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Full Length Article

Earth-sheltered buildings in hot-arid climates: Design guidelines

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ABSTRACT

One of the most effective techniques to meet the tradeoff between thermal comfort and low energy consumption in hot-arid climates is Earth sheltering.

This paper reports the results of research series which aim to measure the suitability of applying the Earth sheltering technique at hot-arid climates, in Egypt as a case study.

The research tested 164 experts' responses about their attitude towards Earth-sheltered buildings and obtained their recommendations and preferences about the architectural and urban design guidelines.

On the other hand, basement's thermal performance was tested, through simulation and measurements to reach the calibration process.

Moreover, measuring the balance between the thermal comfort, and energy savings through a parametric optimization analysis. The tested design variables were 25 window/wall ratio percentages, 23 orientation angles, and five cities location templates; Ismailia, Sharm-El-Shiekh, Al Minya, Marsa-Matrouh and Al Kharga.

The research results present site-specific guidelines, through several topics; architectural design guidelines, site selection and urban planning guidelines, for architects and urban planners regarding the application of this technique for residential buildings.

1. Introduction

This paper is the summation of research series to measure the suitability of the Earth-sheltered buildings' application at hot-arid climates, at Egypt as a case study. There were many categories to measure, however, the research was concentrated on measuring two main categories, which contains a lot of sub-categories for each of them; the people's acceptance, the thermal comfort suitability and energy savings as well. After testing all possible subjects, some design guidelines have been suggested for the application on both the urban and the architecture levels.

The introduction section consists of the literature review, and the research purpose, scope, and objectives.

1.1. Literature review

The building envelope structure design as a passive way to reach thermal comfort is a non-ending issue. Many pieces of research were done in this field. (Okba, 2005) developed a checklist for envelope design techniques, based on the main elements of the envelope design. (Sadineni et al., 2011 introduced very rich study review about the passive techniques for the building envelope, one of them was the thermal mass to maximize the thermal latent heat storage.

Later, (Kharrufa and Adil, 2012) tested many passive techniques against the cooling loads using monitoring equipment to test the effectiveness extent of each technique at the hot-arid climates.

At Saudi Arabia, (Alaidroos and Krarti, 2016) performed multiple monitoring tests on different passive cooling systems, to select the best combination of which could give the best performance for lowering the cooling loads.

Regarding the design guidelines in testing different design parameters, (Takkanon, 2006) tested many design variables against thermal comfort limits in Bangkok, and provided design guidelines for both naturally ventilated and air-conditioned row houses in Bangkok. Earth-sheltering technique is one of the ways to reach thermal comfort passively, through enlarging the thermal capacity of the building envelope and maximizing the thermal lag of heat transfer of the walls (Carmody and Sterling, 1985).

Many examples of the Earth-sheltered buildings at its modern form in the residential sector have been analyzed through previous researches, however, most of them at cold climates (Alkaff et al., 2016 Kaliampakos et al., 2014), Fig. 1. Is an example of a rest area at Ohio (Hoyle, 2011).

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2314-8535/

Fig. 1. Earth sheltered rest area along Interstate 77 in Ohio.

Moreover, (Anselm, 2012) introduced another research regarding the review of energy conservation properties of the earth-sheltered buildings, compared with the conventional ones. And a comparison between different typologies according to many aspects.

Other studies, asserted on the need of evaluating the earth sheltered system at its early design stages (Mourshed et al., 2000l Sheta, 2010).

Our influencer research had confirmed on the need of assessing the suitability guidelines before the application (Al-Temeemi and Harris, 2004).

2. Assessment parameter's categorization

A complete evaluation of the Earth-sheltered buildings' performance is hard to be covered. Therefore, the assessment parameters were categorized according to main general categories. Some of the assessment parameters were covered in this study, others were not. Because, either they are out of the research scope, or they are out of the researcher expertise.

Previous researches demonstrated many design parameters to be evaluated for the application's suitability of the Earth-sheltered buildings. Likewise, economic issues, life cycle cost analysis, natural lighting penetration, and glare, etc.

This research is focused on the suitability evaluation of two main categories:

- Energy savings potential and thermal comfort.
- Public acceptability.

As we think that both are the most important benefits to be gained, and the most important obstacles to be avoided, respectively.

The main purpose of this research is to provide general guidelines about the Earth-sheltered-buildings' implementation for architects and urban planners for the new communities, with emphasis on the thermal comfort.

Besides, measuring the possibility of applying this kind of buildings from many aspects; people's perception, energy savings, and thermal comfort.

3. Methodology

The research methodology was created through a series of researches. In this section, all the previous researches' methodologies are demonstrated, which in turn lead to the creation of this research. (Al-Temeemi and Harris, 2004) suggested some sequential methodologies for the suitability assessment process. We added some other categories to be assessed, although it is not necessarily to be sequential (see Table 1).

Table 1
Suggested methodologies for the application's suitability assessment process. (Al-Temeemi and Harris, 2004; Hassan, 2014; Hassan et al., 2016; Heba, 2012; Ismail et al., 2013).

