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Evaluation of Basement's Thermal Performance against Thermal Comfort Model at Hot-arid Climates, Case Study (Egypt)

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Abstract

Reaching thermal comfort levels in hot-arid climates is becoming more difficult nowadays without the use of high energy consuming mechanical systems. Therefore, the need to use effective passive energy design techniques, such as earth-sheltered buildings, is becoming greater.

This paper describes research, that uses monitoring and simulations, to evaluate basements' thermal performance, which reached thermal comfort levels without active air-conditioning systems, despite the harsh climate conditions. The case study was conducted in Al Minya city, Egypt, which is known for its high diurnal range. The study calibrated a non-conditioned basement simulation model versus the monitored data to simulate its thermal performance. The greatest challenge was to calculate the ground temperature. To do this successfully, we used an iterative approach between packages of the Basement preprocessor and EnergyPlus/Designbuilder until reaching a convergence.

The iterative method results showed significant agreement, between the measured and modeled data, with a correlation of 98 percent, and errors with mean bias error and normalized root mean square error of -1.0 and 7.6 percent, respectively. On the other hand, the EnergyPlus method, integrating the Xing approach, showed significantly divergent results between the simulated models versus the measured data. The calibrated model analysis evaluation, using the Fanger's thermal comfort model, showed satisfactory results within the thermal comfort sensation range.

The research results significance indicates that the precise customized detailed iterative method is essential to create the needed inputs which subsequently lead to near-to-actual outputs compared with other ground-contact simulation methods. In fact, the precise customized detailed iterative method approach may be used as a benchmark for simulators for easy and precise ground temperatures' calculations and earth-sheltered buildings' simulations.

Keywords

Thermal comfort; Basements' Evaluation; Ground Temperature Calculation; Hot-arid Climates

1. Introduction

Earth shelters can be defined as: "structures built with the use of earth mass against building walls as external thermal mass, which reduces heat loss and maintains a steady indoor air temperature throughout the seasons" (Anselm

2012). With regards to that principle, we might consider the basements as one kind of the earth sheltering technique (Hassan and Sumiyoshi, 2017; Heba, 2012; Ismail, Heba, Arima, Ahmed & Akashi, 2013).
Carmody and Sterling analyzed the effect of Earth integration on heating and cooling in a conceptual way, for winter and summer performance. Moreover, providing regional design approaches based on different climate conditions (Carmody and Sterling 1985).
Regarding the ground temperature profile variation with depth, many researchers developed their own numerical expression models to predict the heat flow inside the ground (Al-Temeemi and Harris, 2003; Derradji and Aiche, 2014; El-Din 1999; Janssen, Carmeliet, and Hens 2004; Lazzarin, Castellotti, and Busato 2005; Serageldin et al. 2015; Maja Staniec and Nowak, 2016).
In terms of thermal comfort in underground spaces, some researchers developed a mathematical model for calculating the heat transfer, then calculated the thermal comfort improvements using Predicted Mean Vote (PMV). However, it was only a hypothetical model without actual measurements (Szabó and Kajtár, 2016).
Anselm used fluid dynamics simulation program (Phonics-VR) to predict the energy savings in the earth-sheltered model as a whole building simulation (Anselm 2008). Later on, 2009 Ip and Miller monitored the thermal performance of an Earth ship, as a kind of earth-sheltered buildings (Ip and Miller 2009). However, simulations only or monitoring only is not enough for a complete vision of the issue, one should integrate both into a valuable research.

The most innovative pieces of research performed a comparison between the measured and simulated data, using simulation programs with and/or without mathematical models to predict the boundary condition temperature, and simulate the whole building performance (Andolsun et al. 2011; Freney, Soebarto, and Williamson 2012; Kharrufa 2008; Kumar, Sachdeva, and Kaushik 2007; M. Staniec and Nowak 2011).
The state of the art of this technique is retrieved from Kruis and Krarti's research, they developed a numerical framework to improve foundation heat transfer calculations although it only simulates quadrilateral walls (Kiva^{TM}) (Kruis and Krarti 2016).
This study proves that the iterative approach between the EnergyPlus and the Basement preprocessor packages, is more accurate and gives diverse options for simulating the building shape and volume, especially in the hot-arid climates like Egypt, although it still consumes a large amount of time in the simulation process.
Regarding the chosen hot-arid climate, it is recommended to use the Earth-contact effect with buildings above ground. Besides, it could be integrated with the stack effect architectural means to improve the natural ventilation and air quality as a potential development of this technique.
Regarding the direct solar gain effect, the under-roof rooms are the most to obtain radiant heat gain from the concrete roof directed to the Sun. Therefore, we considered it as the worst case to compare it with the effect of the earth-contact. After the basement calibration, the researcher conducted comparisons between two hypothetical living zones using the same calibrated inputs; one on the roof level and the other one on the underground level, exactly the same as the previously calibrated basement (Hassan et al., 2014).

Nomenclature			
C_p	Specific heat capacity of each layer, J/(Kg-ºk)	T_{av}	Average monthly temperature, °C.
K	Thermal conductivity of each layer per unit area, w/(m-ºk).	T_n	Neutrality temperature (Tneutrality), °C.
L	Thickness of each layer, m.	V	Volume of each layer per unit area, m3.
m	Mass of each layer, Kg.	Greek letters	
R	Resistivity of each layer, ºk/w.	ρ	Density of each layer per unit area, Kg./m^3.

