | MATHEMATICAL METHODOLOGY

Energy analysis has a substantial role in the cost-effective design and improvement of building ventilation systems. Analytical methods are very diverse and with varying degrees of complexity for energy analysis in the building, which, according to available data, accuracy and speed, sensitivity, and other parameters are depended upon. There are two methods, forward and reverse, shown in Figure 1. In the former, building energy consumption is predicted based on building specifications, geometry, location, type of air conditioning system, and building performance. In the latter, building energy consumption is related to typical building characteristics such as building load coefficient (BLC) and building base consumption according to energy consumption based on data-gathering from bills and meters (electricity and gas), weather, and performance data. In general, the reverse method has more complexity than the forward method, where building energy consumption is clear and reachable.

2.1 | Energy consumption calculation

Electricity and natural gas are the most communal sources of energy employed in buildings. Most buildings have individual heating and cooling systems. Though, there is as well district energy system that provides heat and cooling to a group of buildings. Wherever buildings
are near each other, on a university campus, for instance, central cooling and heating systems that distribute hot water, steam, or cooled water to them are efficient. Electricity might also be produced together with heating and cooling in district energy systems. They mostly employ fossil fuels, even though some utilize renewable energy sources too. The main energy exchanges (losses and gains) are from the ground, air infiltration, solar radiation, electrical equipment, individual behavior, and walls and windows. The transferred energy is calculated as:

\[ Q_{\text{Transfer}} = UA \Delta T, \quad \Delta T = (T_{\text{out}} - T_{\text{in}}), \]  

where \( UA \) is the UA-value for the building (W/°C), \( T_{\text{out}} \) is the average outdoor air temperature (°C), \( T_{\text{in}} \) is the average indoor air temperature (°C), and \( Q_{\text{Transfer}} \) is the energy transferred (W).

Also, the thermal load caused by outdoor air which enters the building is:

\[ Q_{\text{out}} = mC_p \Delta T \]  

where \( m \) is the mass flow rate (g/s) and \( C_p \) is the specific heat capacity (J/g °C). Therefore, the total cooling load of a building will be calculated as in Equation (3) where \( q_g \) is the sum of heat transferred from solar radiation (\( q_{\text{sol}} \)), and from each of the exterior surfaces of the building, walls, doors, roof, and windows, and internal sources of heat from occupants and appliances (\( q_{\text{int}} \)). Therefore:

\[ Q_{\text{Total}} = Q_{\text{Transfer}} + Q_{\text{in}} + q_g = UA \Delta T + mC_p \Delta T + q_g \]

\[ q_g = q_{\text{sol}} + q_{\text{int}} \]

\[ q_{\text{cooling}} = UA \Delta T + mC_p \Delta T + q_g \]

\[ = (UA + mC_p) \Delta T + q_g \]

\[ = BLC \Delta T + q_g \]

\[ = BLC \left( \Delta T + \frac{q_g}{BLC} \right) \]

\[ = BLC \left( T_{\text{out}} - T_{\text{in}} + \frac{q_g}{BLC} \right) \]

\[ = BLC \left( T_{\text{out}} - \left( T_{\text{in}} - \frac{q_g}{BLC} \right) \right) \]

\[ = BLC \left( T_{\text{out}} - T_{\text{b}} \right). \]

Herein, BLC and \( T_{\text{b}} \) are the building load coefficient (W/°C) and the cooling base temperature, respectively, which are defined by Equations (5) and (6). The cooling base temperature is the ambient temperature, which requires more cooling if it is greater than the base temperature.

\[ BLC = UA + mC_p, \]

\[ T_{\text{b}} = T_{\text{in}} - \frac{q_g}{BLC}. \]

Finally, by integrating Equation (4):

\[ q_{\text{cooling}} = BLC(T_{\text{out}} - T_{\text{b}}), \]

\[ Q_{\text{cooling}} = \sum_{N_c} q_{\text{cooling}} = \sum_{N_c} BLC \left( T_{\text{out}} - T_{\text{b}} \right)^+ \]

\[ = BLC \sum_{N_c} \left( T_{\text{out}} - T_{\text{b}} \right)^+ = BLC \times \text{CDD}, \]

\[ \text{CDD} = \sum_{N_c} \left( T_{\text{out}} - T_{\text{b}} \right)^+. \]