Assessment categorization parameters	Method	The research achievement
Acceptability	Questionnaire	Done (Visual questionnaire survey)
Urban design typologies	Questionnaire/Previous studies analysis	Done (Urban design guidelines regarding the questionnaire)
Subsurface climate	Temperature and heat flux evaluation	Done (Basement preprocessor of the EnergyPlus)
Energy consumption	Energy monitoring and/or simulation	Done (DesignBuilder/EnergyPlus) & monitoring
Optimization for energy savings.	Simulation software	Done (DesignBuilder/EnergyPlus) parametric optimization
Design	Applying suitable architectural design parameters	Done (Architectural design guidelines)
Solar penetration	Shading simulation using software	Not yet covered by research.
Cost	Life-cycle cost analysis	Not yet covered by research
Geological issues	Simulation software/Studying historical cases	Out of the research scope
Structural issues	Simulation software	Out of the research scope

3.1. Questionnaire and interviews

The questionnaire sample were (n = 164) of Egyptians and Japanese, it passed three sequential steps:

- A pilot study photo questionnaire, with a sample of Egyptians' architecture fourth year grade undergraduates, postgraduate architects and architecture university teachers. Questions were in Arabic language and were moving around their attitudes and reactions. This stage was followed by interviews with the respondents (Ismail et al., 2013).
- The interviews stage was done at Egypt with Egyptian architects and at Japan with Japanese architects, to measure their attitudes about the Earth-sheltering technique and recommendations about the final questionnaire design (Hassan et al., 2016).
- An internet form photo-questionnaire was the last stage which was designed to measure architecture specialists' attitudes. Besides, contribution by their experience in choosing the most appropriate architecture, site selection and urban design guidelines. The sample was limited to postgraduate students, architecture specialists and architecture university teachers. Questions were designed in a photo comparison way in an internet form. There were two forms; English language for Egyptians, and Japanese language for Japanese. Afterwards, a comparison was made between both of their attitudes and different choices directions, as a representative of different climates and attitudes (Hassan et al., 2016).

Results obtained from the questionnaire responses passed a chi-square test to be able to generalize the results on the public. We had chosen the significant results only for the design guidelines' contribution.

3.2. Simulation model

As it was noted on previous researches that Earth-sheltered buildings could be above or under zero level (Sahar N. Kharrufa, 2008). Therefore, to measure the effect of Earth contact with the building on the thermal comfort and energy savings' concern, it was recommended to measure a basement model. Hence, a basement model in Minya city at Egypt was calibrated, as a case study of the harsh hot-dry climate, Fig. 2(a and b).

Using the Basement preprocessor of the EnergyPlus the heat flux and the soil surface boundary temperature for the 3D heat transfer between the building and the soil were calculated. An iterative approach was adopted to reach a convergence of the ground temperature, which was the main sensitive input of the DesignBuilder/EnergyPlus for calibrating the basement model.

Moreover, two zones from the last floor of a residential apartment; conditioned bedroom and unconditioned living room were calibrated. To show the difference between the basement and last floor, the same last floor plan and operating schedules were used as a hypothetical displacement in the underground level.

No direct results were obtained from this step, rather than preparing the accurate model inputs for the next step of the parametric optimization.

3.3. Parametric optimization

We performed a parametric optimization study using the genetic algorithm provided by DesignBuilder/EnergyPlus software V4.7 to reach the optimal performance of the building with the best combination of design variables.

- **Objectives:** was to reach the trade-off between minimizing the discomfort summer ASHRAE 55 Adaptive 90% acceptability, and minimizing the net site energy consumption, which typically conflicts.
- **Constraints:** We excluded the high discomfort hours from the results, choosing only the cases with no more than one month per year (720 h./year), discomfort summer ASHRAE 55 adaptive 80% acceptability. More than this hour's number, we considered them as failed constraint cases.
- **Design Variables:** were the combination of five aspects:
- ***Window/Wall ratio*** percentage, ranging from 20–70% with 2 steps increment, for the building as a target object.
- ***Orientation,*** ranging from 0°–355° with 5° steps increment, for the building as a target object.
- ***Location template,*** with 5 options of the cities' weather files inputs (Ismailia, Sharm-El-Shiekh, Al Minya, Marsa-Matrouh, Al Kharga), for the building as a target object.
- ***Cooling set-point temperature***, ranging from 23-30 °C with 0.1 °C step increment, for the conditioned bedroom zone as a target object.
- ***Heating set-point temperature***, ranging from 10-23 °C with 0.1 °C step increment, for the conditioned bedroom zone as a target object.

After the parametric optimization process, we chose the optimal design variables combination for the design guidelines recommendations, in accordance with the questionnaire results experts' recommendations.

4. Results

Results were the outputs of the questionnaire and optimization studies, we recommended the guidelines for the early stage design and application of the Earth-sheltered buildings at hot-arid climates. We categorized them into three main categories: architectural, site selection and urban planning, and finally the climate, city and usage suitability guidelines.

4.1. Architectural design guidelines

Results of this section are derived from the questionnaire statistical analysis and the parametric optimization simulation study. Hence, we merged and categorized them into the form of an architectural design guidelines.

4.1.1. The plan

The plan should be opened to the outer environment, from both natural daylight and ventilation aspects, to overcome the feeling possibility of darkness or dampness (Hassan et al., 2016).

