Calibrating Building Thermal Simulation Model Using Indoor Environmental Measurements

Dr. Shireen Alqadi [1,2]*, Dr. Amira Elnokaly [2] and Prof. Behzad Sodagar [3]

[1] Palestine Polytechnic University; University of Lincoln, shireenalqadi2020@gmail.com
[2] University of Lincoln; aelnokaly@lincoln.ac.uk
[2] University of Lincoln; bsodagar@lincoln.ac.uk

* Correspondence: shireenalqadi2020@gmail.com

Abstract: Dynamic Building Energy Simulation (DBES) modeling is a useful way to calculate the energy saving through retrofitting of the existing building stock. However, Professionals are concerned about the discrepancy between the calculated and actual energy savings which is known by the performance gap. Calibrating the DBES models is a crucial step before heading towards the optimization step. The existing standardized statistical indices depend on energy bills to perform the calibration. These indices are not easily applied in developing countries where a combination of fuels is sometimes used for heating. In this paper, the heating load in a single house in Hebron, Palestine was modeled as internal gain. Then the model was calibrated using internal environment measurements (internal temperature) that were taken through two monitoring phases for a single house in Hebron, Palestine. A validation method for a single house was presented using the internal temperature depending on the monitoring phases. The results show that the model was calibrated and can be used for optimization.

Keywords: Energy modelling, DBES Calibration, indoor environmental measurements, statistical indices.

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1. Introduction

Many of the developing countries face several challenges like fuel poverty, water scarcity and overheating due to climate change [1]. Despite that these are global challenges, they are more urgent in Palestine due to the political instability. In addition, urban growth and higher standards of living have raised the per capita energy consumption by 8.6% between 2007 and 2014 [2]. This was coupled with the absence of sustainable consumption of energy [3]. One of the main reasons behind the lack of sustainable consumption in the housing sector is the poor quality of housing in terms of thermal performance. The combination of these challenges has several implications for Palestinians. Lack of access to safe and affordable energy in the housing sector affects households' safety, wellbeing and decreases the chances of achieving thermal comfort.

During the last two decades, energy in the building sector received more attention from the government and related organizations. In 2004 the first Energy-efficient Buildings Code was published [4]. Then, in 2013, the Palestinian Green Buildings Guidelines (PGBG) were published [5], followed by constructing public buildings that were LEED-certified, such as the Palestinian Museum and the Abdelmuhsen Qattan Foundation building and Aqaba School, which both earned Palestinian Green Building Council Certification [6].

Due to its location, Palestine has a good potential to use renewable energy sources especially the solar energy as it lays in the north equator on the Mediterranean Sea [7]. This can help the country to overcome the problems of energy insecurity and affordability [8]. Shifting towards renewable energy should be proceeded by optimizing the energy consumed in buildings which can be performed using

Dynamic Building Performance Simulation (DBPS) [9]. In order to decrease the discrepancy between the real building and the simulated model, a calibration process is needed [10]. In this paper, a single house building is calibrated opposite to actual monitored temperature in Hebron, Palestine.

2. Calibration and validation of the simulation models

Several studies [11; 12] have reported discrepancies that of up to 100% differences between DBPS model-predicted and the actual monitored data. To improve the accuracy of the DBPS model results to determine meaningful energy conservation measures, calibration is needed [13]. The main goal is to approximate the DBPS model results to the real data as closely as possible [14].

Four main categories of calibration methodologies were presented by Reddy et al. (2007): manual; graphical-based; calibration based on special tests and analysis procedures and automated techniques [15]. The following is a brief explanation of each:

(a) Manual calibration methods based on an interactive approach rely on the users' experience and understanding of building physics [16]. This is one of the most common methods used for calibration [13; 16; 17; 18]. Although it is time consuming, this method incorporates human intelligence in the process of calibration [19].

(b) Graphical-based calibration methods rely on comparing time series plots. Apart from classical and time-series plots [20] and recently involved 3D Comparative Plots and calibration signature [16].

(c) Calibration based on special tests and analysis consists of short- or long-term monitoring combined with special tests, such as wall thermal transmittance measure or blower door tests (difficult to perform in occupied buildings) or other in situ tests [16].

(d) Automated techniques for calibration, based on analytical and mathematical approaches, which can be useful for non-expert users [19; 21].

3. Criteria of goodness to fit

Standardized statistical indices were proposed to assess the performance of a model to replace the previously used simple per cent ratio [16]. These later became international reference criteria for the validation of calibrated models, recommended by recognized bodies like ASHRAE [22].

- Mean Bias Error (MBE) (%) can be defined as the sum of errors between the measured (real) and simulated data and is a good indicator for the model's overall bias [23]. This is a non-dimensional bias measure (i.e. the sum of errors), which means that positive bias compensates for negative bias (the cancellation effect) and thus a further measure of model error is also required [13; 24]. The (MBE) can be calculated using Equation 1.

$$\text{MBE}= \frac{\sum_{i=1}^{n}(\hat{x}_i - x_i)}{\sum_{i=1}^{n} x_i} \quad , \qquad (1)$$

Where x, $\hat{x}$ are the sampled data and predicted data respectively; and n is the number of samples. An MBE of 0 suggests that there is no bias in the model and the accepted MBE value for calibration in ASHRAE must be within ±10% if the model was developed by using hourly data [22; 24].

- Root Mean Square Error (RMSE) (%) is a measure of average deviation from the true value [23]. It is a non-dimensional bias measure and can be only calculated if the true values (the monitored data) are available [23]. For every point, the error (difference) is calculated and squared, then the sum of squares errors (SSE) is added for the total periods and divided by the number of points, giving the mean squared error (MSE) [13]. The root mean squared error (RMSE) is the square root of the MSE [13] and can be calculated using Equation 2.