Here, CDD is cooling degree day (Days.°C) and \( N_c \) is the number of days in the cooling season and the + sign indicates the cooling period only when the outside temperature is greater than the base cooling temperature, their difference is considered in the equation; otherwise, the value of zero is considered. Equation (7) provides energy consumption in Joule, and if the energy requirement is required in kiloWatt-hour, Equation (8) is used:

\[ Q_{\text{cooling}} (J) = BLC(T_{\text{out}} - T_{\text{b}}) \times 3600 \times 24 \times N_c, \]

\[ Q_{\text{cooling}} (\text{kWh}) = BLC \times \frac{24}{1000} \times \sum_{N_c} \left( T_{\text{out}} - T_{\text{b}} \right)^+ \]

\[ = BLC \times \text{CDD} \times \frac{24}{1000}, \]

\[ \text{CDD} = \sum_{N_c} \left( T_{\text{out}} - T_{\text{b}} \right)^+. \]

For the heating period, equations can similarly be used according to the cooling period:

\[ q_{\text{heating}} = UA \Delta T + mC_p \Delta T - q_g \]

\[ = (UA + mC_p) \Delta T - q_g = BLC \Delta T - q_g \]

\[ = BLC \left( \Delta T - \frac{q_g}{BLC} \right) = BLC \left( T_{\text{in}} - T_{\text{out}} - \frac{q_g}{BLC} \right) \]

\[ = BLC \left( T_{\text{in}} - \frac{q_g}{BLC} - T_{\text{out}} \right) \]

\[ = BLC (T_{\text{b}} - T_{\text{out}}). \]

where \( T_{\text{b}} \) is the base heating temperature and is defined as:

\[ T_{\text{b}} = T_{\text{in}} - \frac{q_g}{BLC}. \]
For the entire heating season, we have:

\[
\begin{align*}
q_{\text{Heating}} &= BLC (T_b - T_{\text{out}}), \\
Q_{\text{Heating}} &= \sum_{N_i} q_{\text{Heating}} = \sum_{N_i} BLC (T_b - T_{\text{out}}), \\
&= BLC \sum_{N_i} (T_b - T_{\text{out}}) + BLC \times \text{HDD}, \\
\text{HDD} &= \sum_{N_i} (T_b - T_{\text{out}}),
\end{align*}
\]

where HDD is the heating degree day (Days.°C) and \( N_H \) is the number of heating days. Equation (11) provides energy consumption in Joule and if the energy is required to be kiloWatt-hour, the following is used:

\[
\begin{align*}
Q_{\text{Heating}} \text{(J)} &= BLC (T_b - T_{\text{out}}) \times 3600 \times 24 \times N_i, \\
Q_{\text{Heating}} \text{(kWh)} &= BLC \times \frac{24}{1000} \sum_{N_i} (T_b - T_{\text{out}}), \\
&= BLC \times \text{HDD} \times \frac{24}{1000}, \\
\text{HDD} &= \sum_{N_i} (T_b - T_{\text{out}}),
\end{align*}
\]

Next, the baseline of the natural gas consumption for the intended construction is executed, based on the proposed method.

3 | RESULTS AND DISCUSSION

3.1 | Natural gas data analysis for base temperature

A general approach to derive energy consumption in terms of CDD or HDD is to use the regional base temperature in the country. Traditionally, 18°C, and 21°C base temperatures are used, which are the conventional values while ASHRAE Standard 55-2017, Thermal Environmental Conditions for Human Occupancy, notes that for thermal comfort purposes, temperature could range from between approximately 67°F and 82°F (19–27°C). But it is worth noting that several factors are effective in determining the base temperature. The most important of these factors is the heat generated by the electrical equipment, lighting, staff, type of building shell, insulators, and solar radiation. Undoubtedly, considering constant fixed temperatures such as 18°C and 21°C, and further estimating energy consumption for all buildings with different physical characteristics and weather conditions in different climates is not valid.

On the other hand, it is necessary to mention that even the base temperature for a particular building is not constant during the year and varies according to the weather conditions. For example, the base temperature of the cooling in April is more than the base temperature in July for a larger building. This is why several articles have been provided, in which the cooling and heating temperatures for different countries are presented, and are subjected to a wide range of considerations, depending on the type of building and climate. Therefore, the first step in the preparation of the baseline of the building is to obtain the base temperature of cooling and heating.