2. Climate Analysis of the selected city in Egypt

The research is focusing on the scope of Egypt's climate zone as one of the hot arid climates. The dilemma was to choose the suitable city for the best earth-sheltered buildings' application.

After numerous weather data analysis using the (Climate Consultant 5.4) software, as shown in (Figs. 1, 2), the researcher found that Al Minya city has the highest temperature differences between day and night, and is one of the cities that has the highest temperature differences between winter and summer.

As known, the most significant value of this technique is the energy preservation potential for the Earth. That is due to the natural principles of annual heat storage, large temperature differences between the internal ground temperatures and the corresponding outdoor air temperatures, and the good insulation form direct solar radiation.

Under extreme conditions, the temperature difference between the outside air and the required comfort conditions for the interior environment, could reach 32°C (Anselm 2012). Making the best use from the daily and seasonal fluctuations underground, therefore, the deeper the building is located, the less severe will be the variation. Because of the thermal storage potential of the soil which moderates the extreme daily and seasonal temperature variations, wherein energy from a day is transferred to night, and energy from one season is transferred to the next, as in the natural Principle of Annual Heat Storage (PAHS).

For the previously mentioned explanation, choosing an extreme climate as a case study would show the great significance of this technique to save energy and to reach the thermal comfort limits easily without the use of any air-conditioning systems. Therefore, we chose Al Minya city with the most extreme climate in Egypt as a case study.

Analyzing the thermal comfort with the Psychrometric chart using the Ecotect Weather Tool, the research finds that it is recommended for the design to have an exposed mass plus night purge ventilation, as shown in (Fig. 3) This will expand the comfort area to cover most of the measured temperatures (H Hassan et al. 2014).

Therefore, it is expected that using the earth sheltering technique, will cover more comfort range at the chart.

Going a step further with testing the ground temperatures at different depths (0.5, 2.0, 4.0 m.); if the earth-sheltered concept is used; we can gain much higher thermal comfort and stable conditions, as shown in (Fig. 4).

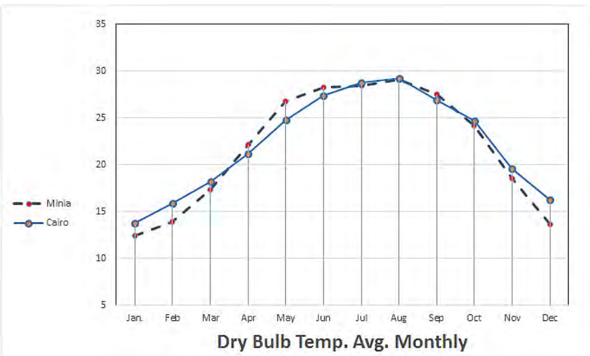

Figure 1. Comparison between Al Minya and Cairo cities of the Dry Bulb Temp. Avg. Monthly. Al-Minya has the highest differences between summer and winter.

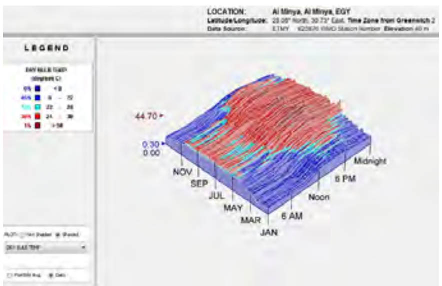

Figure 2. Daily Dry Bulb Temp showing the hottest and coldest day.

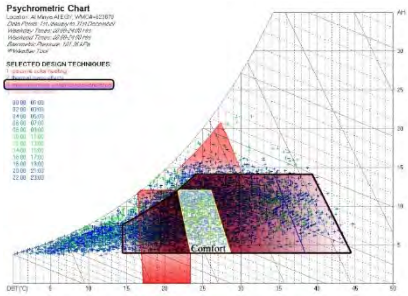

Figure 3. Psychometric Analysis for Al Minya City, showing hourly weather data and the small comfort area, and extreme high and low temperatures. The exposed mass + night purge ventilation will expand the comfort area to a wider range. Other actions have lower effects on covering the discomfort range.

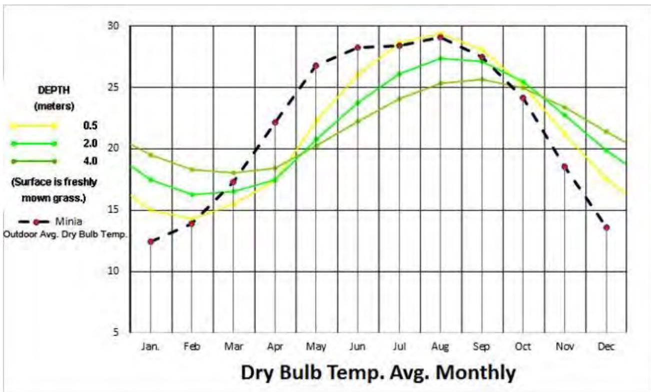

Figure 4. Predicting temperatures under the ground surface, at depths of 0.5, 2.0, 4.0 m. The stable thermal comfort conditions are high with more depths under a ground cover.