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(\hat{x}_i-x_i)^2}{n-1}} \quad , \qquad (2)$$

Where x, $\hat{x}$ are the sampled data and predicted data respectively; and n is the number of samples. This metric can range between 0 and ∞, where a lower value is desirable [24].

- Coefficient of Variation of Root Mean Square Error CV(RMSE) (%) is a statistical measure that determines how well a model fits the data by capturing the errors between measured and simulated data and does not suffer from the cancellation effect [13]. It identifies total uncertainty in the prediction of the model, reflecting the errors' size and the amount of scattering [16]. Lower values are desirable in this metric [24].

$$\text{CV (RMSE)} = \frac{\text{RMSE}}{\bar{x}} \quad , \qquad (3)$$

Where $\bar{x}$ is the mean of the sampled data. Global organizations such as ASHRAE, IPMVP, and FEMP have set their own standards for two of the previous measures of the baseline model, which are as follows for the hourly criteria (%) in Table 1.

Table 1 Protocol for calibration of DBPS models

Standard	MBE%	CV(RMSE)%	Source
ASHRAE Guideline 14	10	30	(ASHRAE, 2002)
IPMVP	5	20	(EVO, 2007)
FEMP	10	30	(US DOE, 2008)

Generally, energy simulation models for predicting energy consumption are considered 'calibrated' if they meet the criteria set out by ASHRAE Guideline 14 [22]. However, several models for the same building can meet these criteria and be considered calibrated. The following section explains the calibration method of the two buildings.

4.The building characteristics and system used

The building is a two-storey single house building with a net floor area of 240m2 and a ceiling height of 3.2m. It was selected as it is a model of the single house building typology in Hebron. The house is occupied by 3 adults. The house was built in 1993 using contemporary building materials and technologies at that time. Most of the ground floor is an open plan area, which consists of reception, salon, dining room, kitchen, WC, guest room and a sunroom. The second floor comprises three bedrooms, two living rooms and two bathrooms. Figure 1 shows the ground and the first-floor plans of the single house.

Since the building envelope was made of concrete, concrete hollow blocks and stone (which all have high durability), minimum maintenance had taken place since the house was built. Thermal insulation was used in the western façade, which faces the dominant wind during winter. Most of the windows of the house are 2.0 x 2.2m2 with aluminium frames and single glazing. External shutters and internal curtains are used to control the internal environment.

The building is naturally ventilated all day during summer. During winter, it is naturally ventilated for certain hours during the day and occupied spaces are heated during the day. A combination of energy sources is used to heat the house i.e. electricity and LPG.

Figure 1. Ground and first floor plans of 1 the single house building

5.Method

The method used for data collection comprised of:

5.1 Semi-structured interview with the household

In order to have a comprehensive picture of the households' behaviour, extensive interviews took place, concerning the behaviour of the household such as typical occupancy periods, and adaptive measures used such as the patterns of opening and closing windows and the patterns of using heating and cooling systems. This data was used later to develop the profiles used for modelling as explained in section 6.3, 6.4 and 6.5.

5.2 Environmental measurement and longitudinal monitoring

Calibrated Extech RH10 loggers (±0.1°C) were used as part of the monitoring phase to assess the actual operational performance of the dwellings [25]. The data loggers comprised a sensor part and a record system that saves the readings. Three data loggers were used for monitoring, two inside the dwellings and one outside. The Extech RH10 loggers recorded the indoor air temperatures and relative humidity (RH) in the living rooms, as well as outdoor air temperature and (RH). The data loggers were named and a time interval of 5 minutes was set for each. Five minutes is the shortest period between the two readings. It was set to this time interval to increase the total number of readings that were used for calibration later on. The data loggers were set about 150 cm above the ground and away from any direct sources of heat or sunlight. They were also concealed to decrease their effect on the households' behaviour. Due to the limited number of available data loggers, only one data logger was used outside. It was set on a windowsill of the single house on the northern façade, away from direct sunlight. The data loggers were in USB form and the readings were downloaded manually onto a computer.

In this kind of research, a longitudinal approach is highly recommended to spread the data across time [26; 27]. Since the collected data will be used to calibrate the model developed using

IESVE, the longitudinal approach was adopted and monitoring covered two periods. The first reading set was collected between 12th October and 1st November 2017, while the second set was collected between 28th January and 24th February 2018. After each monitoring period, the data loggers were collected and the monitored data downloaded into an Excel sheet.

5.3 Creating a weather file for Hebron

Climate is a key factor that defines the energy performance of a building. In order to use DBPS for predicting energy demand, weather files are needed for the location of the assessed building [28]. Weather files are samples of real weather data taken from a certain period that have similar average weather parameters to the actual but it is not the average of weather parameters over a certain period [29]. The simulation weather files can be sourced from various places like Weathershift, CIBSE 2016 Weather Files, Meteonorm, Australia Weather Files, Agrément South Africa or EnergyPlus Weather Files (EPW) [30]. In this paper, the validation of the building energy simulation model, a weather file that represents the exact weather conditions of the context is needed. Accordingly, weather data for the period between March 2017 and February 2018 was obtained for Hebron from the Palestinian Metrological Department on the 20th/March/2018 [31]. The main goal was to create a weather file based on formal measured data representing the actual weather in the context during the monitoring periods that cover the two periods of monitoring.

6. Developing (IESVE) Dynamic Building Energy Performance Simulation model

The detailed modelling encompasses geometric modelling of the buildings, the physical characteristics of the building envelope, the profiles of heating, cooling, lighting and appliances, occupancy of the users and the opening and closing of the internal and external windows, as will be explained in the following sections.

6.1. Creating the geometric models and exporting them to IESVE software

Using the Revit software, the buildings' geometry was considered in relation to the surrounding buildings, as seen in Figure 2. The model was then exported in gbXML (Green Building XML), a format that facilitates the transfer of information from the Building Information Models (BIM) to building performance analysis platforms like IESVE and the export was performed as per Autodesk (2018). Every interior space was defined as a room. All the shading devices were identified, including surrounding buildings. The location of the buildings was assigned based on Hebron latitude longitude coordinates: 31°31'45.66"N, 35°5'37.68"E. The previously developed weather file was allocated for the two models so that the models perform under the same climatic conditions of the real world.

