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Building Green in Jordan? Performance Evaluation of the Aqaba Residential Energy Efficiency Pilot Project (AREE)

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Abstract

The AREE house was built in 2007/2008 to provide a showcase of a high performance building in Aqaba city in the southern part of Jordan. The total energy performance of the building was achieved through three types of measures grouped into passive design elements, material choices and renewable energy installations. The energy performance and associated costs and benefits for each type were modelled to highlight opportunities for low and high income segments of the residential building market in Jordan.

This paper provides a post construction evaluation of the actual energy performance of the building and the real costs and benefits. The sustainability concept of the building is reviewed, as well as the construction process and the life cycle costing of the energy enhancing measures. The findings show that passive design elements and material choices do improve the energy performance. This is derived from the actual indoor comfort monitoring in comparison with base case simulations. The payback time on the incremental investments needed is less than 3.5 years. At the same time, the monitoring also showed that not all passive design measures for energy performance were effective. This paper reflects on the experience and lessons learned from AREE for potential wider integration of sustainability elements into building projects in Jordan.

Keywords: Sustainable building design, energy efficiency, water efficiency, computer simulation, thermal performance, life-cycle cost.

1 Background

Worldwide, the direct and indirect contribution of the built environment (buildings and physical infrastructure) to environmental impacts is estimated to be in the range of 30 to 40 per cent of the total anthropogenic impacts (UNEP DTIE, 2007). The situation in Aqaba, southern Jordan, can be considered more severe than this. The existing urban form is directly contributing to environmental stress in the region. Its design, material composition and spatial layout does not reflect the environmental conditions of the region and locks-in a costly and resource intensive occupancy lifestyle that suits neither the regions' scarcity of resources nor the low income of the majority of the population (Biggs, 2005). Typical construction styles have very poor insulating qualities and do not meet the national code requirements of maximum overall U-values (1.8 W/m²K for walls and 1.0 W/²K for roofs). Prevalent building practices within both residential and commercial segments do not even adhere to the national building code with regard to energy performance requirements. Therefore improving the energy performance of buildings has the potential to deliver substantial environmental improvements at the aggregate level (Commision of the European Communities, 2005).

The *Aqaba Residence Energy Efficiency (AREE)* is a model building for the 9th District in Aqaba city. The aim of the project is to achieve substantial improvements in energy efficiency through integrating passive design elements and material choices without radically departing from the conventional building and cost structures prevailing in the region. A secondary objective is to showcase the potential and the payback time of the application of integrated solar cooling technology in a residential building in southern Jordan.

Aqaba is located at latitude 29°N and longitude 35°E on the Aqaba Gulf of

Figure 1: The building seen from south.

the Red Sea. The meteorological station is 51 meters above sea level. The climate in Aqaba is characterized by very hot summers and mild winters. Average yearly temperature is 24°C, monthly averages range is from 16°C in January to 32°C in July. Daily average maximum is 39°C (July) and average minimum 9°C (January). Prevailing wind direction is from the North.

The project idea was born after the transformation of Aqaba into a special economic zone. Within this new status, the local authorities envisioned a rapid growth in the governorate population from 118,300 inhabitants, year 2006 estimates, to nearly double that in year 2020 (ASEZA, 2007). This rapid growth will put greater demand on the expansion of the built environment, and consequently greater pressure on the already strained energy and water resources.

The AREE project idea was initiated in 2005 following a study by Lund University (Sweden) on the challenges of introducing alternative building practices into the Aqaba built environment. One of the key recommendations of the study was the need for a demonstration project on energy efficient building (Biggs, 2005). The study team from Lund University invited, in collaboration with the Center for the Study of the Built Environment (CSBE), three architectural firms to provide a concept designs for a Green Building on a plot of land purchased for this purpose. In the design brief, the project initiators specified the following requirements for the design: a residential building that;

- showcases design and material elements reflecting Aqaba's dominant socio-economic and landscape features (i.e. sensitivity to landscape features and average socio-economic conditions);
- displays practical 'low-tech' applications of energy, water and material efficiency in a functional way; and
- acts to challenge conventional concepts of the accepted residential building style without alienating it – inspiring Aqaba builders, developers and home owners to adopt a similar approach.