3. Method

In this section, we described the measurements' details with sensors, and the weather file compared with the outdoor measurements, then how we calculated the ground temperature and the basement's calibration process, followed by the inputs at both Basement preprocessor and the DesignBuilder/EnergyPlus.

3.1. Measurements

The research conducted measurements of temperatures and humidity outside and inside the building during three winter and three summer months from 1st. January to 27th. March, and from 1st. August to 25th. October, using (RH) sensors by the increment of (30 minutes) resolution (KN 2010). Measurements were adapted to the resolution of (1 hour) for the comparison purpose with the simulated models' zone temperatures outputs.

Measurements were taken at unconditioned basement gym, and at the last floor of the same building at a residential apartment, at an unconditioned living zone, and at a conditioned bedroom zone. Sensors were located at the height of (1.1 m.) from the slab level of both the basement and the last floor. The basement's slab was located at (-2.7 m.) under zero level of the street.

3.2. Weather File

We compared between the measured outdoor temperatures for the year of 2014; the year when the research was done; and the typical year weather file Egyptian Typical Meteorological Year (ETMY), which was developed for standards development and energy simulation by Joe Huang from data provided by U.S. National Climatic Data Center for periods of record from 12 to 21 years, all ending in 2003. Joe Huang and Associates, Moraga, California, USA. The location of the study is (Al Minya 623870).

We found very slight differences between them at the study period. Therefore, we used the typical weather file for the simulation input and we used the measured temperatures of the six winter and summer months at the year of 2014 for comparison purpose only. Figure 5 shows a comparison at the measured periods (Fig. 5).

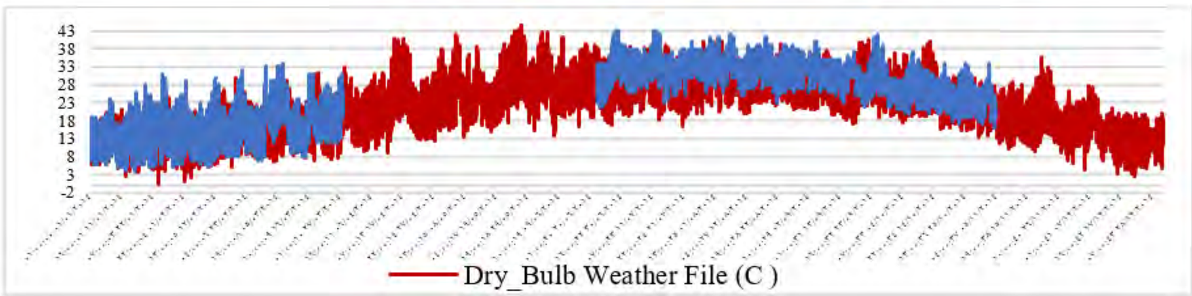

Figure 5. A comparison between the typical year weather file, and the actual measurements' temperatures for the year of 2014.

The previous approach supports what Wasilowski and Reinhart had concluded from their research as they discovered that differences were very slight between the typical weather file and the measured data, and their sensitivity analysis about the inputs proved that it was not worth the big effort that was exerted to create a custom year weather file (Wasilowski and Reinhart 2009).

3.2.1. Ground Temperature Calculation and Basement Calibration Process

Starting to calibrate the basement, the most important problem was to find the best curve of the ground temperature, which is located at the boundary between the ground and the soil. And it is coming more complicated because the basement was not a conditioned space. We could describe the center of the problem as follows:

The building affects the ground temperatures beneath it, and the ground temperatures affect temperatures inside the building. The less insulated the basement is, the greater reciprocal affectation we get.

In terms of simulations (if we are using DesignBuilder/EnergyPlus and Basement preprocessor), it means a paradox; to calculate ground temperatures (Basement preprocessor), we need to know building internal temperatures, to calculate building internal temperatures (DesignBuilder/EnergyPlus) we should know ground temperatures.

If we have a permanently conditioned building the problem is solved, as we already know reasonably building internal temperatures. However, the problem begins when we have a building that is conditioned just for certain periods and becomes significant when the building is not conditioned. We used an iterative approach that implies a series of iterations between packages: (Andolsun et al. 2011), (M. Staniec and Nowak 2011).

1. Run a first basement simulation using comfort conditioning temperatures as internal building temperatures. We used theoretical comfort temperatures for each month calculated with the neutrality temperature Tn (Eq. 1), which provides the center point for a comfort zone (Takkanon, 2006).

$$T_n = 17.6 + (0.31 x T_{av}) \qquad (1)$$

Where Tav is the mean outdoor temperature of the month.

2. Run a first DesignBuilder simulation using obtained ground temperatures.

3. Run a second Basement preprocessor simulation using monthly internal temperatures obtained within DesignBuilder.

4. Run a second DesignBuilder simulation using previously obtained ground temperatures.

5. Run a third Basement preprocessor simulation using previously internal temperatures obtained within DesignBuilder.

After point 5, differences were very slight, but we continued until 5 iterations for each of the DesignBuilder and

the Basement preprocessor. As shown in the chart, (Fig. 6).
The most sensitive parameter for the basement's calibration was the ground temperature. After reaching a reliable ground temperature as an input, we continued to simulate the basement model changing some other uncertain different parameters until reaching a visually near-to-actual zone temperature.
Accordingly, we chose the best curve after measuring the Normalized Mean Bias Error (NMBE), and the correlation coefficient compared with the real actual measurements by the sensors.