- *For bermed or in-hill construction,* a recommended plan is to place the living spaces on the side of the house facing the equator. This provides maximum solar radiation to bedrooms, living rooms, and kitchen spaces. Rooms that do not require natural daylight and extensive heating such as the bathroom, storage, extra rest living room and utility room are typically located on the opposite (or in hill) side of the shelter. This type of layout can also be extended to a double level house design with both levels completely underground. This plan has the highest energy efficiency of earth-sheltered homes because of the compact configuration as well as the structure being submerged deeper in the earth. This provides it with a greater ratio of earth contact with exposed wall than a one story shelter would (Hoyle, 2011).
- *For an atrium earth-shelter,* the living spaces are concentrated around the atrium. The atrium arrangement provides a less

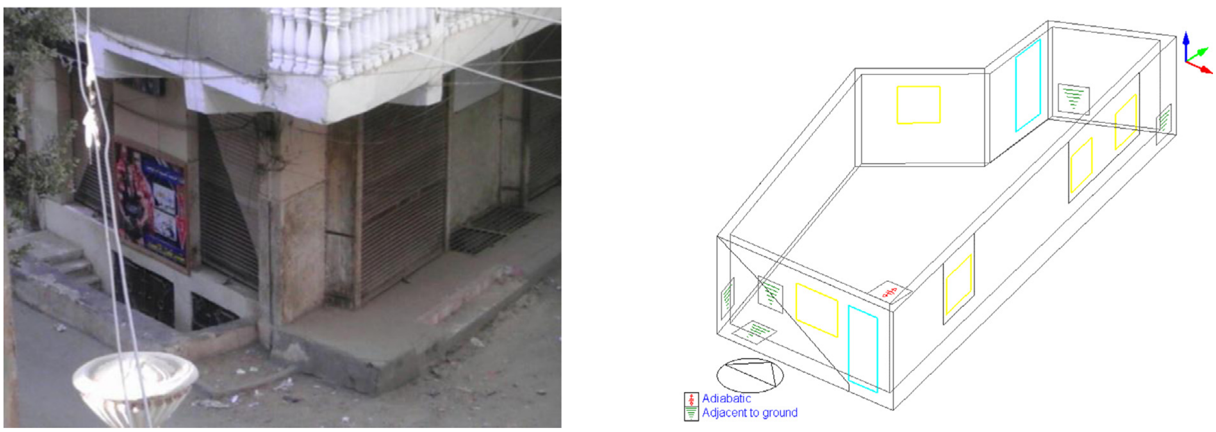

Fig. 2. (a) A photo of the residential apartment's basement. (b) The corresponding drawing zone of the basement in Designbuilder.

compact plan than that of the one or two story bermed or in-hill design. Therefore, it is commonly less energy efficient, in terms of heating and cooling loads. However, the atrium does tend to trap air within it which is then heated by the sun and helps reduce heat loss (Hoyle, 2011).

4.1.2. The entrance level

The preferred access direction is to be upstairs, to prevent water flooding, or sand dunes cover, 65.3% of Egyptians recommended this. Fig. 3(b). We should also concern about the zero-level entrance, with less priority, to give natural feeling like conventional buildings. Fig. 3(a).

4.1.3. The unit accessibility

For the unit accessibility and transition between slopes, 35.6% of Egyptians recommended to use the stairway at the mild slopes, between other two choices, Fig. 4(a). And 39.6% of them recommended to use a car or shuttle bus at the steep slopes, between other two choices, Fig. 4(b) (Golany and Ojima, 1996; Hassan et al., 2016).

4.1.4. Eye contact

Although Egyptians and Japanese preferred the direct eye contact, but Japanese liked it more than Egyptians did, 60.4% of Egyptians and 83.3% of Japanese chose the direct eye contact as their preferred choice.

Egyptians tend to like more privacy. Moreover, the hot environment at Egypt makes people tend to close windows, regardless of the outer view. Fig. 5(a) (Golany and Ojima, 1996; Hassan et al., 2016).

Fig. 3. (a) Zero level entrance direction; (b) Upstairs entrance direction.

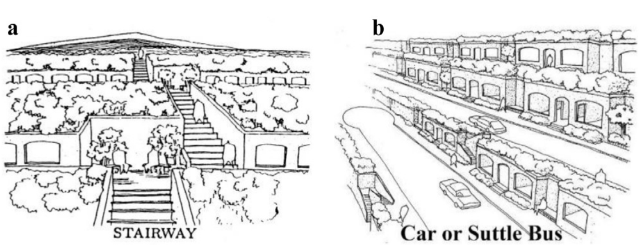

Fig. 4. (a) Stairway for mild slopes accessibility; (b) Car or shuttle bus for steep slopes accessibility.

4.1.5. Building orientation

The questionnaire results pointed out that 72.3% of Egyptians preferred the North direction, to stay far from the direct Sun penetration. The simulation results asserted that choice, where the optimized solutions' orientation was directed to 0.0° from North. Fig. 5(b) (Golany and Ojima, 1996; Hassan et al., 2016).

