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Suitability of sunken courtyards in the desert climate of Kuwait

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Abstract

The paper discusses the suitability of the sunken courtyard concept in the desert climate using Kuwait as a case study. It investigates three issues related to the concept: its ability to modify the harsh climate and to reduce the energy consumption, its construction costs compared to aboveground building, and the occupants' attitude towards living underground. The results are shown to be all positive and will be significant to the policy-makers, designers, and homeowners.

Keywords: Sustainable architecture; Earth-sheltered buildings; Energy-conscious architecture; Kuwait; Occupant interviews; SUNCORT program

1. Introduction

Subterranean dwellings exemplify man's struggle to survive and shelter himself against stressful climates and to achieve safe and comfortable living environment. For centuries these indigenous designs have been used by residents in the arid regions of North Africa such as Matmata in southern Tunisia, the Goreme Valley of Cappadocia in central Turkey, the Province of Henan, Shanxi, and Gansu in northern and others, some of which date back 5000 years [1].

Among the various types of subterranean dwellings one type is very common. It is a vertical design of a deep patio open to the sky and surrounded by walls and rooms, called pit or a courtyard/patio dwelling. The sunken courtyard building, as it will be referred to throughout this paper, is an underground structure that closely follows the introverted design of the famous traditional aboveground courtyard building. In addition to its ability to create a pleasant microclimate, both provide the privacy, safety, and social unity needed in these conservative societies. Underground dwellings add extra protection against climate, and their maintenance costs are usually less expensive than aboveground dwellings of the same sizes. For these reasons, several researchers have recommended its implementation and assured its sustainability in the harsh climate worldwide [2,3] and Kuwait in particular [4,5].

However, there has been lack of studies that quantitatively measure the acclaimed benefits in energy and economic as well as the occupants' attitudes and satisfaction expected from this concept, especially in the desert climate of Kuwait. Such information is vital for the policy-makers to seriously consider adopting this new/old concept. This paper investigates these three areas quantitatively and provides new and significant conclusions suitable to this part of the world.

2. Examples of worldwide sunken courtyards

2.1. Vernacular dwellings

The shape, size, and other design details of a vernacular sunken courtyard dwelling vary between regions and even among households in the same region depending on the socio-cultural background, financial standard, and environmental features such as geomorphological configurations, soil type, climatic pattern, and hydrological systems. However, the overall basic design remains similar. The following discussion is based on surveys of vernacular sunken courtyard dwellings in Tunisia and China as reported by Golany [6–8].

In Matmata, southern Tunisia, the pit (which emulates the courtyard) is usually semi-circular in shape ranging from 5 to 10 m in diameters with a depth measuring about 10 m from the ground level to the floor of the open courtyard (Fig. 1a). In China, the pit is either square or rectangular with typical dimensions of approximately 9 to 13 m and a depth of approximately 9 m (Fig. 1b). In Bulla Regia, northern Tunisia, archeological settlements of the Romans were uncovered showing consistent use of the sunken courtyard concept. The courtyard widths are similar to those in Matmata, but the depth is only about 5 m.

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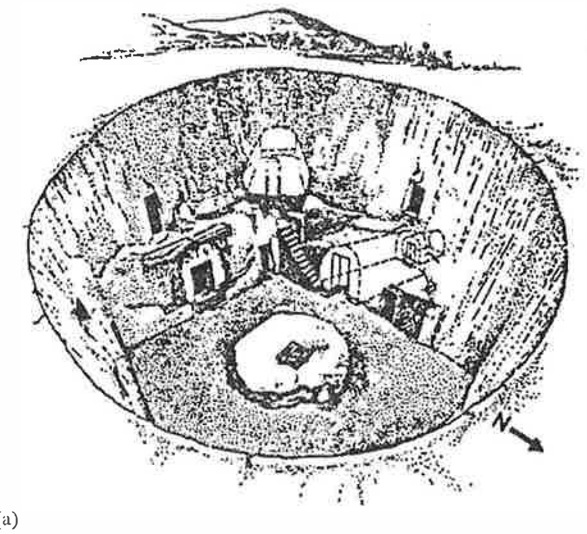
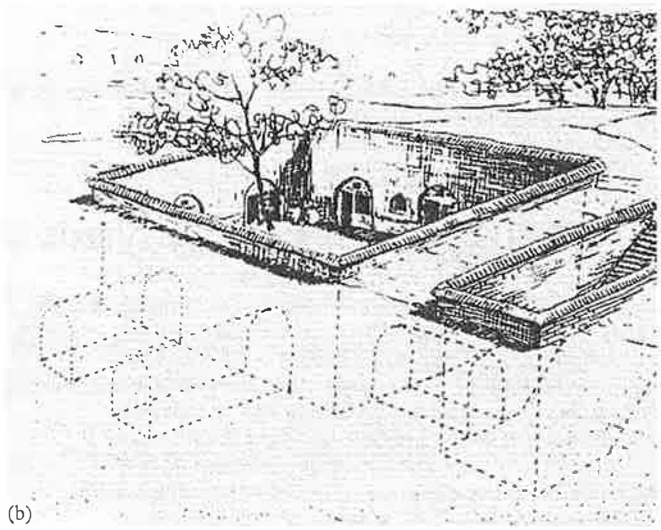


(a)



(b)

Fig. 1. (a) Vernacular sunken courtyard in Matmata, Tunisia [6]; (b) Vernacular sunken courtyard in Matmata, Tunisia [8].