3.2.2. Inputs for the Basement Preprocessor

Using ground temperatures with basements, the basement routine is used to calculate the face (surface) temperatures on the outside of the basement wall or the floor slab.
The output of Basement preprocessor was the ground temperature, which was applied to the outer surface of every surface has a ground adjacency. (Fig. 7) shows the zone of the basement and its adjacencies conditions.
The construction of the basement's wall: cement/plaster 3cm. limestone 20cm. moisture insulation (bitumen) 2cm. and the soil, from inside to outside respectively, with a total thickness of 25cm. The construction of the basement's slab: ceramic tiles 2cm., cement/mortar 2cm., sand 4 cm., moisture insulation (bitumen) 2cm., aerated concrete 15cm., and the soil, from inside to outside respectively, with a total thickness of 25cm. as shown in (Fig. 8).

We tried to localize the inputs of the Basement preprocessor as much as possible as shown in Table 1, in order to reach (close to the real) ground temperature, as an output (EnergyPlus 2015). For the ground thermal effect on buildings, a key element are the thermal bridges, which will depend on the ratio of building area and building perimeter, we considered it under the (EquivSlab) object in the Table 1 below. This object provides the information needed to do the simulation as an equivalent square geometry by utilizing the area to perimeter ratio. This procedure was shown to be accurate by Cogil (Cogil, A. 1998; EnergyPlus 2015).
However, we did not change all the inputs, some of them were kept as the defaults.

Table 1. Localized inputs for the Basement preprocessor, for the Egyptian local building material properties

Basement GHT.idd				
Object	**Category**		**Input**	**Source**
MatlProps	Density (kg/m3)	Density for Foundation Wall	1575	Calculated*
		Density for Floor Slab	2108	Calculated*
		Density for Soil	1960	Designbuilder, Alluvial clay 40% sand
		Density for Gravel	1840	Designbuilder, Gravel
	Specific Heat Capacity (J/Kg-K)	Specific Heat for Foundation Wall	979	Calculated**
		Specific Heat for Floor Slab	951	Calculated**
		Specific Heat for Soil	840	Designbuilder, Alluvial clay 40% sand
		Specific Heat for Gravel	840	Designbuilder, Gravel

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Table 1 continued

Basement GHT.idd				
	Thermal Conductivity (W/m-K)	Thermal Conductivity for Foundation Wall	0.63	Calculated***
		Thermal Conductivity for Floor Slab	0.7	Calculated***
		Thermal Conductivity for Soil	1.21	Designbuilder, Alluvial clay 40% sand
		Thermal Conductivity for Gravel	0.36	Designbuilder, Gravel
Insulation	R-Value (m2-K/W)	R-value of any exterior insulation	0.01	
		Flag: Is the wall fully insulated?	(FALSE)	
SurfaceProps	ALBEDO	Surface albedo for No snow conditions	0.3	For “Asphalt” (T.R. 2015)
	EPSLN	Surface emissivity No Snow	0.95	For “Asphalt” (T.R. 2015)
	VEGHT (cm.)	Surface roughness No snow conditions	0.032	For “Asphalt”
BldgData	DWALL (m.)	basement wall thickness	0.25	The model
	DSLAB (m.)	the thickness of the floor slab	0.25	The model
ComBldg	Every month’s average air temperature	specifies the 12 monthly average basement temperatures (air temperature) (C)	- First, calculated by the formula (Eq.1) using Tav. For each month. - Then, the zone temp. output from EnergyPlus.	
EquivSlab	APRatio (m.)	the Area to Perimeter (A/P) ratio for the slab	(63.9533/36.1396) =1.023 m. The model.	
	EquivSizing	Flag	(FALSE) the dimensions will be input directly	
AutoGrid	SLABX (m.)	X dimension of the building slab	7	The model
	SLABY (m.)	Y dimension of the building slab	13.5	The model
	ConcAGHeight	Height of the fndn wall above grade	0.0	
	SlabDepth (m)	Thickness of the floor slab	0.25	The model
	BaseDepth (m)	Depth of the basement wall below grade	2.4	The model

* Density: Calculate the Mass of each layer. Then, Sum. of Masses and Sum. of Volumes, to calculate the Density of the assembly (Eq. 2).
** Specific Heat Capacity: A mass-weighted addition of the parts (Eq. 3).
*** Thermal Conductivity: To obtain the R-value of each layer, according to its thickness, per unit area. Then,