From the start the accessibility of design and approach to inspire adoption was emphasized. As the 9th district of Aqaba was a newly established district, part of the planned expansion of the city, the choice of the project location was seen as an opportunity by the project developer to influence the urban development. The local authority, the Aqaba Special Economic Zone Authority (ASEZA) had issued specific building guidelines for this district, including informal town setting, variety in building massing, simple cubical forms, vertical windows, and the use of shadows and earth tones for facades.

The final design for AREE builds on the winning entry by one of the architects to the above mentioned design call. Section 2 of this paper describes in detail the features of the final design, including energy efficiency concepts. In Section 3 the evaluation of the energy performance is presented and compared to modeled performance based on both the actual design and a reference building representative of the conventional local construction. In Section 4 the life-cycle costs are analyzed, and in Section 0 the lessons learnt from the execution of the energy concept are discussed.

2 Building Concept

The final version of the AREE building concept included the following elements:

Building type: residential; a one family house that can also be converted into three apartments. Additionally the design should provide flexibility for other kinds of use such as guest lodging or office space. Total floor area is 420 m².

Architecture: The architectural design is adapted to the local climate and makes use of the following design elements to improve the energy performance: building orientation, compact building mass, floor plan layout (individual rooms on the north side; circulation space as buffer-zone to the south side), shading for windows, facades and roofs, roof garden, improved natural ventilation, recessed windows, evaporative cooling, and thermal mass for heat accumulation and solar gain in the winter.

Perceptions of comfort and energy saving behavior: Outdoor living space is provided by shaded terraces on each floor to encourage outdoor living during the day and to prevent excessive cooling of internal spaces. Furthermore, night-ventilation is promoted to release heat during the night, preventing overheating of the interior space during the day.

Relation to urban quality: Urban quality and community character are important, and required by the local design guidelines. The garden space is optimized to facilitate shading and privacy around the house. This also relates well to the required informal town concept. The garden walls are designed to be planted. Unity in building expression, according to its location, makes the house a land mark on the corner plot. The main building volume is situated perpendicular to the main road, where the entrance is located. The sub-volume along the secondary road is built upon the plot line according to the building regulations and provides parking space.

Cost factors: The rational design in structure and room planning aimed for cost efficiency in the construction. For instance, the bathrooms are situated in the same location on each floor, on top of each other, next to the installation shaft to facilitate economical plumbing infrastructure. The distance to the grey water reservoir was also taken into consideration in the total lay-out design.

2.1 General Sustainability

The sustainable design concept of the building focuses on water and energy efficiency as the two primary concerns for built environment in Aqaba.

The water efficiency strategy aims at reduction of water consumption and reuse of grey-water for garden irrigation. In all bathrooms a dual sewerage system was installed, separating grey and black water. The low-tech grey water filtration and storage system was based on a low-cost design for rural water recycling projects by the Jordan Hashemite Fund for Human Development (JOHUD). The garden design by Matilda Nilsson includes drought resistant plants to minimize water consumption for irrigation (Biotopia).

The energy efficiency concept is further detailed in the next section.

2.2 Energy Efficiency Concept

The energy efficiency concept is based on an integrated approach incorporating measures for energy conservation, rational use of energy and application of renewable energy sources. Since Aqaba is located in a hot-arid zone, the strategy is mainly aimed at reducing end-energy for cooling in the following ways:

- architectural design;
- building materials; and
- installations.

2.2.1 Architectural Design

The building is oriented with bedrooms towards north and east to protect the interior rooms from summer afternoon heat. The zones towards the west side are buffer areas with a short term use; as corridors and bathrooms. Windows are recessed in the thick walls and have Venetian shutters to allow shading and ventilation. The upper communication space has large windows towards south-west for winter heating (Figure 2).