4.1.6. Window wall ratio percentage (WWR%)

This section was quantified by the parametric optimization simulation analysis. Therefore, there is no fixed optimum solution for the window wall ratio for the Earth-sheltered buildings, but it depends on many other variables. The most effective variable is the climate weather file of a certain city. Hence, we categorized them according to the optimum solutions' weather file (city), then we had chosen the best performance window wall ratio for the least discomfort hours at each city. Therefore, for Sharm-El-Shiekh city, the best window wall ratio was 50%. For Al-Minya city, the best window wall ratio was 24%. For Al-Kharga city, the best window wall ratio was 20%. Fig. 6.

4.1.7. Building cross-sections typologies' suitability

Earth sheltered houses are often constructed with energy conservation and savings in mind. Study of the most efficient application of the earth sheltered principles reveals classifications of the major typologies that are utilized in the construction of earth houses.

Anselm categorized these buildings into two major concepts as: The bermed or banked with earth type and the envelope or true underground type.

The energy conservation values of these typologies also vary depending on climate and physical challenges related to each typology (Table 2) (Anselm, 2012).

Our research categorized them regarding the relationship with the zero level into four typologies: Totally underground, at zero level, above zero level and on the hill-side, Fig. 7.

We measured the experts point of view about the suitability of each one of them from many aspects regarding implementation possibility; suitability for elderly and disabilities, suitability against crime and robbery, safety against natural hazards, suitability as a living space, suitability for fire escape, easy architectural design, economical use of air-conditioning energy, suitability of long life span and low required maintenance, easy access to maintenance points, economical initial cost and the best structural performance for bearing loads.

By calculating the mean ranking of multiplying the four cross sections with the suitability factors according to each of the Egyptians and Japanese. We gained different attitudes, but still the trend is the same; the most suitable cross sections are (B& C), and the most unsuitable are (A& D), as shown in Appendix A (Table 3 & Fig. 13) (Hassan et al., 2016).

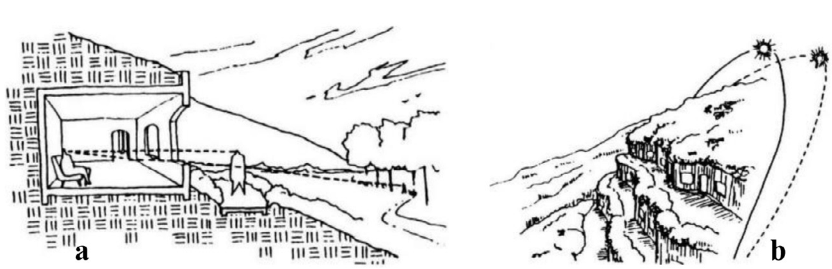

Fig. 5. (a) Direct eye-contact is preferred; (b) North direction is preferred by Egyptians.

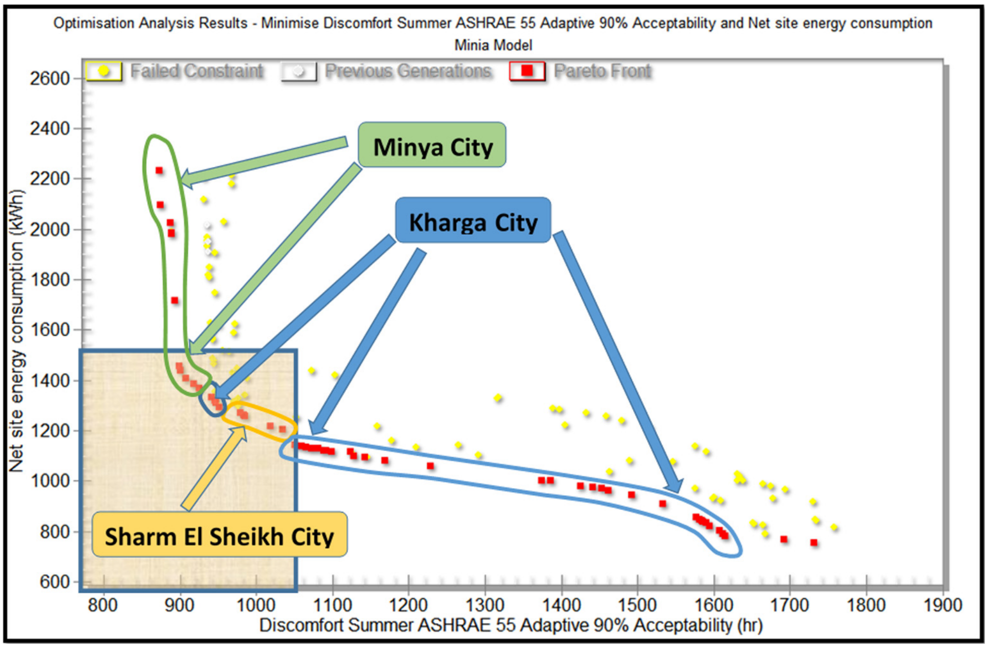

Fig. 6. The Designbuilder parametric optimization study, best weather choices, according to the compination of many design variables.

Table 2
Comparing efficiency values of the earth shelter building typology (Anselm, 2012).