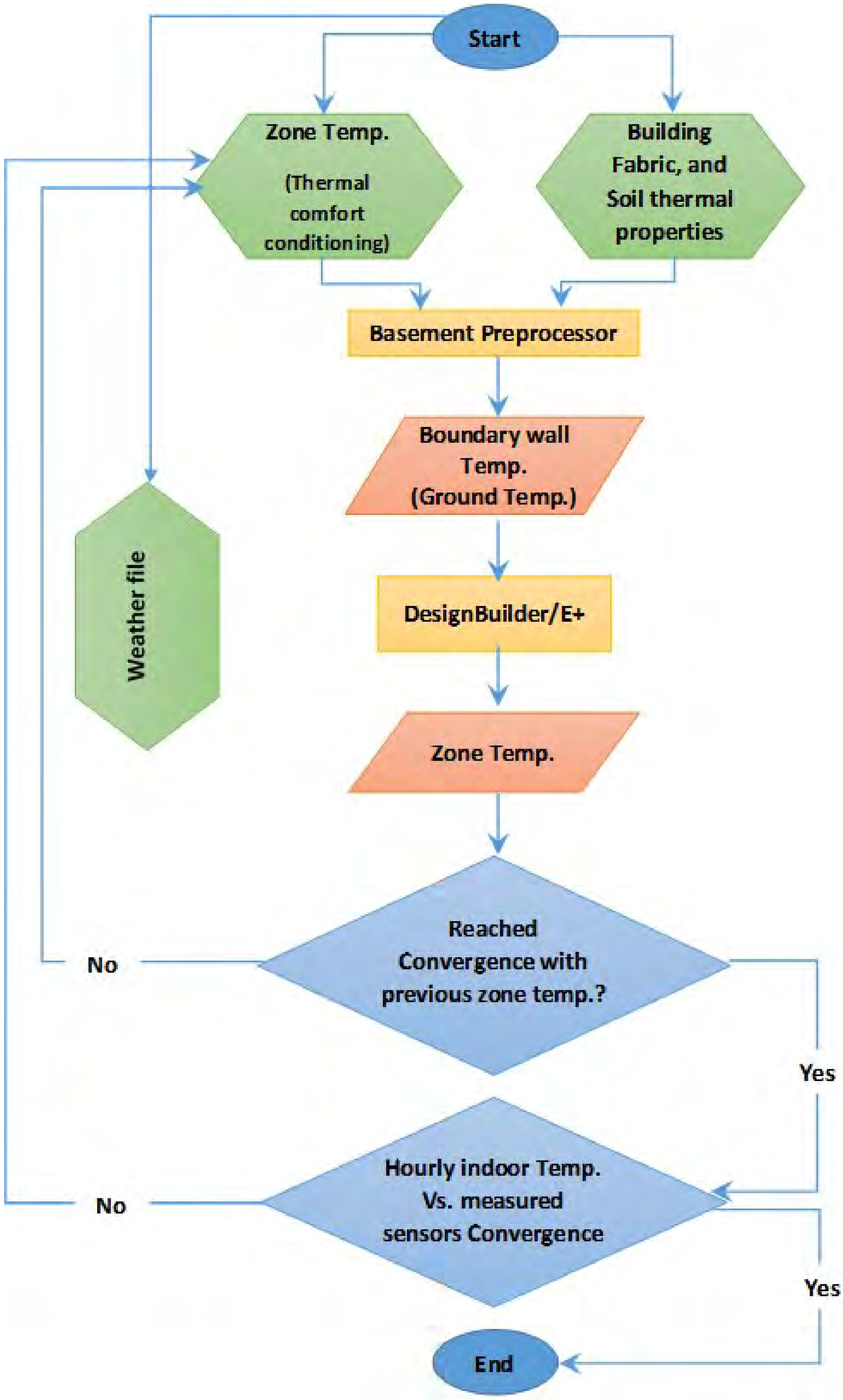

Figure 6. A flow chart describing the ground temperature and basement's calibration process.