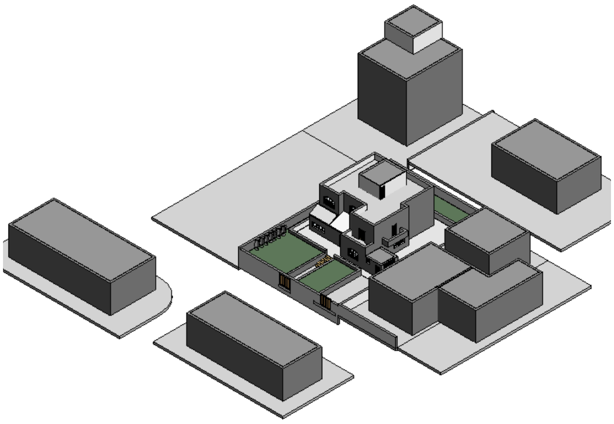


Figure 2. Geometry in Revit

6.2.Assigning building materials

Based on the data collected during the site visits as explained, the building materials of the envelopes were defined. The materials' characteristics were assigned based on the local materials specifications in the Building Energy Efficiency Code [32]. There were no guidelines before 2004 and no specifications were available, hence the most compatible guidelines with the modeled building was used. The full details of the materials like conductivity, density, specific heat capacity, resistance and vapour resistivity, in addition to the U value and thermal mass k of the buildings' envelopes, can be seen in Table 2.

Table 2 Building's components specifications

Building component	Configuration (cm)	U value (W/m²k)	Thermal mass (kg/(m².K)
External walls	Stone 15, concrete 15, concrete hollow blocks 7, plaster 1.5	1.5	160
Ground	Reinforced concrete20, concrete baking8, sand 5, mortar 2, concrete tile 2	1.5	175.7
Roof	Waterproof membrane 0.3, concrete baking 8, bricks and ribs 17, plaster 1.5	1.7	108.4
Ceiling	Concrete tiles 2.5, mortar2.5, sand 2.5, concrete baking 8, bricks and ribs 17, cement plaster 1.5	1.3	108
Internal walls	Plaster1.5, concrete hollow blocks 7, plaster1.5	2.4	66.8
External doors	Iron 0.5, cavity 2 , iron 0.5	4.2	---
Glazing (g) value 0.5, transmittance (T) 0.7	Single glazing	5.7	---

6.3. Assigning the heating and cooling systems

In the IESVE the ApacheSim is a dynamic thermal simulation program that uses first-principles mathematical modelling of the heat transfer processes occurring within and around a building [30]. Assigning the thermal conditions for the ApacheSim in the IESVE include defining the system, space condition, internal gains, air changes and building regulations. Since there is a discrepancy between occupancy and the (HC) profiles of the rooms, a separate thermal condition was defined for each of them. When defining the rooms' conditions, it was not possible to assign the individual heaters and fans used by the households in the IESVE models. After consulting the IESVE support team, they advised to consider the (HC) systems in these building as though they are continuously off and to add the heating systems as internal gains and the cooling load as a heat loss instead [30]. For this research, the (HC) loads were termed miscellaneous gains. The (HC) loads were calculated based on the voltage of systems and usage period. In addition, other internal loads were assigned for each room based on data from the physical survey and the semi-structured interviews. These internal gains included the lighting, people and appliances. At steady-state conditions, and based on the conservation of energy principle, the total heat output is equal to the total power input [33]. Although the cases here are not in steady-state conditions, the researchers assumed that the input energy is equal to the output. Moreover, the efficiency of the system is beyond the scope of this research and hence the output was defined based on watt-hour calculations. These were obtained from the system's manuals and the duration of usage as expressed by the households.

There are not any studies quantifying the infiltration rate in buildings in Palestine. Hence, the air exchange rate that was assumed by this study was the infiltration of 3.0 ach since the air exchange due to natural ventilation was assigned in the Macro-flow section. This value was assigned following consultation with the IESVE support team [30]. This value is not far from what the Palestinian Green Building Guidelines recommend which is 2.7 ach [32].

6.4. Assigning the users' occupancy profiles

There are four implementation approaches to occupants' behaviour models: (i) direct input where the user defines and inputs temporal schedules; (ii) Built-in Occupants behaviour (OB) models where the user selects one of the built-in models; (iii) the user function in which the user behaviour is modelled by writing functions or custom code; and (iv) co-simulation, which allows certain components to be simulated by different simulation tools running simultaneously [33]. In IESVE, user behaviour is modelled using direct input, just as other model inputs like building materials and geometry [34].

There are two general approaches when modelling the occupancy pattern in the residential sector: the individual approach and the family approach. The first approach obtains occupancy data based upon national survey data of people's time-use distributions, while the second relies on data regarding a family's schedule, based on the most common household occupancy patterns [35]. Because tracking down detailed information for the individual occupant is difficult, the 'family' approach is adopted in this study.

The usage of the rooms, heating and cooling systems, appliances and pattern of window-opening in each dwelling was discussed during the interview with the households in order to establish an occupancy profile. The interview revealed that the rooms were occupied for different periods. Besides the appliances, the heating and cooling systems and the opening of the windows (natural ventilation) were used in different patterns.

The occupancy patterns are generally affected by the number of users and the lifestyles which defines the time a person wakes up in the morning, the time spent at home and the time the person goes to bed [34]. Based on Aerts et al. (2014), there are three realistic possible occupancy states: (1) at home and awake (active); (2) sleeping (non-active); or (3) absent . Based on that, Figure 3 illustrates the pattern of using the building [36].