2.2.2 Building Materials

The structure is heavy with high thermal capacity combined with an insulation layer of 50 mm mineral wool in the cavity walls of the envelope. The U-values for the wall systems range between 0.4–0.5 W/m²K. The windows are made of steady steel frames with good weather stripping and double glazing. Extra effort has been put into high-quality construction detailing and execution to prevent air leakage. Table 1 provides a description of the building envelope and the U-values, compared to common building practice in the region.

The ground floor living area has a green roof, which serves as terrace garden on the first floor. This garden roof also functions as an extra thermal mass, and has a positive effect on the indoor climate of the living room beneath.

2.2.3 Installations

A solar-driven adsorption cooling system is installed on the top roof. The solar hot water matrix delivers domestic hot-water, heating and energy for the adsorption chiller, which delivers cooling at a high efficiency rate. An underground cooling system is incorporated in the floor of the living area, and for evaporative cooling of incoming air a water fountain is installed outside the kitchen window. Energy efficient lighting and appliances are selected based on the best available options in Jordan.

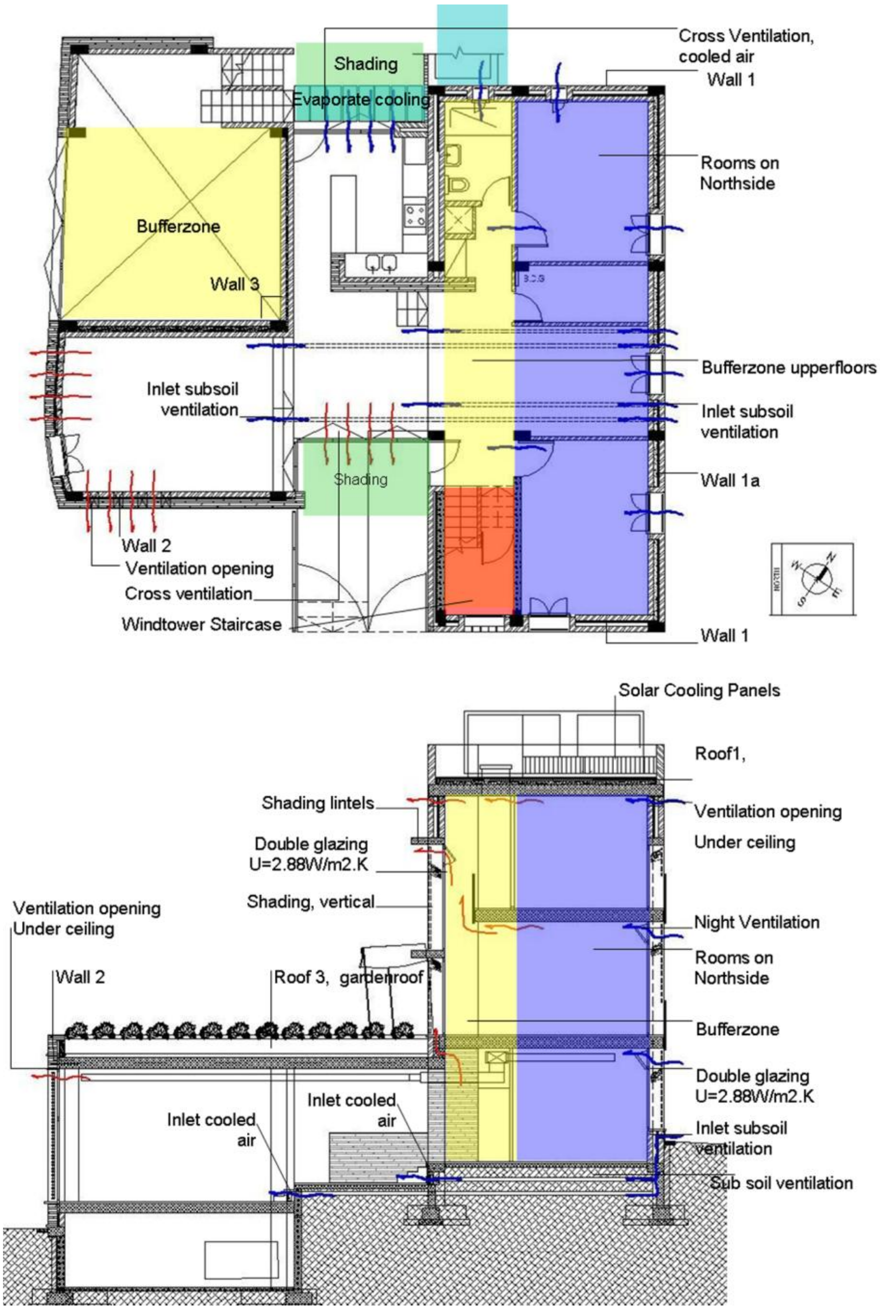

Figure 2: Ground floor plan and section.

Table 1: Building envelope in AREE compared with conventional buildings.

Construction elements	Description	U-Value [W/m²K]
AREE Project		
Wall 1: Double CHB (Concrete Hollow Block) wall with 10 cm cavity, used in main volume.	▪ Cement plaster mixed with straw (20mm) ▪ CHB with perlite aggregate (150 mm) ▪ Insulation layer Rockwool (50 mm) ▪ Air Cavity filled with sand and straw (50 mm) (filling applied to North walls only) ▪ CHB with volcanic aggregate (150 mm) ▪ Cement plaster mixed with straw (20 mm) *Total = 44 cm*	0.34 - 0.39