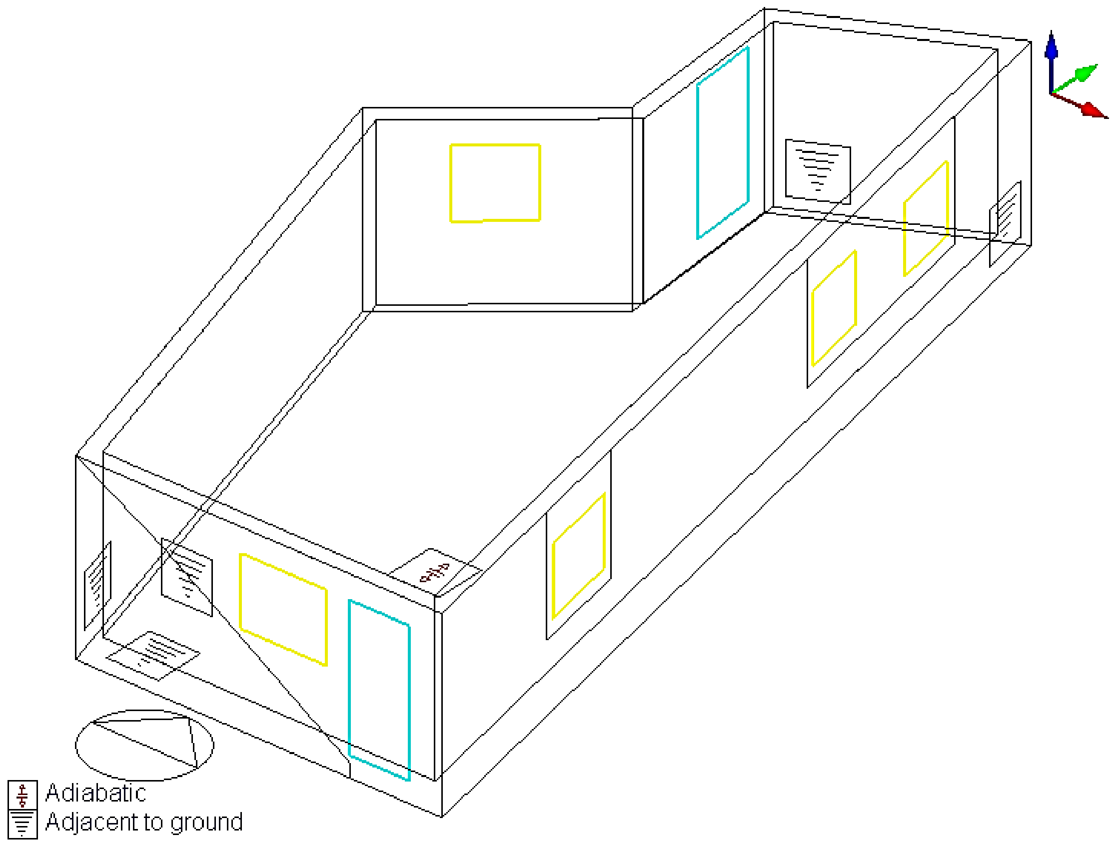

Figure 7. The basement zone's adjacencies conditions.

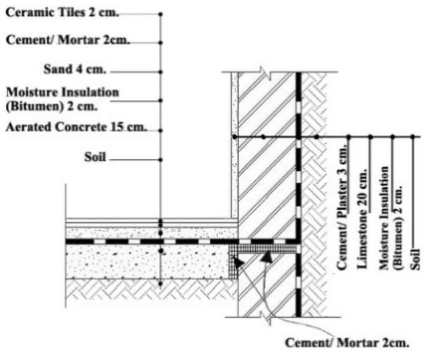

Figure 8. Cross-section of the calibrated basement floor and slab layers

Sum. of R. Finally, calculate the total Thermal conductivity according to the total Thickness and Sum. of R-values, (Eq. 4).

To calculate the wall's and slab's thermal properties, we used the cross-section at (Fig. 8) and equations (Eq. 2 - 4).

$$\rho_{Total} = \frac{\sum(m)}{\sum(v)} \tag{2}$$

$$\sum C_p = \frac{m_1}{\sum m} x c_{p1} + \frac{m_2}{\sum m} \times c_{p2} + \frac{m_3}{\sum m} \times c_{p3} + \cdots ... etc. \tag{3}$$

$$K_{Total} = \frac{\sum(L)}{\sum(R)} \tag{4}$$

The inputs for The Site:GroundDomain:Basement, Xing approach was for the Al Minya city table 2, (Xing 2014).

Table 2. Constant values for the Site:GroundDomain:Basement, Xing approach inputs (Xing 2014), p158.

Region	Country	Station	Latitude	Longitude	$T_{s,\ avg.}$	$T_{s,\ amplitude,1}$	$T_{s,\ amplitude,2}$	PL_1	PL_2
1	EGY	Al Minya	28.08	30.73	24.1	9.0	0.8	21	2

3.3. Inputs for the Simulated Model

In Table 3., we mentioned only the customized inputs for the local buildings' construction details of the calibrated model in Egypt. Other than these inputs, was kept as the default of the Designbuilder program.

Table 3. Customized inputs for the building model calibration in Designbuilder

Category	Sub-category	Item			Input
Activity	Occupancy	Density (People/m^2) Latent fraction Metabolic rate Metabolic factor Occupancy schedule			0.15 0.5 Exercise 1.0 From 15:00 to 22:00
	Other gains	Computers, load (w/m^2) Workday profile Miscellaneous (two ceiling fans), load (w/m^2) General lighting, workday profile			300 From 15:00 to 22:00 2*88= 176 From 15:00 to 22:00
	Environmental control	Natural ventilation Natural ventilation set point (°C) Lighting, target illuminance (Lux) Default display lighting density (w/m^2)			24º 300 20
Construction	Walls	Name External/Air. External/ground. Internal/Partition.	Thickness (m.) 0.25 0.25 0.15	No. of layers 4 3, Fig. 8 3	U-value 2.08 1.771 3.369
	Roof/Floor/ Slab/Ceiling	Flat roof. Floor slab (Basement).	0.2 0.25	5 5, Fig. 8	2.695 1.767
	Thermal mass	Same as (Internal part.)	0.15	3	3.369
	Doors	External door.			Metal door
	Airtightness	Infiltration rate (ac/h).			0.5, very poor
Openings	Glazing	Single clear (6 mm.), 1 layer, painted wooden window frame, U-value (w/m^2.k) Total Solar Transmission (SHGC)			5.778 0.819

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Table 3 continued

Category	Sub-category	Item	Input
	Shading	Window blinds type: Blind with medium reflectivity slats. Position: Inside. Control type: Night outside low air temp. + day cooling.	
Lighting		Fluorescent, compact (CFL), Normalized power density (w/m^2-100Lux). Luminaire type.	5.00 Suspended
HVAC		Natural ventilation – No Heating/Cooling	