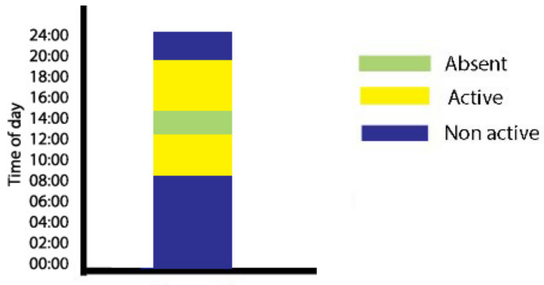
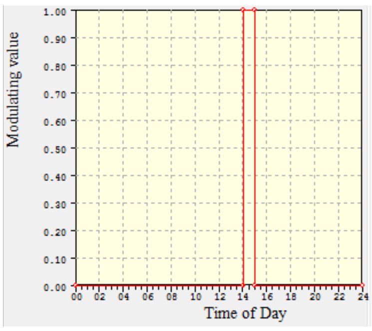
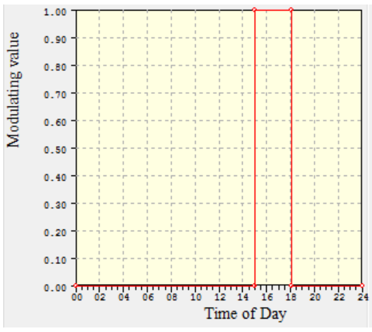


Figure 3. Occupancy profiles in the building

During a typical day, the ground floor is occupied by one member of the household during the day, while in the evening the household members move to the first floor. A separate occupation profile was used for each of the reception, sunroom, kitchen, living room and bedrooms. At night, three bedrooms are occupied. Since the other rooms' usage is for very limited periods, the occupancy of these spaces is neglected. The daily occupancy profile of each of these rooms is shown in Figure 4



(a)



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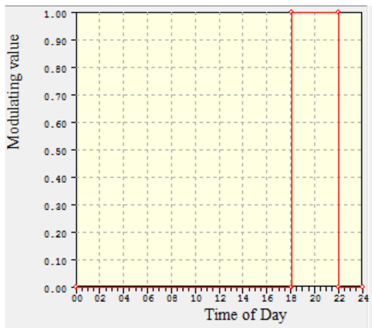
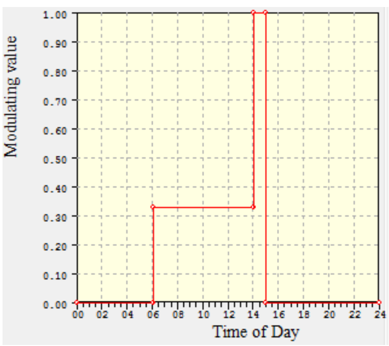
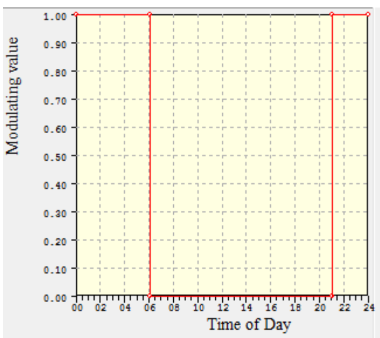


(c)



(d)



(e)

Figure 4. The occupancy profiles for the rooms in the(a)living room, (b)reception, (c)sunroom, (d) kitchen and (e) bedrooms

6.3. Assigning the heating, cooling and internal gains profiles

The heaters were on during the months indicated by the households (15th November-30th April) and were off during the rest of the year. The different heating systems were assigned based on the data gathered from the interview. The wattage was assigned from the manual. Since two elements are used for an hour on a typical winter day, the total wattage is 1200W in this case.

Internal gains were specified in the model according to the pattern of use as indicated by the household in the interview. The main source of lighting in all the rooms was florescent, estimated at 17W/m2. The profile of daily use was developed in the model based on the interviews. The lights were on usually between 17:00-20:00 in the occupied rooms.

There are three TV units in three different rooms (sunroom, reception and living room). Each of the TV units has a wattage of 100W. In the IESVE model, three different working schedules were developed for each TV unit depending on the usage. In the kitchen, the fridge is permanently on, and the household uses an LPG cooker which depends on Blue LPG cylinders of butane. The family indicated the cooker is used usually for 2 hours a day between 12:00 and 14:00. The maximum sensible gain from the users was assigned as 90W/person while the minimum latent gain is 60W/person. The number of persons was assigned depending on the space.

7. Calibration

Since more than one energy source is used for heating, it was not useful to collect the energy bills. No energy meter readings were involved so the calibration of the models was based on the internal monitored temperature. This approach was used in other similar research where energy readings were not available [17; 37]. There are no specific standards for calibration using the measured temperature. Research-based on calibrating buildings' temperature behaviour relies on the same energy validation protocols, rather than on specific temperature ones [17].

The uncertainty in the DBPS models was classified into four main sources by de Wit and Augenbroe (2002): (i) specification uncertainty (inaccurate system or building specification), (ii) modelling uncertainty (simplification of complex physical processes), (iii) numerical uncertainty (errors during simulation process) and (iv) scenario uncertainty (related to external conditions)[38]. As the researcher has no control over the modelling and numerical uncertainties, the goal was to decrease the first and the fourth effect on the simulation results. During the interviews, the households described their typical day in both summer and winter. Using the obtained data, the heating and cooling loads, occupancy profiles, heating and cooling and natural ventilation and the other system profiles were developed and input. In addition, local weather parameters were collected from Hebron weather station and a weather file was developed to reflect the actual climatic conditions that affected the building performance during the monitoring phase. Hence, this source of uncertainty was minimised.