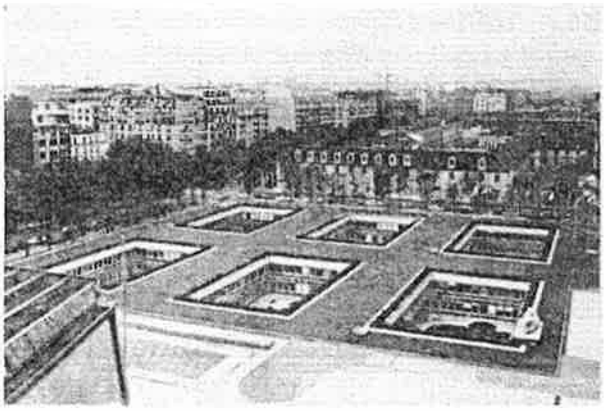
The entrance usually consists of stairways or graded tunnels leading to the interior courtyard with L-shaped corridor to insure privacy. The vernacular rooms in sunken courtyards are usually scooped out from the courtyard surfaces, and are usually long and narrow in the lower level, and smaller in the upper level (if the soil strength permits). The ceiling are usually vaulted to accommodate daylighting and ventilation needs. The typical dimensions of the rooms in Matmata are 4–5 m wide and 8–10 m long with a height of about 3 m for the large rooms, and between 3–4 m wide and 4–5 m long with a height of 2–5 m for the smaller ones. Similar room dimensions are found in Bulla Regia. The rooms in the Chinese dwellings are generally smaller with average dimensions of 3 m × 7 m and a height of 3 m.

The soil cover from the ground level to the room ceiling in Matmata ranges from 6–7 m and in China it ranges from 3–4 m. Such thickness eliminates any potential for water leakage caused by possible heavy rainfall and it significantly reduces the heat gain and the heat loss rates into and out of the building.

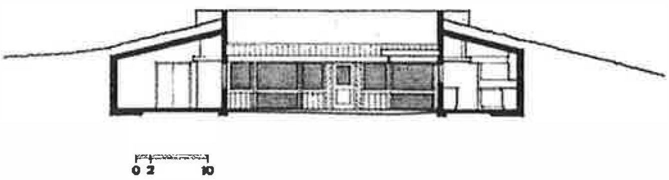
2.2. Contemporary buildings

Since the 1940s, underground building constructions l been adopted in contemporary building designs all ove world for various purposes ranging from defence to servation of landscape [9]. The concept of using un ground buildings received more widespread attention the energy crisis in 1973 primarily due to its suitability climate control strategy and to the subsequent energy ings it provides, among others. Housing and military in lations have been popular in the United States; shop centers in Japan and Stockholm; oil storage spaces in l way and Sweden; and parking spaces, theatres, libraries, other examples of public and private underground build can be seen throughout the world [10].

Examples of contemporary sunken courtyards car found in large scale projects such as the UNESCO build in Paris (Fig. 2a), the undergraduate library at the unive of Illinois, the state capital of Texas at Austin, and expansion of the Louvre museum in Paris, France. Also,



(a)



(b)

Fig. 2. (a) UNESCO building, Paris; (b) Bordie house [3].

can be found in residential houses such as the Bordie house (Fig. 2b) and John Barnard's ecology house prototype. The sunken courtyards in such residential houses are usually one story high (3.0 m), square or rectangular in shape, with 5 to 6 m in dimensions, and the soil cover is about 0.5 to 1.0 m in thickness. In larger scale buildings such as the undergraduate library at the University of Illinois it is 22 m × 22 m and in the UNESCO building it is 15 m × 25 m, both are 7.0 m deep with soil cover of about 1.0 m.

The main advantage of living or working underground is the relative isolation from the outside environment. For vernacular buildings this meant thermal stability which led to thermal comfort. For contemporary buildings this isolation leads to several significant environmental and economic advantages over above ground conventional buildings. First, these buildings are energy efficient due to the soil's thermal stability, with significant savings in utility bills for space heating and cooling. Second, they can withstand natural disasters such as fires, tornadoes, and hurricanes. Third, they control surface noise and vibrations. Fourth, they require low initial (construction and mechanical equipment costs) and maintenance costs. Fifth, they are hard to vandalize. Sixth, given all these benefits, the insurance rates are subsequently lower than the above-ground buildings. Finally, underground buildings provide several urban planning advantages such as more open spaces amenity for the community, preservation of historical settings, savings in land acquisition costs, and the ability to create a desirable mixture of office, residential and recreational functions.