Wall 2: Stone cladding wall used in sub-volume	▪ Granite stones (200 mm) ▪ Concrete backfill (50 mm) ▪ Insulation layer Rockwool (50 mm) ▪ CHB with volcanic aggregate (150 mm) ▪ Cement plaster mixed with straw (20 mm) *Total = 47 cm*	0.50
Glazing	Double glazed windows	2.88
Roof 1: Concrete roof used in main volume	▪ Terrazzo tiles (30 mm) ▪ Cement mortar (30 mm) ▪ Waterproofing layer (4 mm) ▪ Insulation layer of extruded polystyrene (50 mm) ▪ Sand (70 mm) ▪ Reinforced concrete (70 mm) ▪ Concrete rib blocks (240 mm) ▪ Cement plaster mixed with straw (20 mm) *Total = 51.4 cm*	0.44
Roof2: Concrete roof with garden used in sub-volume	▪ Earth (400 mm) ▪ Stone aggregates (40 mm) ▪ Geo-textile (5 mm) ▪ Waterproofing layer (4mm) ▪ Reinforced concrete (250mm) ▪ Cement plaster mixed with straw (20 mm) *Total = 71.9 cm*	0.87
Conventional Building		
Wall 1: Cavity HCB	Single layer CHB (stone aggregate), no insulation + 15 mm plastering on both ends	1.62
Wall2: Stone cladding	Stone cladding + concrete backfill + cavity + CHB (stone aggregate) + 15mm cement plastering	1.92
Glazing	Single glazed windows	5.88
Roof	Similar to AREE roof 1 without the insulation layer	2.20

3 Evaluation of the Energy Efficiency Performance

Evaluation of the energy efficiency was made through long-term temperature measurements and validated by computer simulations. Since the solar cooling plant did not come to full operation during this period, any energy use in relation to enhanced indoor comfort could not be monitored. Instead, these estimations were made through the simulations, see Section 3.2.

3.1 Monitoring

The building was monitored by a 16-channel Grant Squirrel SQ2020-1F8 data logger, which recorded hourly air and surface temperatures from May 2008 until November 2009, see Figure 3.