Factor	Earth shelter building type			
	Bermed	*Envelope/true underground*		
Passive solar potential	Excellent	Less effective		
Thermal stability	Less effective	Excellent		
Natural lighting potential	Effective	Less effective		
Wind protection	Less effective	Excellent		
Noise protection	Less effective	Excellent		
Visual convenience	Excellent (one directional view)	Poor (allows only open sky view)		
Appropriate Climate	Effective for temperate	Most effective for tropical		
Structural cost	*Modern design*	*Vernacular design*	*Modern design*	*Vernacular design*
	Intermediate	Less expensive	Most expensive	Least expensive

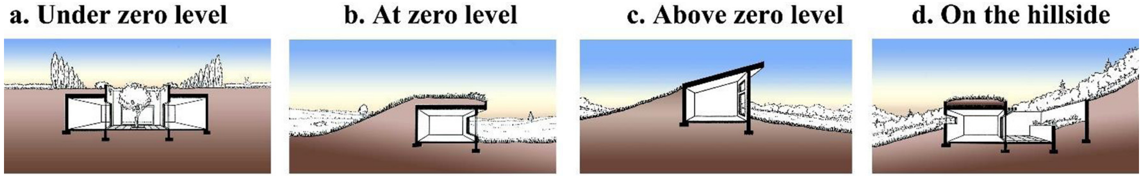

Fig. 7. Earth sheltered cross sections' typologies in relation with the zero level.

4.1.8. Thermal comfort and energy savings

Balancing between the two main objectives of the parametric study optimization analysis, as mentioned in 3.4. was to reach the trade-off between minimizing the discomfort summer ASHRAE 55 Adaptive 90% acceptability, and minimizing the net site energy consumption, which typically conflicts. Therefore, to reach the optimum design solutions, we categorized them according to the weather file, as mentioned before. Afterwards, we had chosen the best performance cooling set point temperature, and heating set point temperature of the conditioned zone, for the least discomfort hours at each city. Therefore, for Sharm-El-Shiekh city, the best heating set point was 15 °C and cooling set point was 27 °C as a combination. For Al-Minya city, the best heating set point was 22 °C and cooling set point was 23 °C as a combination. For Al-Kharga city, the best heating set point was 21 °C and cooling set point was 27 °C as a combination. Fig. 6.

4.2. Urban planning guidelines

Results of this section are derived from the questionnaire statistical analysis, and guidelines from previous studies.

4.2.1. Extension direction

Regarding the neighborhood extension; the horizontal extension direction for the urban community is recommended by 51.7% of the Japanese sample, Fig. 8(a), while two or three levels

Fig. 8. The extension direction possibilities for an Earth-sheltered neighborhood. The horizontal and two or three levels are acceptable.

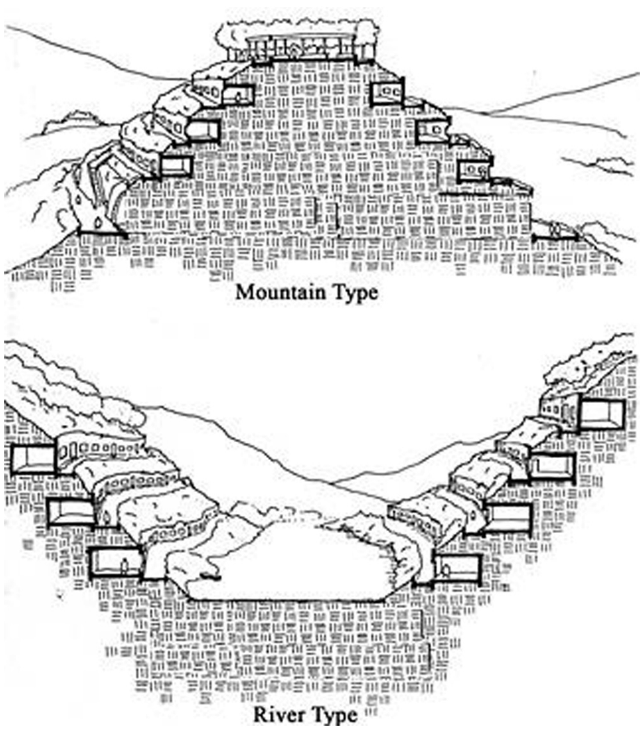

Fig. 9. The Closed (River) Type is the recommended for new communities.

are recommended by 51.5% of the Egyptian sample, Fig. 8(b). That result matches the recommendation for the building plan by (Hoyle, 2011) for the best energy performance to maximize the soil-building contact. The vertical extension is not preferred (Hassan et al., 2016), Fig. 8(c).

4.2.2. Cluster skyline

The closed (river type) is preferred to avoid wind turbulence and rain erosion. 66.3% of the Egyptian sample preferred the skyline type, rather than the opened one (mountain type) which gained 33.7% of votes (Hassan et al., 2016), Fig. 9 (Golany and Ojima, 1996).

4.2.3. Slope gradient angle

More than half of the expert sample, 61.4% recommended the slope gradient angle for new communities as of 30% slope degree (Hassan et al., 2016). Other three different slope degrees, 15%, 60% and 80% are not recommended by experts for this kind of construction, Fig. 10 (Golany and Ojima, 1996).