3. Thermal benefits of sunken courtyard buildings

3.1. Theoretical background

The courtyard as one concept, and underground as another, each possess unique means for modifying the climate to a certain extent, but when they are integrated as in the sunken courtyard building their combination provides integrated thermal interaction which is highly effective in modifying the climate (Fig. 3). There are three important thermal advantages for being underground: first, the elimination of the solar radiation from reaching the roof and all embedded walls thus reducing the effect of one major heat gain sources in desert buildings. Second advantage is the reduction of infiltration rate which is another major heat gain source in desert buildings. One study showed that infiltration could be responsible for 53.3% of the total peak cooling load in a two-story residential building in Kuwait [11]. The joints between cladding components and around frames are major sources for infiltration in a typical above-ground building, however, infiltration rates are significantly reduced in earth-sheltered buildings, thanks to its buried walls. Third, heat gain through the embedded walls and roof is also greatly reduced since the temperature of the surrounding environment (soil) is lower than the air temperature of the outside in the summer season. For example, in Kuwait, the soil temperature in mid July at 3.0 m depth is around 31°C [12] while the air temperature aboveground reaches 45°C and more. If the soil is shaded and covered with vegetation the soil temperature will be modified even further and its temperature could be lower than the measured 31°C.

While the soil covers most of the building envelope and isolates the building from the direct impacts of the stressful desert climate, the courtyard becomes a source of light, fresh air, and interaction to the outside environment without the extreme conditions. The geometrical shape of the courtyard creates a unique microclimate and a buffer zone between the outside and the building inside. Two important advantages could be gained from the courtyard concept. Although the solar radiation is not completely eliminated as in the case with soil cover, the courtyard geometry itself shades at least two of the courtyard wall surfaces and part of the courtyard floor surface. The direct solar radiation can be controlled through horizontal shading devices located on top of the courtyard opening. Only diffused solar radiation and may be sparkles of sunlight should be allowed for day-lighting purposes as well as psychological and physiological pur-

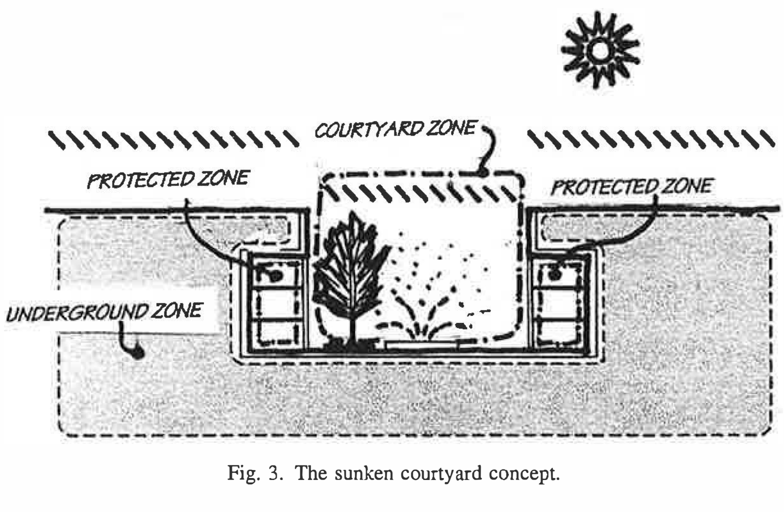


Fig. 3. The sunken courtyard concept.

poses. The second advantage is the creation of a pool of cool air contained within the courtyard. The modified air, thanks to the garden and water fountain located in the courtyard, can not escape anywhere except to the interior rooms resulting in a lower heat gain rates to the courtyard surfaces.

This integration between earth-shelter and courtyard concepts, which exist in sunken courtyard design, provides an effective climate control system. The thermal advantage of this design has been qualitatively discussed in few studies. Brown and Novitski [2] discussed the thermal advantages of the concept and recommended its implementation but without a quantification of its thermal benefits. Golany [6] monitored the thermal performance of a vernacular sunken courtyard in Matmata, Tunisia and provided extensive and pertinent data. He showed that, while the maximum outside dry-bulb temperature was around 42°C in mid summer, the temperature of the rooms facing the sunken courtyard was nearly stable at 25°C, about 17°C cooler. And while the minimum outside dry-bulb temperature was around 7°C in mid winter, the temperature of the rooms facing the sunken courtyard was nearly stable at about 16°C, about 9°C warmer. In the Gulf region there has been very few studies in this subject. Al-Mutawwa [4] and Al-Temimi [5] both recommended adopting the concept as a strategy to combat the climate and to reduce the rising electrical consumption in Kuwait. Again, these studies were qualitative and no indication to the energy savings expected from the concept was given.

With such lack of quantitative information and appropriate tools to measure the thermal performance of sunken courtyards, designers are not sure how much of a benefit this design can provide and how to optimize it so maximum thermal benefits could be obtained. Most of the available energy simulation programs are suited to predict the thermal behavior of boxlike buildings whose envelope are above-ground and exposed to typical weather conditions. Therefore, there was a need to develop a computer code to simulate the heat flow in a typical sunken courtyard design. The code should incorporate all the climatic factors involved, should simulate accurately the heat flow processes in this design, and be flexible enough to allow for cha the values of certain design variables.