The other source of uncertainty was the specification uncertainty. Regarding the external input data (i.e. assigned by the user and not embedded in the software), Macdonald (2002) suggested three distinct methods that can be used for calibration: changing one parameter at a time; changing one set of parameters at a time; or changing all the parameters at the same time. The last method is known as the Monte Carlo method [39]. In this research, the manual calibration approach was adopted and one parameter was changed at a time, which is simple and valid for calibration [17]. For calibrating the models, the U value of the external walls and the infiltration rate was used to calibrate the models. Although there are a lot of other factors that can affect the simulation results like the solar radiation, U and g values of the glazing, the colour of the envelope.

Three rounds of calibrations were done for the whole year focusing on the impact of two major parameters: the U value of the external walls and the infiltration rate of the windows. The model was calibrated based on the monitored internal temperature profiles (baseline temperature). For the living room on the first floor, the monitored data covered the period between 12th October and 1st November and in the sunroom on the ground floor between 28th January and 24th February. For this, building materials characteristic values were inputted using the local Energy Efficient Building Code [32] as it includes local building materials' characteristic values like conductivity and density. Other values were input based on the operator's judgment and experience, such as the infiltration rate. In the first round, all users, lighting and equipment schedules are inputted as they have been communicated or observed. In the second round, the envelope (external walls U-value and thermal mass) was increased by increasing the conductivity rate and density based on the value limits presented in the local Energy Efficient Building Code [32]. Since the thickness of the walls was measured during the physical survey, it was considered constant and unchanged during the calibration process. Table 3 shows the external walls' conductivity, density and U values, which were changed in the second round of simulation.

Table 3. External wall thermal characteristics used in the calibration of case 1

		Stone	**Concrete**	**Concrete blocks**	**Plaster**
Conductivity	Round 1	1.1	1.0	0.7	0.25
	Round 2	1.75	1.85	1.0	0.7
Density (kg/m^3)	Round 1	2500	2000	1400	1500
	Round 2	2700	2600	1600	1850
U value (W/m^{2}k)	Round 1	1.7			
	Round 2	2.5			
Thermal mass (J/K)	Round 1	*709.7kg/m^2*			
	Round 2	*788.5 kg/m^2*			

In the third round, the infiltration rate was increased from 3 to 5 ach and the MBE, RMSE and CV(RMSE) were calculated for each of the rounds. Table 4 presents the three calibration rounds including these values for each of the calibrated rooms and the overall weighted value.

Table 4. Characteristics of the three calibration rounds for the calibrated rooms for case 1

		Calibration characteristics		
		Round 1 (red)	*Round 2 (green)*	*Round 3 (blue)*
		HL 4.9 kWh *CL 0* *U value 1.7* *Mass 788.5 kg/m²* *Infiltration rate 3 ach*	*HL 4.9 kWh* *CL 0* *U value 2.5* *Mass 709.7kg/m²* *Infiltration rate 3 ach*	*HL 4.9 kWh* *CL 0* *U value 1.7* *Mass 709.7kg/m²* *Infiltration rate 5 ach*
Living room (n= 4046*)*	*NMBE*	-3.78%	-4.01%	1.02%
	RMSE	1.616504	1.558926	1.577039
	CV(RMSE)	8.581455	8.275794	8.37195
Sunroom (n= 2908)	*NMBE*	-10.70%	-9.70%	-2.10%
	RMSE	1.119067	1.106221	2.884535
	CV(RMSE)	26.43174	25.08063	23.09135
weighted	*NMBE*	-1.64%	-1.73%	0.413%
	RMSE	1.327083	1.295531	2.337771
	CV(RMSE)	18.96717	18.05324	16.93604

In the first round, the simulated temperature in both the living room and the sunroom was considerably warmer or colder than the recorded ones, as shown in Figures 5 and 6. In round two, the U value of the external walls was increased. Figure 5 shows that in the living room the second round of simulation matched the recorded temperature in the periods 13th-18th and 23rd-27th October and 29th October-1st November 2017. In the sunroom, the second simulation matched the recorded temperature between 20th and 24th February 2018. In the third round, the infiltration rate was increased from 3 to 5 ach and the simulated living area showed good values as the number of matching values with the recorded temperature increased, whereas the sunroom was still not in the acceptable range as seen n Figure 6. Nevertheless, the weighted indices of the two rooms are within acceptable ranges (16.9 for CVRMSE and 0.41 for NMBE). Based on these statistical metrics, the model can be considered calibrated. However, this should be considered during the optimization step.

The validation process included modifying the envelope U-values and increasing the infiltration rate. Figures 7 and 8 compare the monitored with the dry bulb temperature and the simulated temperature. In the living room, the simulated temperature is mostly higher than the dry bulb outdoors temperature at night and lower than the ambient temperature in the daytime in several days during the period between 12th October and 1st November. In the sunroom during the first half of the monitoring period (28th January-10th February), the internal temperature was lower than the dry-bulb temperature and higher than or equal to the dry-bulb temperature in the second part of the monitoring period. Moreover, in both the living area and the sunroom, peak simulated temperatures are mostly higher than the monitored ones. This should be considered during optimization of this model, as the actual results can be lower than the simulated after retrofitting.