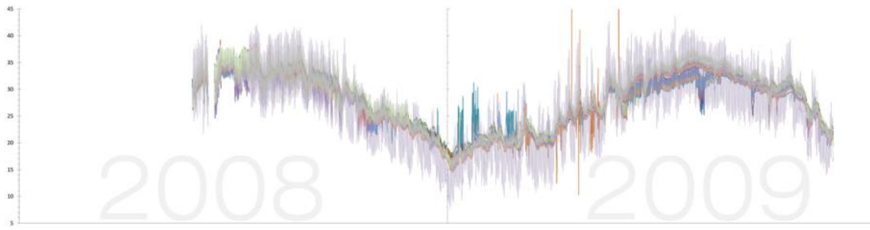

Figure 3: Overview of the monitoring period.
(Occasional spikes due to disturbances.)

Generally, when the building is kept closed the indoor climate is very stable, and shows a considerable time lag which helps to overcome extreme periods of heat or cold. The free-running building produces an excellent winter comfort; however, in the summer passive climatization is not sufficient in Aqaba.

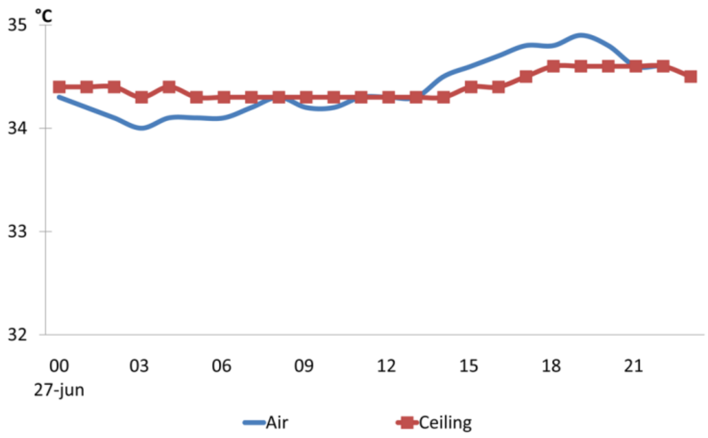

Figure 4: Summer temperatures in the top floor bedroom (closed/passive).

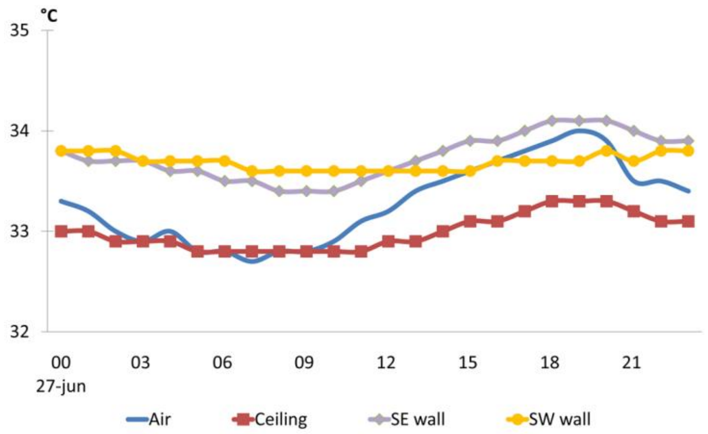

Figure 5: Summer temperatures in the ground floor living room (closed/passive).

3.1.1 Summer performance

The positive effect of roof insulation is seen in 4, where the ceiling temperature remains very stable regardless of heavy solar radiation on the outer surface during the hot period. The green roof has an even better performance; the stable ceiling temperature is at the same level as the minimum indoor air temperature, thus helping to cool the interior of the living room, see Figure 5. However, indoor temperatures are uncomfortably high in both spaces.