3.2. Thermal simulation program for sunken courtya SUNCORT

A computer program written in FORTRAN was c oped by the author and called "SUNCORT". The progı based on the CONDUCT program which is a gε purpose program used to solve the partial differential tions for heat conduction by the finite difference meth two dimensions [13]. SUNCORT is composed of components: (1) WEATHER data file which includes h weather data; (2) SHADE program which calculate shaded area of the courtyard surfaces every hour; an ADAPT which is a subroutine that describes the geome the calculation domain (such as the one shown in Fig. addition to the thermal properties of the material invc heat sources, reaction states, boundary conditions, dε out, and others. ADAPT reads the data from the weathe shade files and incorporates all of the items listed earliε sends the information in terms of finite difference equa to (4) the invariant part of CONDUCT to solve them output is temperatures in selected nodes from which gain and heat loss can then be calculated.

The computer program was validated through two stu (1) simulation of the temperatures of undisturbed s Kuwait; and (2) simulation of a room temperature vernacular sunken courtyard hotel in Matmata, Tunis both cases, empirical data were available and showed very close to the ones generated by SUNCORT [14].

The flexibility of the program allowed the auth conduct extensive number of simulation runs for a va of sunken courtyard geometries, soil cover thickness the roof, insulation lengths and locations, and passive ing strategies such as soil surface shading and evapoı cooling, and to compare them with the results of al ground buildings of similar design configurations. A p type design of a sunken court measuring 15 m × 15 m building footprint dimensions of 25 m × 25 m was use

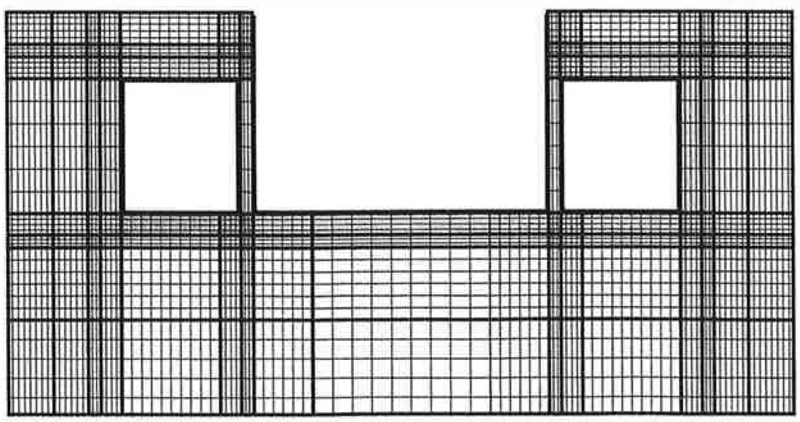


Fig. 4. A sample of a grid design for thermal simulation (not to scale).

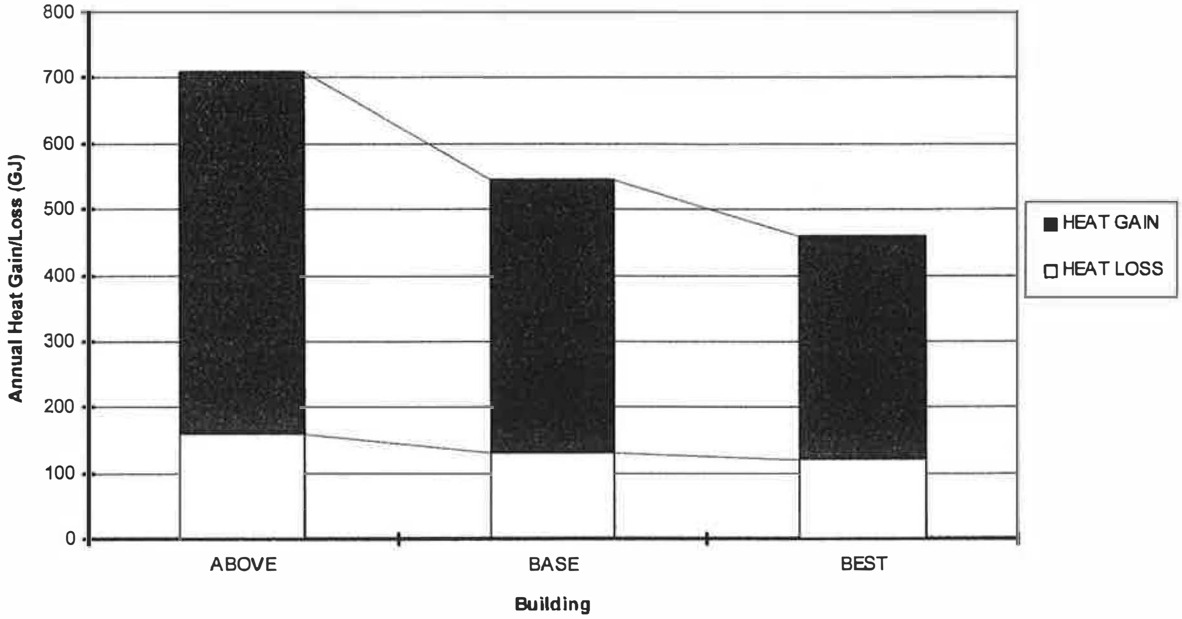


Fig. 5. The annual heat flow divided into summer gain and winter loss for the three cases: aboveground courtyard building, base case (sunken courtyard without the extra thermal modifications), and best case scenario (sunken courtyard with several thermal modifications).