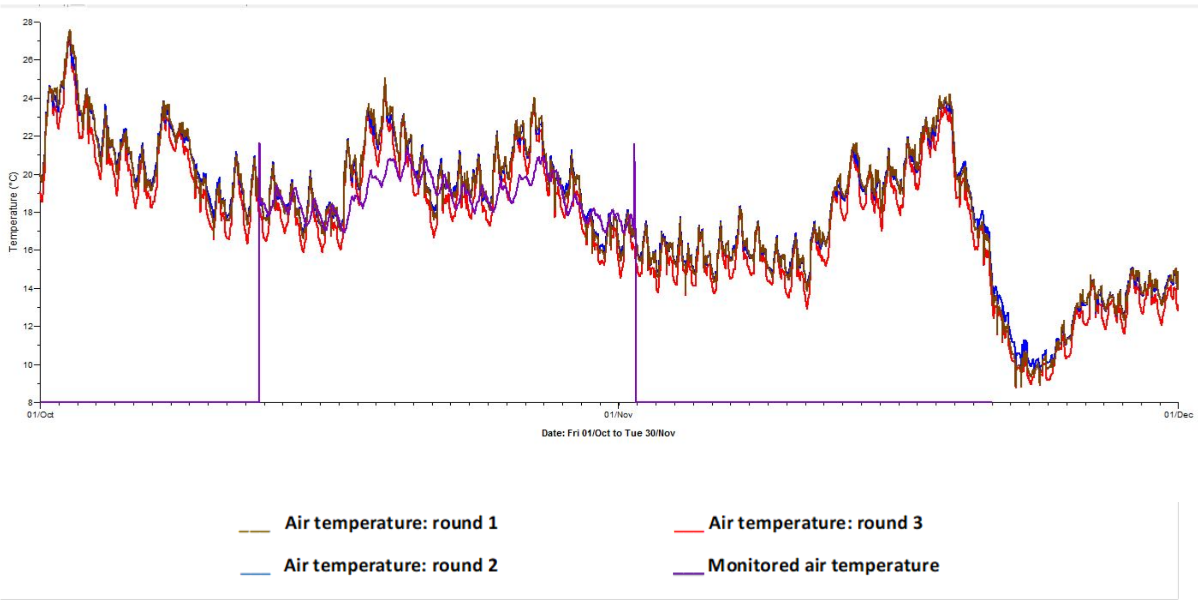


Figure 5. Simulation results of the three rounds and the monitored temperature in the living room for the period 12th October-1st November/2017

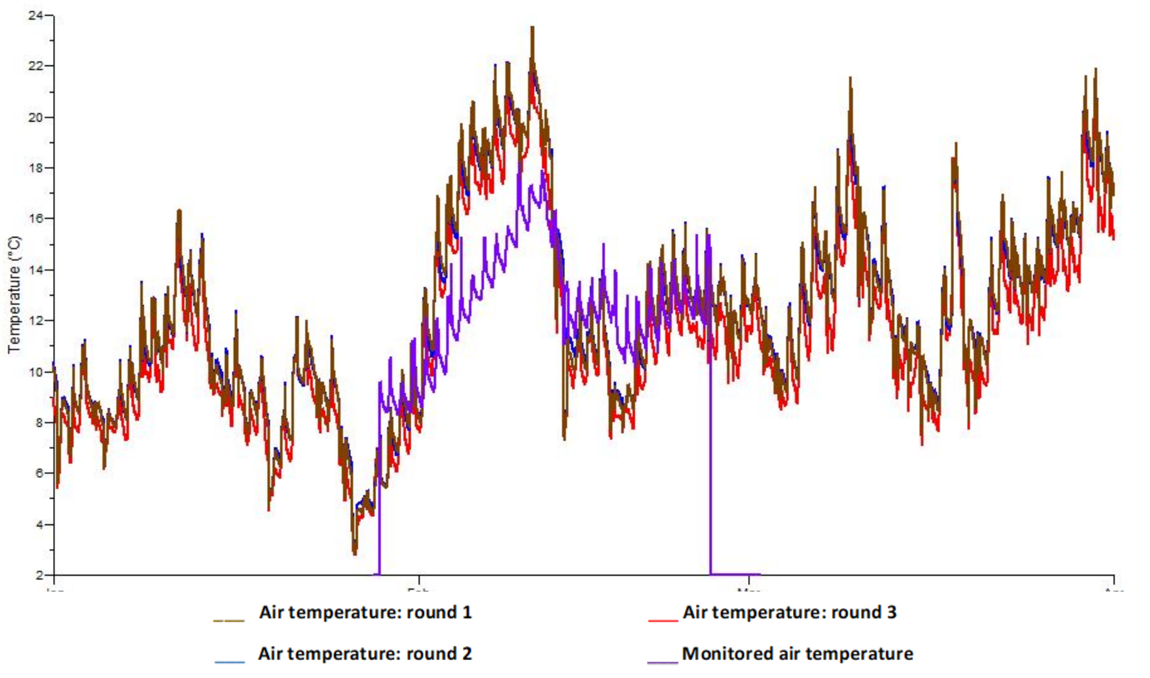


Figure 6. Simulation results of the three rounds and the monitored temperature in the living room for the period 12th October-1st November/2017

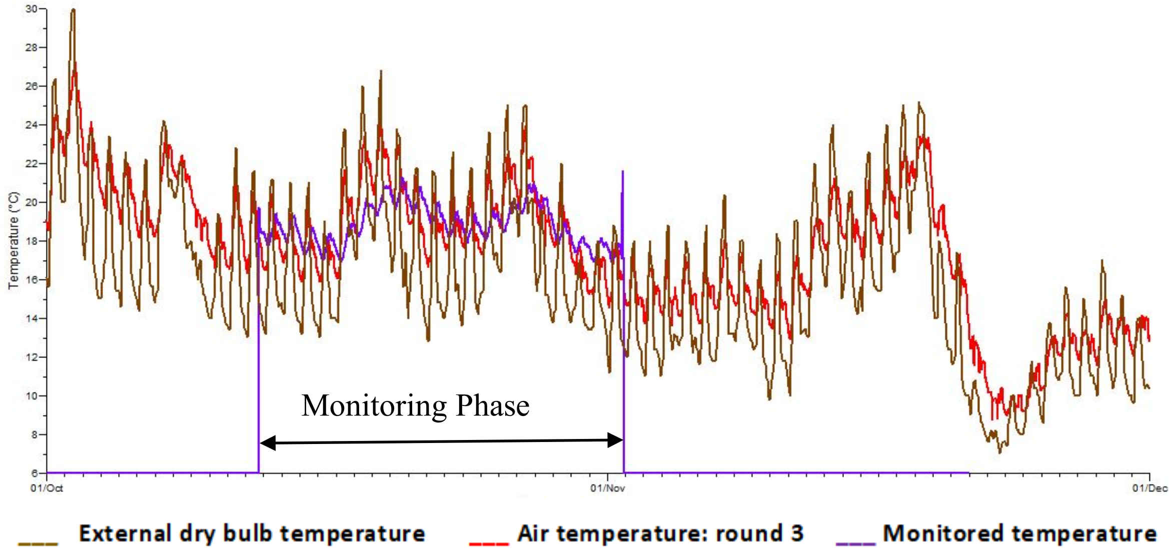


Figure 7. Simulation results of the third round in the living room, the monitored temperature and the external temperature for the period 12th October-1st November/2017 (Case 1)