Despite several trials, the adsorption cooling plant did not come to regular operation. Therefore, an evaluation of the energy use in the building could not be made. Figure 6 shows a one-day test run of the ground floor system, where the

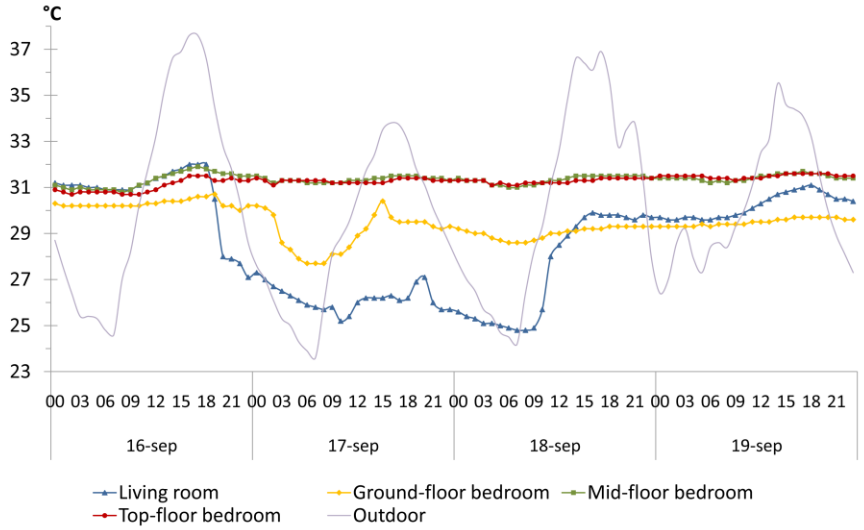

Figure 6: Test of solar cooling plant in the ground floor (closed/passive).

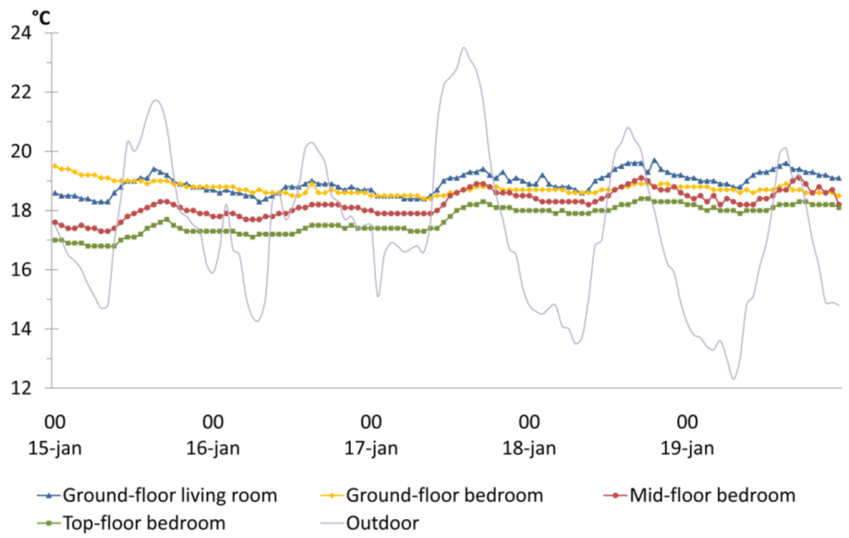

Figure 7: Winter temperatures in selected rooms (closed/passive).

living room temperatures were brought down to around 26°C, while the bedroom, served by the same air distribution system, did not reach the comfort level.

Because the measurements started before the mounting of the shades on the large south-west windows, the results were very negative for summer comfort – the bedrooms behind the corridor got over-heated through the partition wall.

3.1.2 Winter performance

In January, a cold week was selected for controlled measurements during which the building was kept closed. Figure 7 shows that the larger the envelope area, the lower are indoor temperatures, and that the warmer ground clearly contributes to a better comfort. However, in this case the indoor temperatures are close to comfortable, and, considering that the building is inhabited, a normal occupation of the building would probably raise this level a couple of degrees, especially if daytime ventilation is utilized. Thus, the building performs passively very well in the winter.