As indicated, the energy consumption graph in terms of days intercepts the vertical axis (energy consumption axis) in the base energy consumption. If any basic temperature is defined to calculate the cooling or heating day, the consumption of the base energy corresponding to it is also changed, and finally, the energy consumption is predicted correctly. But since the base temperature of a building is also effective in interpreting the building’s condition, the base temperature should be correctly selected. The base temperature of the building gas consumption is obtained according to Table 1, from 2014 to 2016. As shown in this table, the lowest gas consumption is in April, November, and March, which are the months with the least heating or cooling requirement. Regarding the holidays in April and March, the month of November is the benchmark for calculating the base consumption of natural gas. Also, the negative number of HDD and CDD must be neglected and it means there is no need for turning on any cooling or heating systems.

3.2 | HDD calculation

After calculating the base consumption of the natural gas of the building, the next step is to calculate the base temperature for cooling and heating. According to Equation (4), if the energy consumption graph is expressed in terms of CDD or HDD, the vertical interception of the graph origin should be equal to the base energy consumption of the building. Considering that the base gas consumption of the building is gauged at about 5600 m³ (approximately 21,000 MJ), the cooling and heating temperature must be determined so that the vertical interception of the origin of the graph is equal to the base consumption.

Gas consumption during the cold months of the year in terms of the HDD is presented in Figure 2. The calorific value for the heating day in this chart is based on the temperature of 14°C. For calculating the day heating temperature with a heating base temperature of 14°C, the
| Year | Season | Gas consumption (m³) | Electrical consumption (kWh) | Temp. (°C) | CDD | HDD |
|------|--------|----------------------|-----------------------------|-----------|-----|-----|
| 2014 | Spring | 6543                 | 87,906                      | 17        | −48 | −90 |
|      |        | 19,460               | 69,426                      | 22.05     | 103.5 | −241.5 |
|      |        | 47,948               | 102,251.5                   | 27.75     | 274.5 | −412.5 |
|      | Summer | 51,547               | 108,251.5                   | 29.8      | 336  | −474 |
|      |        | 63,047               | 133,131                     | 28.4      | 294  | −432 |
|      |        | 44,478               | 112,611                     | 26.4      | 234  | −372 |
|      | Autumn | 26,590.0             | 119,096.5                   | 22.1      | 105  | −243 |
|      |        | 6099.0               | 86,336.5                    | 14.8      | −115.5 | −22.5 |
|      |        | 15,713.0             | 70,981.5                    | 8.9       | −292.5 | 154.5 |
|      | Winter | 22,961.0             | 75,541.5                    | 7.5       | −334.5 | 196.5 |
|      |        | 16,705.0             | 70,935.5                    | 7.7       | −328.5 | 190.5 |
|      |        | 5424.0               | 67,095.5                    | 13.2      | −162  | 24  |
| 2015 | Spring | 3608.0               | 87,545.0                    | 14.7      | −118.5 | −19.5 |
|      |        | 21,281.0             | 78,621.0                    | 22.8      | 124.5 | −262.5 |
|      |        | 50,802.0             | 116,676.5                   | 26.1      | 223.5 | −361.5 |
|      | Summer | 52,714.0             | 12,1164.2                   | 30.5      | 355.5 | −493.5 |
|      |        | 53,952.0             | 152,065.6                   | 29.8      | 336  | −474 |
|      |        | 44,622.0             | 134,413.6                   | 26.7      | 243  | −381 |
|      | Autumn | 28,439.0             | 105,868.4                   | 21.5      | 85.5  | −223.5 |
|      |        | 11,326.0             | 84,722.5                    | 16.1      | −75  | −63  |
|      |        | 11,668.0             | 74,432.9                    | 10.4      | −247.5 | 109.5 |
|      | Winter | 10,512.0             | 65,618.2                    | 10.7      | −237 | 99  |
|      |        | 23,356.0             | 80,957.8                    | 7.8       | −324  | 186 |
|      |        | 15,868.0             | 75,311.4                    | 12.3      | −190.5 | 52.5 |
| 2016 | Spring | 5437.0               | 78,954.4                    | 17.1      | −45  | −93  |
|      |        | 19,035.0             | 76,564.9                    | 22.4      | 112.5 | −250.5 |
|      |        | 39,499.0             | 117,831.9                   | 27.5      | 267  | −405  |
|      | Summer | 55,263.0             | 126,928.6                   | 29.7      | 333  | −471 |
|      |        | 47,403.0             | 116,366.1                   | 28.9      | 307.5 | −445.5 |
|      |        | 43,996.0             | 118,981.0                   | 25.3      | 201  | −339 |
|      | Autumn | 20,870.0             | 94,907.0                    | 21.1      | 75   | −213 |
|      |        | 7204.0               | 66,826.0                    | 14.7      | −117 | −21  |
|      |        | 18,079.0             | 56,730.0                    | 8.8       | −294 | 156  |
|      | Winter | 27,019.0             | 67,253.0                    | 8.2       | −312 | 174  |
|      |        | 21,551.0             | 70,394.0                    | 7.5       | −333 | 195  |
|      |        | 9963.0               | 63,891.0                    | 12.7      | −177 | 39  |