the analysis. All studies were conducted using the hot-arid climatic conditions and the soil thermal properties of Kuwait. For each study the ADAPT subroutine was modified by changing the length of the nodes, the thermal properties of the grids, or the heat balance equations at the soil surface.

3.3. Simulation results

Results show that the annual energy savings of 23–35% is expected for one-story residential sunken courtyard with 1.0 m of soil cover and roof insulation (Fig. 5). The higher percentage is possible when wall insulation is applied on the upper 1.5 m only, and the soil is covered with summer vegetation (to provide shading and evaporation). In the three-story case, the reduction is estimated to be at least 28% without any wall insulation and is expected to be higher when the soil surface is covered with summer vegetation.

These savings are for buildings with low internal heat gain (skin load dominated buildings) such as residential and small offices. Another simulation was conducted to measure the energy reduction for three-story sunken courtyard building with high internal heat gain (internal load dominated building) and was found to be only 11.8%. Therefore, one can conclude that this concept is *thermally* effective for residences and small offices and may be not for commercials or building with high internal activities. More results were discussed in the author's dissertation [14].

4. Construction costs of sunken courtyard buildings

There was a concern that the soil surrounding sunken courtyards would require extra structural reinforcement that is costly and may outweigh the energy savings. The need for protection against water and humidity in addition to the excavation costs would all add up making the concept unfeasible. On the other hand, savings from the outside cladding and from the wall thermal insulation might make the concept attractive. Therefore, a study to compare the construction costs between the two design strategies was necessary to draw better conclusions.

Detailed cost analysis for four cases were made: (1) one floor aboveground; (2) one floor underground; (3) two floors aboveground; and (4) two floors underground, all listed in Table 1. All cases were of the same courtyard dimensions, 15 m × 15 m, and building footprint dimensions of 25 m × 25 m. Only differences in the construction materials and labor costs between sunken and aboveground courtyards were estimated. Construction costs shared by the two concepts such as internal partitions, courtyard windows, flooring, interior finishing, and others are not included in this table since they are the same in both cases. These figures were based on detailed structural analysis, required reinforcement and materials, and labor costs, all based on mid-1999 average market costs in Kuwait and evaluated in US dollars (1 KD = US$ 3.28).

Two important conclusions could be drawn from this table. First, the total construction costs of the sunken courtyard concept, whether it is one or two floors, are less expensive than the costs of similar sized courtyards aboveground. This is attributed mainly to the savings in the roof tiles, wall cement blocks, wall bricks, and wall thermal insulation. The total costs of these materials are US$ 21,230 and 25,850 for one and two floors aboveground compared to zero cost in the sunken courtyard. On the other hand, due to the excavation and structural costs of the sunken courtyard,

Table 1
Comparison between the construction costs (US$) of the four courtyard buildings

Construction	One floor		Two floors	
	Above ground	Underground	Above ground	Underg
Excavation	1540	6380	1540	10990
Backfill	3070	1970	3070	1970
Roof membrane	3280	3280	3280	3280
Roof coping	1050	390	1050	390
Roof terrazzo tiles	7220	–	7220	–
Roof thermal insulation	1450 (7 cm)	1020 (5 cm)	1450 (7 cm)	1020 (
Roof foam concrete	150	160	150	160
Roof plastering	20	–	20	–
Roof expansion joints	660	–	660	–
Roof gravel	–	360	–	360
Parapet paint	525	–	525	–
Parapet walls	1570	–	1570	–
Parapet thermal insulation	–	160	–	160
Wall cement blocks	4430	–	4430	–
Wall sand-lime bricks	7220	–	12630	–
Wall thermal insulation	790 (5 cm)	–	1580 (5 cm)	–
Wall membrane	–	2950	–	5410
Footings asphalt layer	50	–	50	–
Footings water-membrane	–	1560	–	5120
Reinforced concrete	30070	38050	50620	59220
Total	63095	56280	89845	88080

which are US$ 12,820 and 18,050 higher than its counterpart aboveground, the overall savings are reduced to only US$ 6815 and 1765 for the one and two floor cases. Second, the difference in the construction costs diminishes as more floors are added. As mentioned earlier, while the difference in the total construction costs between aboveground and underground building for the one-floor case is US$ 6815 it is only US$ 1765 for the two-floor case due to the rise in the excavation and structural costs. It is expected that three-floor sunken courtyard would probably be more expensive than its counterpart aboveground.