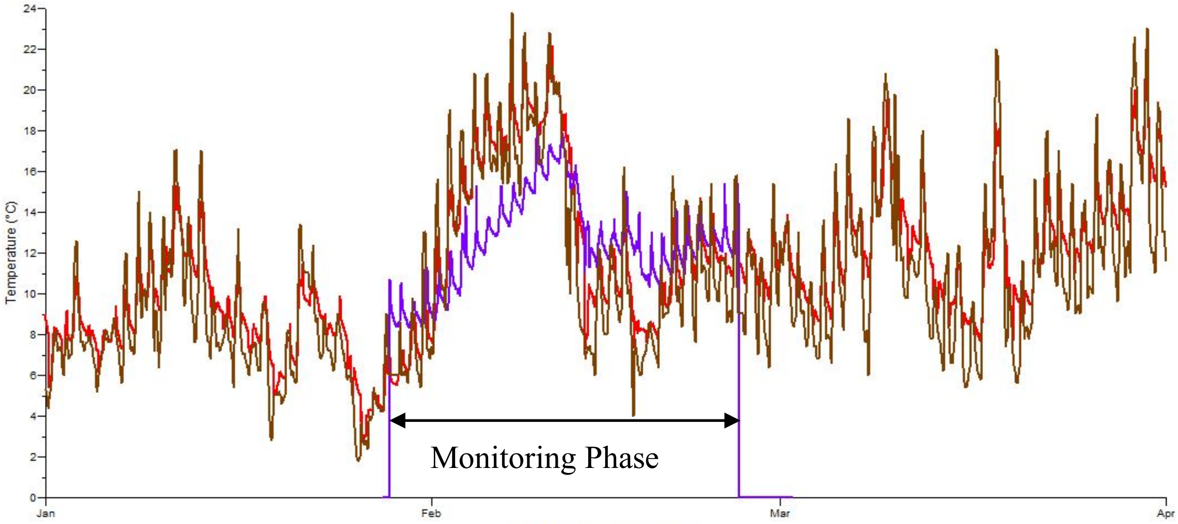


Figure 8. Simulation results of the third round in the sunroom, the monitored temperature and the external temperature for the period 28th January-24th February/2018

8. Conclusion

There is an urgent need to improve the energy efficiency of the existing building stock around the world to confront climate change and to respond to the energy prices. DBPS are essential tools to predict energy savings through energy optimization. However, calibrating these models is essential to calculate valid energy savings through retrofitting. The existing Standardized statistical indices which are the international reference criteria for the validation of calibrated models depends merely on energy bills. In certain contexts, like in the developing world, there is a need to use a combination of energy sources or to use certain types of informal fuels, calibrating the models through the energy bills is inapplicable. In this paper, a validation method for a single house in Palestine was presented using the internal temperature depending on two monitoring phases. The results show that the model was calibrated and can be used for optimization later on. The paper contributes to knowledge in the field by making available a calibrated model for use in this region, where there is a clear lack of studies. To generalize this method, more cases are needed to be calibrated using the internal environment measurements. Moreover, statistical indices should be developed for DBPS models depending on the internal environment measurements to be used when the energy bills calibration method is inapplicable.

References

1. Al Qadi, Shireen Bader, Elnokaly, Amira and Sodagar, Behzad (2017) Predicting the energy performance of buildings under present and future climate scenarios: lessons learnt. In: First International Conference on Climate Change (ICCCP), 5-8 May 2017, Palestine.
2. PCBS (2017) Selected energy Performance Indicators in Palestine, 2014-2017. Available from http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/energyEfTS-2017-7E.html [accessed 16 February 2019].
3. Al Qadi, Shireen, Sodagar, Behzad and Elnokaly, Amira (2018) Estimating the heating energy consumption of the residential buildings in Hebron, Palestine. Journal of Cleaner Production, 196 . pp. 1292-1305. ISSN 0959-6526
4. PEA, P. (2004) Energy efficient Buildings Code. Available from https://www.paleng.org/wpcontent/uploads/2015/09/Energy%20Effecient%20Building%20Code.pdf [accessed 21 January 2019].
5. PEA, P. (2013) Palestinian Green Buildings Guidelines. Ramallah. Available from https://www.researchgate.net/publication/262915250_Palestinian_Green_Buildin gs_Guidelines [accessed 21 January 2019].
6. PEA, P. (2019) Green buildings projects. Available from https://www.paleng.org/?p=2746 [accessed 11 March 2019]
7. Juaidi, A., Montoya, F., Ibrik, I. and Manzano-Agugliaro, F. (2016) An overview of renewable energy potential in Palestine. Renewable and Sustainable Energy Reviews. Available from http://Renewable and Sustainable Energy Reviews [accessed 23 January 2019].
8. Al Qadi, Shireen and Alrjoub, M. (2011) The Economics of Solar Energy, Solar Energy in the Palestinian Schools. In: The 4th International Energy Conference, Engineers Association - Jerusalem Center. Ramallah: Engineers AssociationJerusalem Branch
9. Clarke, J. (2015) A vision for building performance simulation: a position paper prepared on behalf of the IBPSA Board. Journal of Building Performance Simulation, 8(2) 39-43.
10. Cacabelos, A., Eguía, P., Febrero, L. and Granada, E. (2017) Development of a new multi-stage building energy model calibration methodology and validation in a public library. Energy and Buildings, 146, 182-199.
11. Karlsson, F., Rohdin, P. and Persson, M. (2007) Measured and predicted energy demand of a low energy building: important aspects when using Building Energy Simulation. Building Services Engineering Research and Technology, 28(3) 223- 235.
12. Scofield, J. (2009) Do LEED-certified buildings save energy? Not really…. Energy and Buildings, 41(12) 1386-1390.
13. Coakley, D., Raftery, P. and Keane, M. (2015) Corrigendum to "A review of methods to match building energy simulation models to measured data" [Renew. Sustain. Energy Rev. 37(2014) 123–141]. Renewable and Sustainable Energy Reviews, 43, 1467