4.2.4. Urban form (detached/ attached)

Both Egyptians and Japanese preferred the detached form rather than the attached one, concordant with the proposed research hypothesis. We recommend the detached form to enlarge the heat exchange between the building and Earth contact. 79.2% of Egyptians recommended the detached form for the urban community (Hassan et al., 2016), Fig. 11.

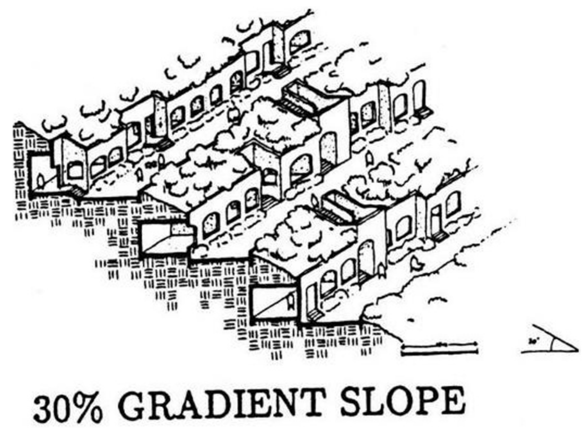

Fig. 10. The most preferred slope gradient degree for new Earth-sheltered construction is 30% slope.

4.3. Site selection (climate & city type) and usage suitability guidelines

Selecting the suitable climate, usage and city type for new community establishments, can guarantee the best performance to reach the thermal comfort easily. Experts recommended special considerations about each of them.

4.3.1. Selecting the city style

Most of the votes was dedicated to the application at a (touristic city with mild climate), 91 out of 164 was the highest number of people whom chose that kind of city, which was represented by (Ain-Sokhnah port) Suez city.

The (beautiful, hot climate) city came after it with high gap lower rank, with 37 votes, which was represented by (Minya) city, Fig. 12. Followed by the (extreme climate) city, and (other) with 25 and 11 votes, respectively.

What worth to mention here is that the hidden answers for (other) were representatives of extreme climate cities.

4.3.2. Recommended usage

Contrary to expectations; 71 out of 164, the total number of the expert sample, chose the residential usage.

Previous researches outcome argued the unacceptability of living at the Earth-sheltered buildings (Al-Temeemi and Harris, 2004; Bartz, 1986; Sydney, 1981). However, most of them were at the eightieth of this century. Since the pilot study of the research, we investigated about the acceptability of living in or dealing with this kind of buildings (Ismail et al., 2013).

Fig. 11. The detached urban form is recommended for gathering units at new communities of Earth-sheltered buildings.

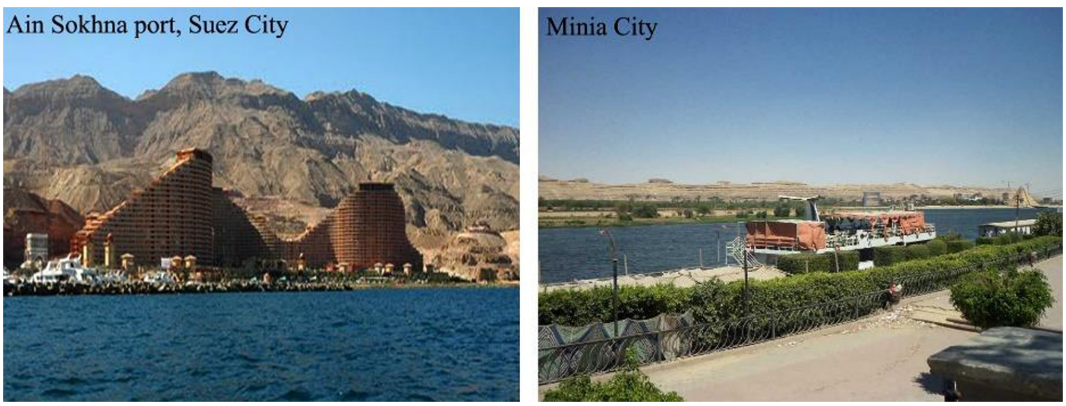

Fig. 12. Ain Sokhna port vs. Minya city, was recommended by experts for the Earh-sheltered buildings' application.

Finally, our research proved the acceptability of living as a first choice with 71 votes, followed by 66 votes to the touristic usage, which is also concerned as a representative of the living activity. Two other activities came at a lower rank; the storage and commercial usages by 18 and 9 votes, respectively (Hassan et al., 2016).

4.3.3. Climate's best performance

Choosing the best climate's performance was discussed and evaluated through both the questionnaire analysis and the parametric optimization simulation.

Regarding the questionnaire, most of the votes were given to the mild climate 91 votes, followed by the hot climate 37 votes, then the arid climate 36 votes, after grouping the (extreme climate) and (other climates) (Hassan et al., 2016).

Regarding the parametric optimization study, the optimum best solutions of the design variables, went to the same three weather files as representatives of those climates, out of five tested weather files. Sharm-El-Shiekh city as representative of the mild to hot climate, and Al-Minya city as representative of hot climate, and El-Kharga city as representative of hot-arid climate. The other two climates failed to reach the best performance required.

However, we cannot prefer one of them over the others, because it is depending on the other variables tested in the optimization process. But still, those three are on the top of the weather file choices, Fig. 6.