Materials and construction costs that coexist in both designs such as interior partitions, windows and aluminium frames, flooring, decoration and others are currently around US$ 150.00 per square meter. Therefore, the total cost for a 400 m^2 (one floor) sunken courtyard would be around US$ 116,280 ($400\,m^2 \times 150 + US\$\,56{,}280$) and around US$ 208,080 for two floors ($800\,m^2 \times 150 + US\$\,88{,}080$). The total costs for one and two floor aboveground courtyard would be US$ 123,095 and 209,845 respectively.

Table 1 focuses on the main initial construction cost and shows that the sunken courtyard concept is equivalent if not less expensive than aboveground, however, the table still does not justly show the real savings expected from the earth sheltering strategy. The table does not include the maintenance and running costs which would give the sunken courtyard concept a much better advantage. Being protected from the outside harsh climate, sunken courtyard components would deteriorate in slower rate and require less maintenance than aboveground. This protection against the harsh climate would also allow for smaller and less expensive air conditioning units with less maintenanc unit replacements. Another study is indeed necessa investigate the costs of these items and to provide a com and comprehensive picture of the overall savings exp from the concept.

5. Occupants' reaction to local sunken courtyard houses

The Kuwaiti experience with earth-integrated s varies depending on their functions. For example, the cept of buildings totally underground is very rare. negative perceptions towards living underground suc the dull and gloomy environment and the fear of dra problems have discouraged the public from impleme such a concept. In addition, there was no reason to since land was plenty, energy cost was cheap, an information of the savings potential were offered. underground spaces such as basements have been con in the Kuwaiti buildings for storage purposes only an for living. These basements were often dark, stuffy shelters for insects and rats, and therefore, negative reac have always been associated with them.

Partial integration to earth started to become accep since mid 1980's. Lands became rare and prices have rising dramatically. A price of 350 KD/m^2 (US$ 120 for a land only is not uncommon. A small lot of 4C could cost US$ 300,000 and building costs would be tional US$ 160,000 totalling US$ 460,000 to own a h while the annual income of a newly college gradua

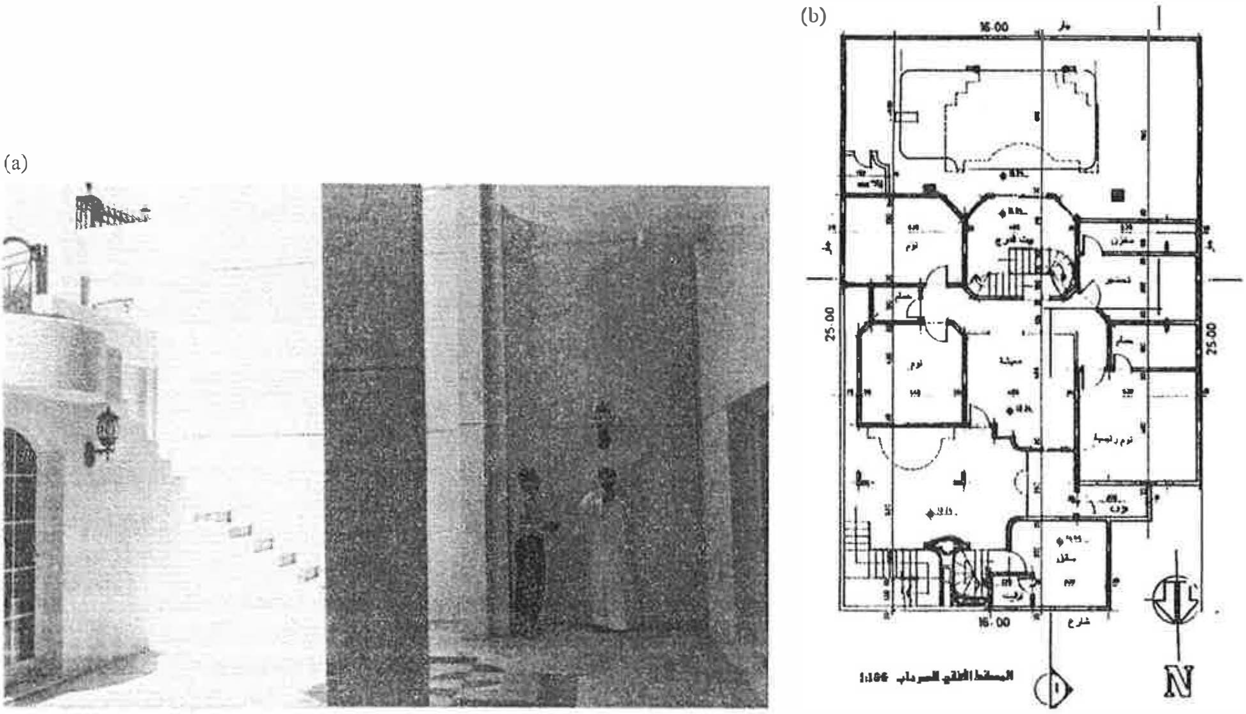


Fig. 6. (a) Sunken courtyard of house; (b) Plan of the sunken floor.

around KD 6000 (US$ 20,000). Therefore, more than one family are now starting to live together in one house and the need for extra spaces in the same purchased land is becoming popular. With the current building code that limits the built area to three floors (ground, first, and second floor) owners are starting to look favorably into having extra spaces in the sunken floors which are not counted in the code regulations. Finally, the negative perception towards sunken floors started to disappear with evidences of successful designs found in several local residences such as the ones discussed below.