Abbreviations: CCD, cooling degree day; HDD, heating degree day.
vertical interception of the origin of the graph is 5656 m³ and is approximately equal to the base consumption. Also, the BLC based on the slope of Figure 2, is calculated by considering the efficiency of the heating equipment (80% boiler efficiency), as 26829 (W/K) by considering two air changes per hour (ACPH) in Equation (13).

To make clear, in accordance with Figure 2, if the HDD is plotted with two different heating temperature values, when the base temperature is lower, the HDD values are increased and the graph is moved horizontally to the right, and the base energy consumption decreases; for the temperature which is higher than the base, the values of the HDD is reduced, and the graph is moved horizontally to the left and the base energy consumption is increased. Therefore, reducing the HDD elicits increasing base consumption and also, and increasing the HDD, leads to reducing the base consumption, and ultimately the total energy consumption is estimated correctly. The CDD follows an identical trend.

The BLC, according to Figure 2, is calculated as:

\[
\text{Slope} = 76.9 \text{(m}^3/°C), \\
\text{BLC} = \left[\text{Slope} \times (\text{Gas LHV}) \times (\text{Boiler efficiency})\right] \times 24 \text{ h} \times 3600 \text{ s}, \\
\text{BLC} = \frac{(76.9 \times 37.65 \times 0.8)}{24 \text{ h} \times 3600 \text{ s}} = 26,829 \text{(W/K)}. \\
\]

(13)

The gas consumption during cold months based on the outside temperature is presented in Figure 3. This diagram crosses the horizontal axis (outside temperature axis) at a temperature of 13.4°C, which means the base heating temperature is 13.4°C, which is approximately consistent with the base temperature obtained from the HDD (14°C).

### 3.3 CDD calculation

Gas consumption during hot months of the year in terms of CDD is presented in Figure 4. The cooling temperature in this graph is 18.6°C. For the calculation of cooling with a cooling temperature of 18.6°C, the width from the origin of the graph is 5685.6 m³ and is approximately equal to the base consumption. Also, the load factor of the building based on the slope of the diagram, by considering the efficiency of the cooling equipment (boiler efficiency at 80%, COP of absorption chiller at 0.49) is measured in Equation (14) at 27,217 (W/K), which corresponds to the amount obtained from the energy consumption graph in terms of heating (26,829 W/K).

The gas consumption during hot months based on the outside temperature is presented in Figure 5. This chart crosses the horizontal axis (outside temperature
axis) at 18.5°C, which means the cooling temperature is 18.5°C, which corresponds to the base temperature obtained from the CDD (18.6°C) this means cooling is needed during the cooling period if ambient temperature reaches this value.

The BLC, according to Figure 5, is calculated as:

\[
BLC = \frac{\text{Slope} \times (\text{Gas LHV}) \times (\text{Boiler efficiency}) \times (\text{Chiller COP})}{24 \, \text{h} \times 3600 \, \text{s}}
\]

\[
BLC = \frac{(158.7 \times 37.8 \times 0.8 \times 0.49)}{(24 \, \text{h} \times 3600 \, \text{s})} = 27,217 \, \text{W/K}.
\]

The actual natural gas consumption of the building and the estimated consumption has been compared with each other according to the proposed baseline in Figure 6. As observed, gas consumption is estimated with high precision by the proposed baseline.
**Figure 7** Comparison of real and estimated calculating the gas baseline. CCD, cooling degree day; HDD, heating degree day.