5. Discussion

Prior to this research, the historical context of Earth-sheltered buildings involved negative attitudes. Therefore, it was very important to measure people's perception and attitudes towards living in or dealing with these kinds of buildings.

We proved, by statistical tests, that negative attitudes were related only with the name "Earth-sheltered", as it connotes "Underground", although "Underground" is only one kind of "Earth-sheltered" system.

Moreover, regarding the research significance, we proved that negative attitudes could easily be changed using the right knowledge and correct sources of information about the system. In addition, using sketches, photos, and videos were very important in the questionnaire survey to ensure information delivery to the respondent, thus resulting in obtaining accurate answers.

Equally important was selecting the questionnaire survey: sample due to the experts and university teachers who provided the research with logical answers, and participated in creating the architectural and urban guidelines.

Creating the design guidelines in a single effort would lead to errors and uncertainties. Therefore, we relied on creating them according to the survey test results. After passing the chi-square test, and according to the reasonable number of the experts' sample (n = 164), we could generalize the resulted guidelines on both communities; Egypt as a developing country and representative of hot-arid climates, and Japan as an advanced country and representative of cold-humid climates.

For new communities, it is better to begin applying the Earth-sheltered on the tourist buildings. Afterward, we can enlarge the application scope to the residential sector. This approach was recommended by experts in this field from interviews which were accompanied with the pilot study questionnaire survey. For example; for a certain nation, if people tried using these kinds of buildings as a hotel or motel, they may wish to have their homes built with this same style. On the contrary, if we, as architects, were to propose designing their new homes as earth-sheltered, homeowners may refuse the idea, as they have never before experienced this design system.

To highlight the questionnaire results, we performed the simulation tests using the EnergyPlus and its Basement preprocessor as a tool for simulating a basement at Minya city, Egypt; one of the cities chosen by the respondents, as a kind of earth-sheltered buildings. As there is no existence of an earth-sheltered building in its modern form in Egypt. We therefore, chose a basement to assess thermal comfort and energy savings.

The parametric optimization results confirmed the questionnaire survey's trend. The climate file was used as one variable to be measured, and the optimized solutions pointed towards three of the five cities; Minya city, Kharga city, and Sharm El-Sheikh city, to be the ideal choices for application performance.

In addition, analyzing the cooling and heating points recommended from the parametric optimization study, we can observe that, the difference between the cooling and heating set points is the least in Minya city, which means that the best thermal comfort performance of the earth-sheltered buildings was at Minya city. On the other hand, the cooling and heating points for the other cities displayed huge gaps between them, which indicates low thermal comfort efficiency of the earth-sheltered buildings at those cities. Those results support the hypothesis that the best performance of the earth-sheltered buildings may be gained in cities with extreme climates with high diurnal lags. In this particular case, it was Minya city which the experts recommended as the first city to participate in the implementation process.

6. Conclusion and future prospects

In this research, the outputs of research series were discussed and analyzed measuring the possibility of applying the earth-sheltered buildings in hot-arid climates from different aspects; people's perception to live in or deal with it, energy savings' extent, and thermal comfort aspects. Moreover, we created an architectural design, urban planning, and site selection guidelines based on the previous possibility measurements' analytical data.

Regarding people's perceptions and reactions about these types of buildings, we analyzed the questionnaire survey data. The survey was designed for proposed buildings and non-occupants' interviewees, and we used photos, sketches, and videos, to gain precise answers that would contribute to the formation of the design guidelines.

Regarding the thermal comfort and energy savings, we calibrated a basement in Minya, Egypt, then performed a parametric optimization study to measure the optimum variables which would be used in the design guidelines.

For future research, we recommend monitoring the internal thermal environment and energy consumption at existing modern earth-sheltered buildings using energy monitoring equipment and simulation programs. Also, more research should be done on the parametric optimization analysis, to add more tested variables related specifically to earth-sheltered buildings.

Moreover, we recommend future lengthy studies involving economics and life cycle cost analysis.

Finally, regarding people's perceptions, we recommend future studies involving actual user habitation in earth-sheltered buildings, versus only using proposed questions and participants' reactions to them.

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The researcher would like to acknowledge the building owners for the kind help in the calibration process., they allowed us to place many sensors inside their apartments.

We would also like to acknowledge the Egyptian and Japanese architects, postgraduates and university teachers for their cooperation in the questionnaire process.

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Appendix A: Cross-section's suitability according to different aspects.

Table 3
Cross sections' suitabilities' (Mean) for whole sample.