5.1. House 1

The house is located on a 400 m^2 land (16 m × 25 m) with its main entrance in the shortest dimension and oriented towards north (Fig. 6). The house is a two-story building (ground and first floor) plus a sunken courtyard. A whole living area is placed in this sunken floor and includes a living room, three bedrooms, three baths, a kitchen, and a central space with spiral stairs that connects with the upper floors and ends in the roof with a skylight. The homeowner indicated that the extra space below ground once not a popular idea can now be rented to generate extra income, could be utilized for social activities, or could be used as future accommodation for his kids. In addition, having a sunken floor allowed his house to look "humane" and well proportioned when compared to other houses in the same neighborhood. While many conventional houses reached the allowed height limit of 15 m, the height of his sunken courtyard houses reached only 9 m with the same built area. He explained that while other houses look like office complexes, his looks like a real house. He added that he prefers to spend his spare times in the sunken courtyard because it is cozy and thermally comfortable compared to the aboveground front-yard. He stressed that no negative feelings are associated with living underground since there is a good view and enough daylighting into the interior spaces.

5.2. House 2

The house is located on a 1000 m^2 land with its main facade facing south-east. The house was once totally underground then a new owner added extra floor on top of the existing structure. The original sunken floor consisted of a reception, a living room, three bedrooms, an office, a kitchen, a dining room, and three stairs leading to aboveground (see Fig. 7). Most of these rooms are facing a swimming pool located in the center of the sunken court. Later, several rooms were added aboveground but the original sunken rooms were kept unmodified.

The sunken courtyard concept was not the reason behind purchasing this house, instead it was the prime location of the land as admitted by the owner. She added that she later loved the idea of the sunken court because it provided the needed privacy for her family especially during swimming and barbecuing. The owner also added that she usually meets her guests in the reception hall located on the ground level and then she escorts them downstairs to have dinner in the dining room facing the sunken swimming pool. This movement gives her guest and herself dynamic, lively, and lovely times. No negative perceptions have been associated

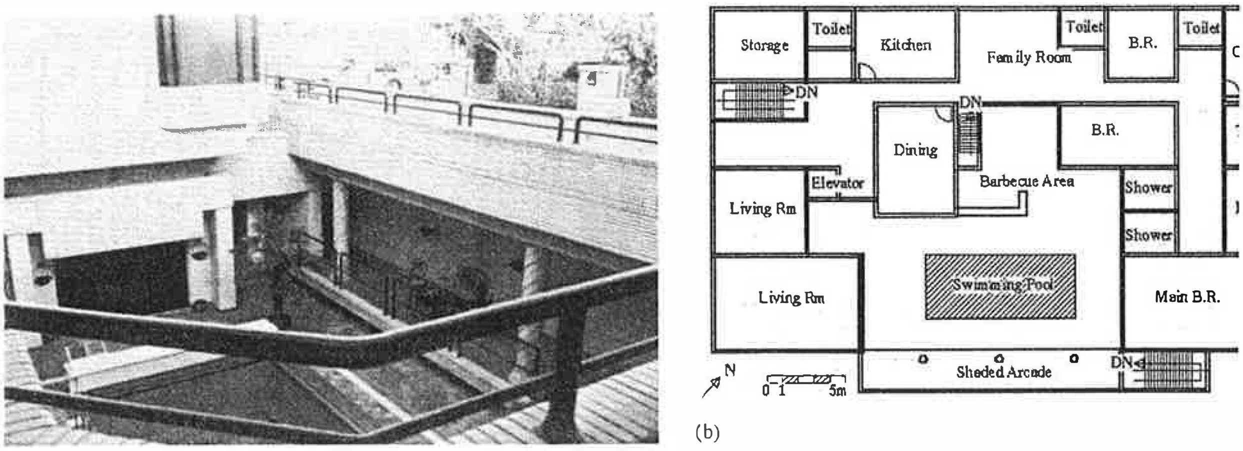
(a)


Fig. 7. (a) Sunken courtyard of house; 2 (b) Plan of the sunken floor.

towards living in the sunken floor because daylight is abundant and the view, which is towards the swimming pool, is very satisfactory and feels like aboveground. Most of the sunken room surfaces are covered with marble and fired clay creating, at least psychologically, thermally cooler atmosphere. On the contrary, the owner complained about the discomfort in the reception room aboveground which is surrounded by large areas of windows. Double glazing the windows and shading them did not solve the problem and they are opting for a bigger cooling system hoping to ease the thermal discomfort.