3.4. The Model Hypotheses and Limitations

- The model is a basement in a conventional reinforced concrete conventional building, which is the clear majority of this kind of buildings at Egypt.
- The basement usage is a gym. The metabolism rate was taken into consideration during simulation. However, for the proposed hypothetical residential usage, this would be different.
- The calibrated model basement's roof is a semi-exterior non-conditioned room. That was considered during the calibration process within setting the boundaries conditions. However, the proposed earth-sheltered building for application, should have a ground thick layer at the roof.
- The research compared afterwards, a hypothetical earth-sheltered zone with the same corresponding conventional roof zone. In order to confirm the effect of ground-contact and show the effect of roof ground cover. This might not be a very accurate process because we did not calibrate the zone with ground cover on the roof before this comparison.

4. Results

4.1. Ground Temperature and Basement Calibration Comparisons

The Iteration results between the (Basement preprocessor) and the (DesignBuilder/EnergyPlus) software shown in (Figs. 9, 10), are the output of the process described in the chart (Fig. 6).
We changed some of the uncertainty inputs resulting in 15 different curves to reach the most near-to-actual curve, compared with the measured period. The most sensitive input was the ground temperature, which differed greatly when we changed to the Site:GroundDomain:Basement, Xing approach (EnergyPlus Development 2015). We chose the best-fit curves to go through the statistical analysis test as shown in (Fig. 11) for about three weeks in October.
Calibration 11 inputs were the best to give very precise outputs as it showed high agreement, between the measured and modeled data, with correlation of 98%, and errors with Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (NRMSE) of -1, 1.65 and 7.6%, respectively.

4.2. Thermal Comfort Analysis and Comparisons

After the basement calibration, we conducted comparisons between two hypothetical living zones, after modifying the occupancy schedule of the basement from gym to the same living occupancy schedule of the roof, using the same calibrated roof inputs. This resulted in two very similar living zones, one on the roof level and the other one

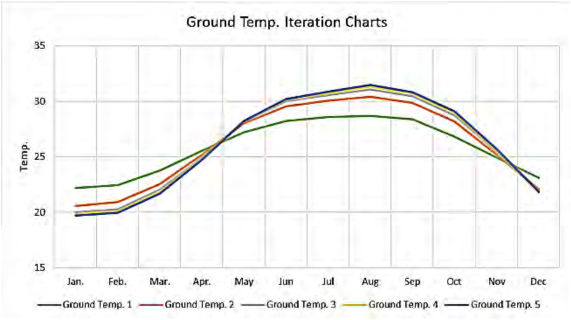

Figure 9. The basement zone's adjacencies conditions.

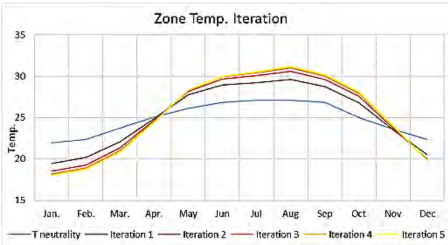

Figure 10. Cross-section of the calibrated basement floor and slab layers.

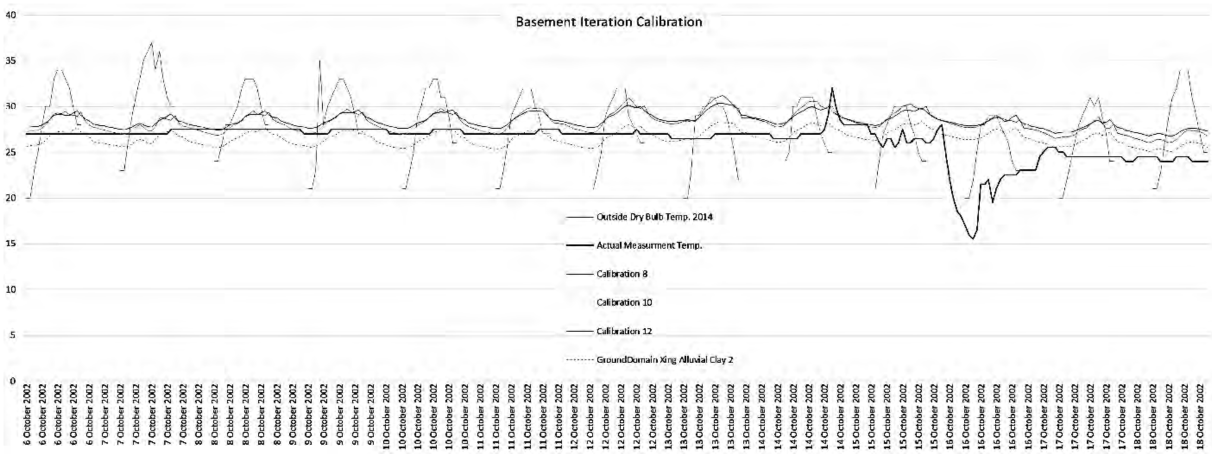

Figure 11. The most visually typical sequence that is near-to-actual trials during the basement calibration process, using the ground temperature from the iterative approach, compared with the Site: GroundDomain: Basement, Xing approach

on the underground level.