Descriptive Statistics	N	Mean
Fire_escape_A	164	1.57
Elderly_A	164	1.82
Elderly_D	164	1.95
Easy_Maintenance__A	84	2.00
Initial_Cost_A	84	2.00
Natural_Hazards_Safety_D	164	2.07
Living_Space_A	164	2.08
Natural_Hazards_Safety_A	164	2.11
Easy_Arch__Design_A	164	2.16
Initial_Cost_D	84	2.27
Fire_escape_D	164	2.28
Sustainabilty_D	84	2.43
Easy_Maintenance__D	84	2.46
Crime_safety_B	164	2.47
Easy_Arch__Design_D	164	2.49
Sustainabilty_A	84	2.50
Structure_Performance_D	84	2.51
Structure_Performance_A	84	2.52
Crime_safety_A	164	2.53
Elderly_C	164	2.53
Crime_safety_D	164	2.55
Natural_Hazards_Safety_B	164	2.66
Economic_Energy_C	84	2.69
Economic_Energy_D	84	2.70
Crime_safety_C	164	2.72
Living_Space_D	164	2.82
Sustainabilty_C	84	2.83
Economic_Energy_B	84	2.83
Natural_Hazards_Safety_C	164	2.84
Initial_Cost_C	84	2.87
Structure_Performance_C	84	2.94
Fire_escape_C	164	2.96
Structure_Performance_B	84	3.04
Sustainabilty_B	84	3.04
Living_Space_B	164	3.08
Easy_Maintenance__C	84	3.08
Easy_Arch__Design_C	164	3.09
Easy_Maintenance__B	84	3.19
Living_Space_C	164	3.20
Easy_Arch__Design_B	164	3.22
Initial_Cost_B	84	3.23
Fire_escape_B	164	3.33
Economic_Energy_A	84	3.33
Elderly_B	164	3.50
Valid N (listwise)	84	

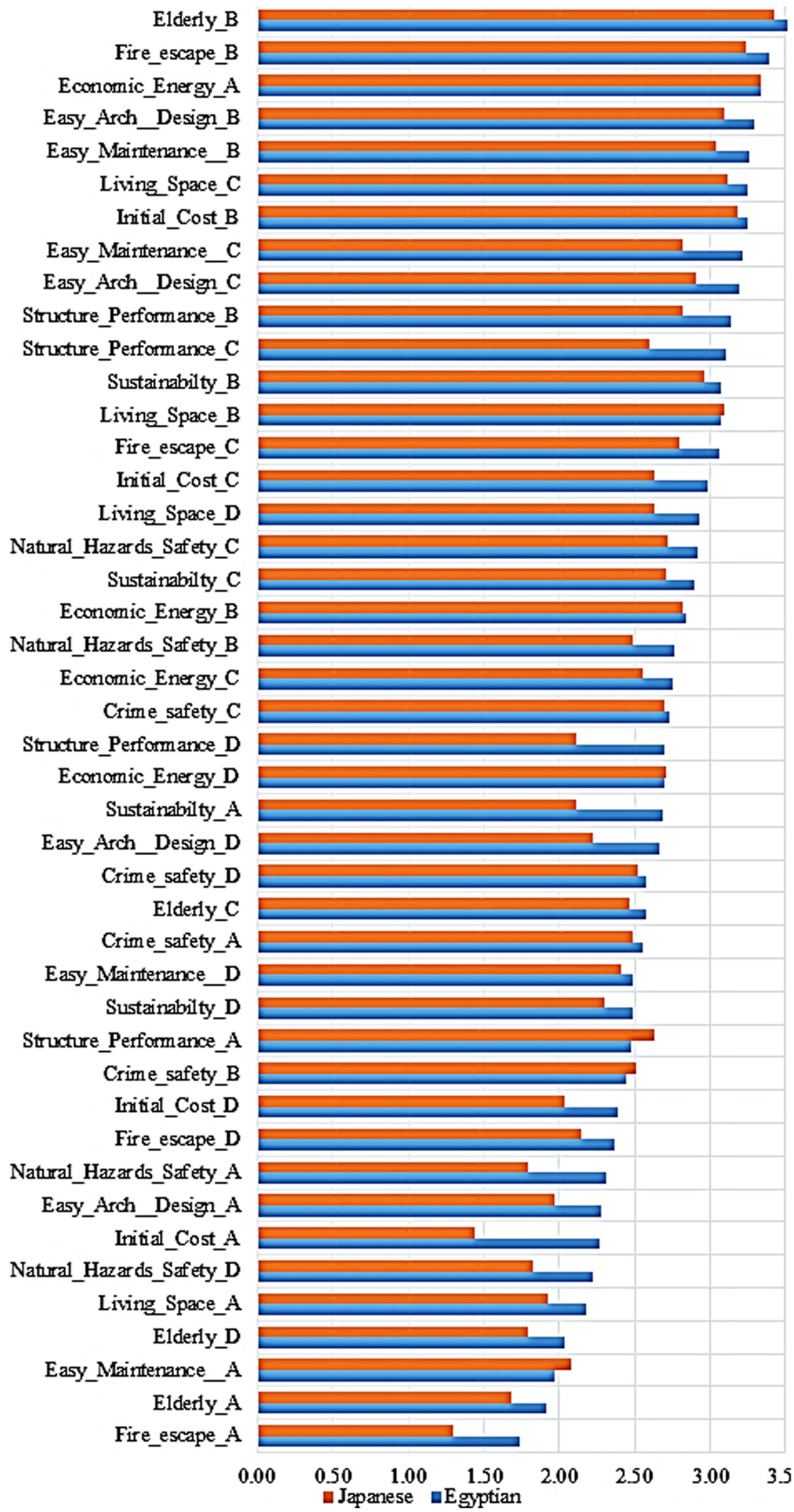

Fig. 13. Cross sections' suitability preferences according to different aspects.

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