**Figure 8** Electrical energy consumption

**Figure 9** Total energy consumption based on (A) HDD and (B) CDD. CCD, cooling degree day; HDD, heating degree day.
In Figure 7, the baseline presented based on the integrated method is compared with the actual amount of gas consumption in the cooling and heating period. The electrical energy consumption of the building based on ambient temperature is presented in Figure 8. As witnessed, it is almost constant at 17°C below the electric power consumption. The consumption has been calculated in terms of the share of electricity consumption in the heating system at about 3% and in the cooling at about 30%. The electrical energy consumption is almost constant at temperatures below 17°C (no cooling required).

The total energy consumption (electricity and gas) is presented throughout the heating and cooling period, according to the HDD and CDD in Figure 9A,B, respectively and, the real total energy consumption in tandem with the estimated consumption is compared in Figure 10. In this study, the basis for the total consumption of natural gas and electrical energy was prepared. The forward and reverse methods are the two main methods in this study for energy consumption analysis in buildings, in which the basis of the construction is presented based on the combination of these two methods.

As seen in Figure 11, applying these temperature figures to the building energy smart system as a temperature set-point that controls the volume and temperature of the air and water, comprising boilers, chillers, electro pumps, fresh-air conditioners, and end-users fan coils, reduces yearly energy consumption gently to 30% in 2019 compared to the base year 2016.

4 | CONCLUSION

This study underscored the application of the energy consumption model and benchmarks of a 10-story commercial building in Iran. Building information and energy-related data were gathered from the 3 years based on real values for developing the energy baseline model. According to ASHRAE Standard 55-2017, the thermal environmental conditions for human occupancy could range between approximately 67°F and 82°F (19–27°C). Undoubtedly, considering constant fixed temperatures for all buildings with different physical characteristics and weather conditions in different climates need to be assessed properly. In this study, forward and reverse methods have been integrated for building an energy model. In the forward method, building energy consumption is predicted according to building specifications, location, geometry as well as the type of air conditioning system. In the reverse method, the energy consumption is evaluated using typical building characteristics such as building load coefficient and building base consumption according to some effective factors such as weather data and appliance performance.

On the other hand, it is necessary to mention that even the base temperature for a particular building is not constant during the year and varies according to the weather conditions. Eventually, the natural gas and electricity consumption of the building baseline.
based on the proposed method was provided for cooling and heating periods. The energy consumption of the building owing to the implementation of base temperature to configure the energy management system setpoints denoted the validation of the method. The research revealed that using reverse and forward methods simultaneously can be effective not only in calculating the base building temperature, instead of considering constant fixed comfort temperatures such as 18°C, and 21°C for the HDD and CDD but also in the renovating stage to choose better materials to mitigate energy usage and obtain energy performance compliance. Also, thermal comfort is achieved by implementing a smart building energy management system using base temperature as an input set-point to start-up-down the system.

**NOMENCLATURE**

**ACRONYMS**

BLC building load coefficient (W/°C)
CDD cooling degree day (°C days)
HDD heating degree day (°C days)
HVAC heating, ventilation, and air conditioning

**PARAMETERS**

$A$ heat transfer surface area (m$^2$)
$C_p$ specific heat capacity (J/kg K)
$m$ mass flow (g)
$N_c$ the number of cooling days
$N_H$ the number of heating days
$U$ overall heat transfer coefficient (W/m$^2$ °C)

**GREEK LETTERS**

$\Delta T$ the difference in temperature (°C)

**VARIABLES**

$E_{base}$ base building energy consumption (J)
$E_{H/C}$ energy consumption during heating/cooling period (J)
$Q_{cooling}$ total cooling load (W)
$Q_h$ total heat generation/radiation (J)
$Q_{grad}$ ground loss (J)
$Q_{heating}$ total heating load (W)
$Q_{infiltration}$ heat infiltration/convection (J)
$Q_{grad}$ equipment and person heat generation (J)
$Q_{solar}$ solar heat supply (J)
$Q_{total}$ total heat (J)
$Q_{Transfer}$ heat transfer/conduction (J)
$T_b$ base temperature (°C)
$T_{in}$ indoor temperature (°C)
$T_{out}$ outdoor temperature (°C)

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