5.3. House 3

The house was built in 1977 on a 1000 m^2 land, the oldest among the other selected homes and one of the first underground buildings in Kuwait. Originally, the entire living areas were built as a basement then several years later the owner added the upper floors. The sunken floor have an outside swimming pool and a main living room, three bedrooms, a kitchen and a laundry, and two bathrooms, all in distinctive semi-circular shapes (Fig. 8). Although the exterior walls are not coupled with earth as they are i previous two cases, they are 50 cm thick with unique shaped windows facing a lush outside garden. The roof to be covered with 30 cm of soil but later another floo added instead. The owner mentioned that he discovere enjoyed several benefits from this design: (1) energy servation; air conditioning operates in the summer 22:00 h to 07:00 h only, and sometimes it felt so cool th AC had to be turned off in the middle of the summer n The result is utility bills that are about 50% of his neighl (2) Privacy; the owner and his friends and relatives swimming and barbecuing in the sunken court withou curiosity of the neighbors. (3) Better environment fc vegetation; being in the shelter of an enclosed environ and away from the hot winds and dust, and being clo the underground water table, the owner indicated th vegetation in his sunken court is lush and requires irrigation. The only draw back is the humidity leve might be noticeable in the interior and a dehumidif needed sometimes. He explained that this humidity w result of the poor workmanship during the installation wall membrane. (4) Special atmosphere; the unique d

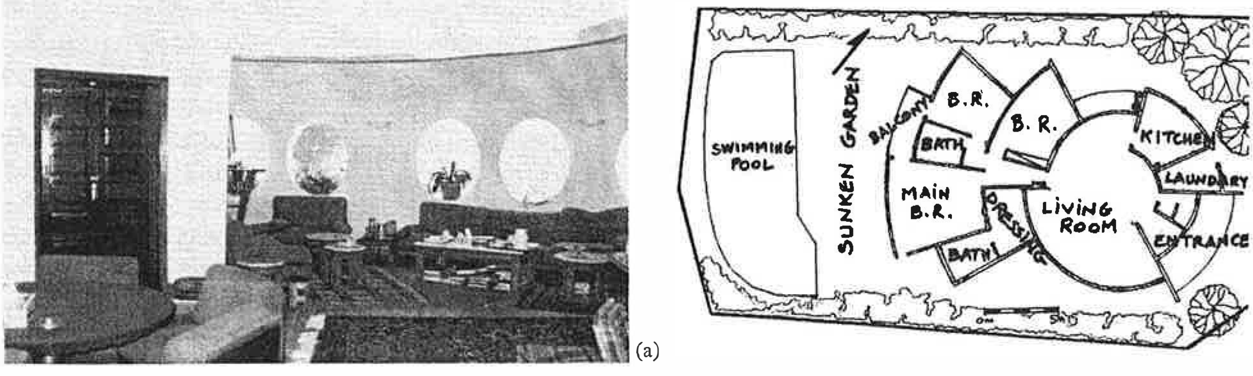


Fig. 8. (a) Sunken room of house; (b) Plan of the sunken floor.

has brought the outside inside. It feels like they are integrated creating a cozy and unique environment.

6. Conclusions

This paper discussed the suitability of the sunken courtyard concept in the desert climate using Kuwait as a case study. It demonstrated some vernacular and contemporary examples and investigated three main issues related to this design: how effective it is in modifying the climate, how expensive it is to construct compared to conventional aboveground buildings, and how well perceived by the local occupants.

A computer simulation program was developed and validated to calculate the heat flow and energy consumption in the sunken courtyard design. It showed that the concept would provide 23–35% reduction in the annual energy consumption when compared to the annual energy consumption of a conventional design. In addition to this energy saving, detailed study of construction costs showed that underground courtyards is almost the same if not less expensive to build than its counterpart aboveground. The reduction is attributed to savings in the exterior cladding, wall materials, and thermal insulation, however, as the number of sunken floors increases, the excavation costs and the structural requirements would be more. It is shown that the cost of one floor sunken court is less expensive, two floors is about the same, but three floors and more would probably be more expensive than aboveground courtyard building. This comparison, which focused on the initial construction costs, should also include the running costs and this would have made the sunken courtyard concept a big winner. However, the extra needed information was not available at the time of the study and additional study is needed to investigate and to prove this point.

Finally, negative feelings associated with being underground could be eliminated. Interviews with three local occupants showed that they have been enjoying the concept with no negative feelings. Beside the required waterproofing and other necessary construction materials, all of interviewed owners agreed on one important key for the success of the design: adequate opening to the outside. Adequate openings would provide the needed view to outside pool or garden, and adequate daylight and sunlight to the interior. Once these features are provided, one would enjoy economical, cozy, cool, and better-suited design for such harsh climate.

Sunken courtyard building proved to be suitable for the desert climate of Kuwait. Its ability to provide annual savings in energy costs, to protect the building components from fast deterioration, and to have a cozy environment with extra "free" spaces for any possible future needs would make it an excellent sustainable design concept.

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