We analyzed the thermal comfort using the Fanger model which is divided into the range of (+3: -3) of the Predicted Mean Vote (PMV). The ideal comfort sensation based on Fanger is (zero). We chose the Fanger analysis because this building was highly sealed, and the infiltration rate was very low, and the building was at the steady state condition (Attia and Carlucci 2015). The thermal comfort sensation in Egypt has a wider range and could be reached with a simple ceiling fan (Attia, Evrard, and Gratia 2012).

The roof floor unconditioned living zone thermal comfort reached 5035 hrs. 57% of the year. However, the proposed perspective underground zone reached 8655 hrs. 99% of the year. With an increase by 58% of comfort hours.

5. Discussion

Based on this research, we conclude that earth-sheltered buildings are the great passive solution for saving energy. The big dilemma related to this structural option is the difficulty inherent in simulating it precisely. In fact, the most sensitive input variables are the ground boundary temperature and the 3-D thermal bridging effect.

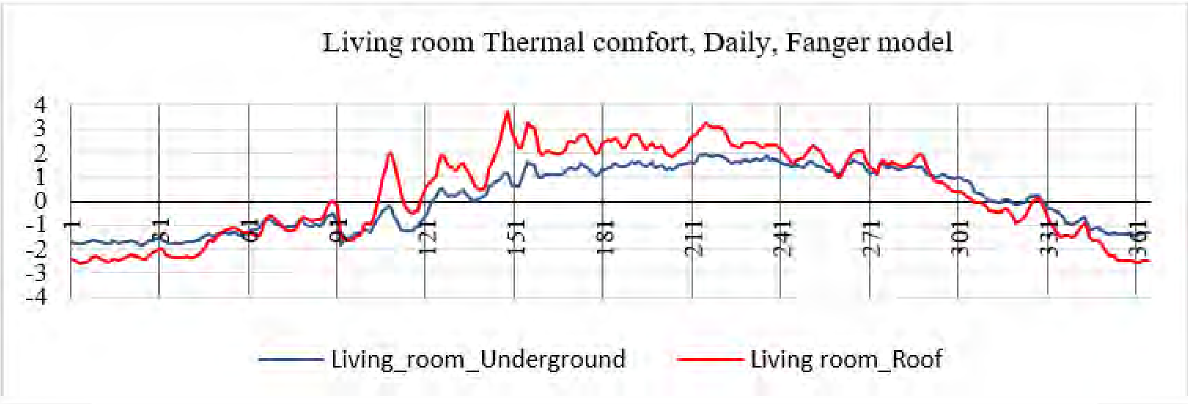

Figure 12. Thermal comfort comparison between roof floor and underground floor of the same living zone, showing the stable thermal conditions with basements, compared with the conventional ones during 365 days.

There are two methods for simulating 3-D thermal bridging effect and ground coupling using the EnergyPlus method; the first is Basement preprocessor through the GroundHeatTransfer:Basement object and the iterative approach which we introduced in detail in this paper, and the second is integrated Site:GroundDomain:Basement object. To distinguish which method is the most accurate, we compared both methods' outputs with the actual zone measurements, given that we used the Xing inputs for the second approach.

After the calibration process, we compared the thermal comfort of roof floor and underground floor living zones. Thermal comfort sensation depends on each country's climate and people's acceptance of extreme climate change differences. In Egypt, people tend to use ceiling or floor-length fans as their first choice to increase the thermal comfort zone. Their second choice is to use the AC, and only during a narrow range of the extremely hot weather months, to save energy. Consequently, we increased the PMV sensation range from zero to $\pm$ 2 levels, a range which may be reached easily by using a ceiling fan rather than an AC unit.

Finally, this research did not examine basements for living purposes but examined basements to simulate them as a structural approach for an early design stage of earth-sheltered buildings in hot-arid climates, as a passive method for achieving thermal comfort. We did, however, conduct a different parallel research to measure people's acceptance to live in earth-sheltered buildings (Heba Hassan et al. 2016; Ismail et al. 2013).

6. Conclusion

In this research, we compared the results between two ground temperature calculation methods, in comparison with the actual measurement. Moreover, we provided a detailed simplified way to localize the inputs of the building materials' thermal properties. The research demonstrated that the classic iterative way between EnergyPlus and the Basement preprocessor "GroundHeatTransfer:Basement" methods, to gain the ground boundary temperature, is more effective than the integrated "Site:GroundDomain:Basement" object, Xing approach.

More specifically, the iterative approach and the precise local customized inputs displayed significantly high correlation curves compared with the actual measurements, with correlation results of 98%, and errors with Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (NRMSE) of -1, 1.65 and 7.6%, respectively.

In addition, the Fanger model, using PMV, was used in this research to evaluate the underground level versus the roof level's thermal comfort of the same living zone. More precisely, the earth-contact effect in the underground level increased the thermal comfort by 58% of Comfort hours, compared with the roof floor of the perspective zone.

Finally, this research does not suggest that people should live underground, but rather that architects and structural engineers should introduce the innovative earth-contact effect for use in buildings as an implementation approach for the modern type of earth-sheltered building structures.

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