3.2 Computer Simulations

Since the adsorption cooling installation was not operational during the measurement period, advanced computer simulations were used to evaluate the energy efficiency of the building. The software *DesignBuilder* (DesignBuilder Ltd), which uses the powerful engine *EnergyPlus* (US Department of Energy), was chosen for these calculations. The building was modeled with high accuracy, including 17 zones whereof nine were conditioned. See Figure 8.

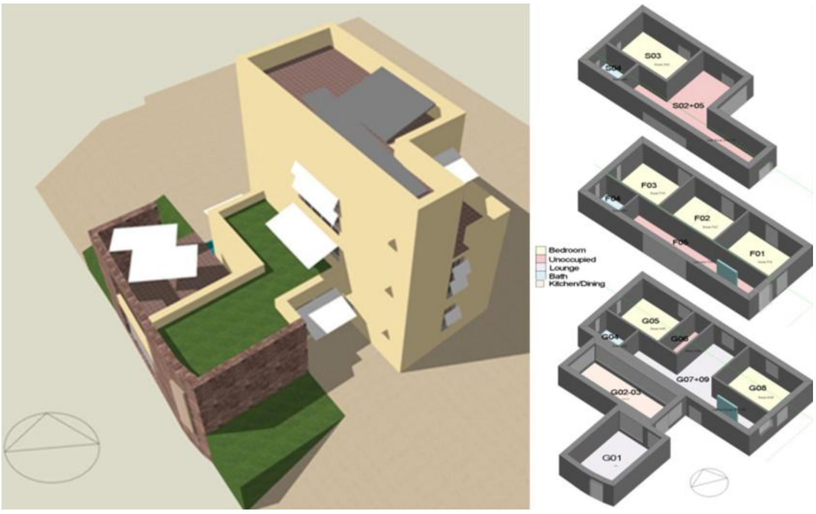

Figure 8: Computer model of the building.

3.2.1 The Actual Building

Simulating the ‘as built’ project with internal loads and ventilation for normal occupancy and full-time space conditioning (19–24°C), resulted in an annual cooling energy use of 6 MWh, or 19 kWh/m² apartment area (310 m²). Figure 9 shows that the cooling season is principally from April to November, and heating is not needed at all. The highest specific cooling need is in the top-floor bedroom

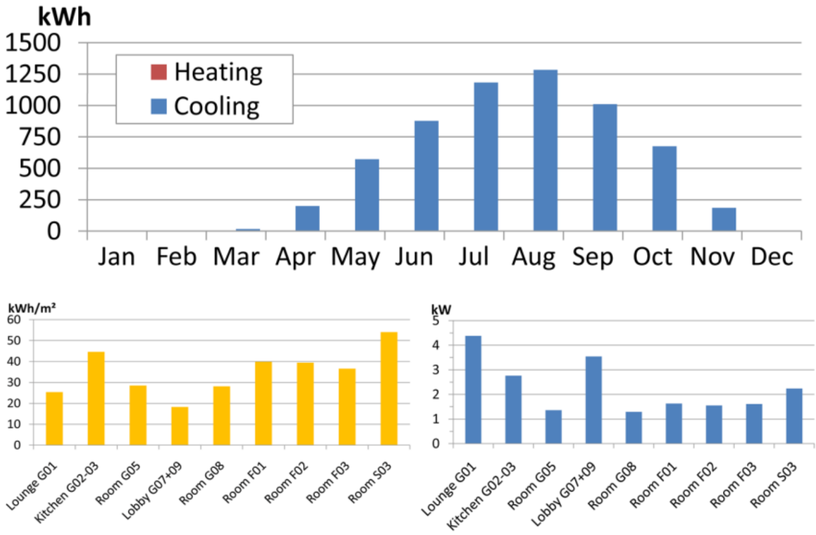

Figure 9: Simulated energy use of the building.
Top: per month. Bottom per room:
Left: per m² net area; right: peak power requirement.

(S03), followed by the kitchen/dining area with a large window area rate. The requirement for installed cooling effect is 20 kW, where the ground-floor living area accounts for the highest demand, and its central air distribution system adds up to a 13 kW peak load, while requirements for individual units in bedrooms are 1.6–2.2 kW, the top-floor representing the higher level.