14. Raftery, P., Keane, M. and Costa, A. (2011) Calibrating whole building energy models: Detailed case study using hourly measured data. Energy and Buildings, 43(12) 3666-3679.
15. Reddy, T., Maor, I. and Panjapornpon, C. (2007) Calibrating Detailed Building Energy Simulation Programs with Measured Data—Part II: Application to Three Case Study Office Buildings (RP-1051). HVAC&R Research, 13(2) 243-265.
16. Fabrizio, E. and Monetti, V. (2015) Methodologies and Advancements in the Calibration of Building Energy Models. Energies, 8(4) 2548-2574.
17. Saleh, P., Schiano-Phan, R. and Gleeson, C. (2018) Heavy Weight Thermal Calibration and Validation Methodologies: from Modelling to Full Scale Built Test Cells in Lebanon. In: 4th Building Simulation and Optimisation Conference, Cambridge, UK
18. Wainer, G. and Qi Liu (2009) Tools for Graphical Specification and Visualization of DEVS Models. SIMULATION, 85(3) 131-158.
19. Chaudhary, G., New, J., Sanyal, J., Im, P., O'Neill, Z. and Garg, V. (2016) Evaluation of "Autotune" calibration against manual calibration of building energy models. Applied Energy, 182, 115-134.
20. Pedrini, A., Westphal, F. and Lamberts, R. (2002) A methodology for building energy modelling and calibration in warm climates. Building and Environment, 37(8-9) 903-912.
21. Monetti, V., Davin, E., Fabrizio, E., André, P., & Filippi, M. (2015). Calibration of Building Energy Simulation Models Based on Optimization: A Case Study. Energy Procedia, 78, 2971–2976.
22. ASHRAE (2002) ASHRAE Guideline 14-2002: Measurement of Energy Demand and Savings. Atlanta, GA: ASHRAE.
23. Cimbala, J. (2011) Basic Statistics. Penn State University. Available from https://www.mne.psu.edu/cimbala/me345web_Fall_2014/Lectures/Basic_Statistic s.pdf [accessed 19 October 2018].
24. Chakraborty, D. and Elzarka, H. (2017) Performance testing of energy models: are we using the right statistical metrics?. Journal of Building Performance Simulation, 11(4) 433-448.
25. Extech, A. (2018) RHT10: Humidity and Temperature USB Datalogger | Extech Instruments. Available from http://www.extech.com/display/?id=14707 [accessed 8 October 2018].
26. Azizi, N., Wilkinson, S. and Fassman, E. (2015) do occupants in green buildings practice better energy saving behaviour in computer usage than occupants in conventional buildings?. Journal of Green Building, 10(4) 178-193.
27. Bros-Williamson, J., Garnier, C. and Currie, J. (2016) A longitudinal building fabric and energy performance analysis of two homes built to different energy principles. Energy and Buildings, 130, 578-591.
28. Jentsch, M., Bahaj, A. and James, P. (2008) Climate change future proofing of buildings—Generation and assessment of building simulation weather files. Energy and Buildings, 40(12) 2148-2168.
28. Tiwari, P. (2000) Architectural, Demographic, and Economic Causes of Electricity Consumption in Bombay. Journal of Policy Modeling, 22(1) 81-98.

30. IESVE (2018) About IES | Integrated Environmental Solutions. Available from http://www.iesve.com/about [accessed 15 October 2018].
31. Palestine Meteorological Deportment (2018) Hebron Historic weather data [email]. Sent to S. Alqadi, 20th/March/2018
32. Palestinian Ministry of Local Government (2004) Cost Efficiency Of Thermal Insulation

33. Evren, M., Özsunar, A. and Kılkış, B. (2016) Experimental investigation of energy-optimum radiant-convective heat transfer split for hybrid heating systems. Energy and Buildings, 127, 66-74
34. Hong, T., Chen, Y., Belafi, Z. and D'Oca, S. (2017) Occupant behavior models: A critical review of implementation and representation approaches in building performance simulation programs. Building Simulation, 11(1) 1-14.
35. Ren, Z., Foliente, G., Chan, W., Chen, D., Ambrose, M. and Paevere, P. (2013) A model for predicting household end-use energy consumption and greenhouse gas emissions in Australia. International Journal of Sustainable Building Technology and Urban Development, 4(3) 210-228.
36. Aerts, D., Minnen, J., Glorieux, I., Wouters, I. & Descamps, F. (2014), 'A method for the identification and modelling of realistic domestic occupancy sequences for building energy demand simulations and peer comparison', Building and Environment 75, 67–78.
37. Paliouras, P., Matzaflaras, N., Peuhkuri, R. and Kolarik, J. (2015) Using Measured Indoor Environment Parameters for Calibration of Building Simulation Model- A Passive House Case Study. Energy Procedia, 78, 1227-1232
38. de Wit, S. and Augenbroe, G. (2002) Analysis of uncertainty in building design evaluations and its implications. Energy and Buildings, 34(9) 951-958.

39. Macdonald, I. (2002) Quantifying the effect of Uncertainty in building simulation. PhD