It is difficult to find reliable figures on electricity use for residential space cooling in Aqaba, but sources from Department of Statistics (DOS, 2007) and Biggs (2005) indicate that a reasonable average level is about 120 kWh/m². This would mean that the AREE building saves 84% energy compared to 'normal' buildings. There could be several reasons behind this huge difference, which we will see in the next section.

3.2.2 Variations and Improvements

One possibility to compare to a 'standard' building is to replace the actual envelope elements for normal Jordanian building practice, i e with U-values of 1.8 W/m²K for walls and 1.3 W/m²K for roofs. This would increase the annual energy use by 21% to 23 kWh/m², and also the cooling power requirement by 30%. These are still levels far below the assumed 120 kWh/m², which could depend on a clever building design, but also on the 'disciplined' occupant behaviour built into the simulation model. Probably both factors influence, and it is not possible to say how much each of them contributes.

A traditional method of cooling is by increased night ventilation. In Aqaba, however, night temperatures do normally never come down to comfortable levels (<24°C) during June–September. However, in April, May and October there is an opportunity to utilize this nocturnal heat sink. If windows are opened during this time instead of running the air-conditioning ('hybrid ventilation'), a saving of 10% on cooling energy can be obtained.

Another possibility of saving cooling energy is by increasing the envelope insulation. A case with tripled insulation (150 mm mineral wool) was simulated, and also here the saving potential compared to the actual design was 10%.

In hot areas and during hot periods the upper limit of the comfort zone is normally higher than in cooler places and seasons – unless people get used to cooled spaces like shopping malls or offices ('adaptive' comfort model). Assuming an extended AC set-point limit of 18–27°C instead of 19–24°C may result in a considerable energy saving; 38% compared to the baseline case. Furthermore, installed cooling capacity can be reduced by 25% which brings down the investment costs for the cooling installation.

Finally, combining hybrid ventilation, increased insulation and an extended comfort zone, we end up with a saving potential of 52% of the energy use compared to the AREE design and regular operation, and 98% saving compared to the assumed normal level in the residential sector of Aqaba today. It should be kept in mind that only the increased insulation requires an extra investment cost, the other cases provide costless methods of saving energy.

The specific energy use of all the cases discussed above is presented in Figure 10.

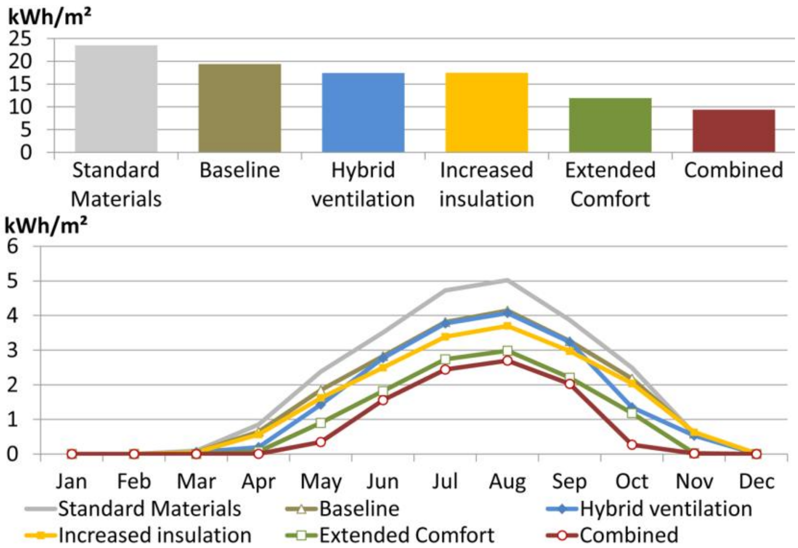

Figure 10: Specific cooling energy for six scenarios.
Top: annual. Bottom: monthly.

4 Life-Cycle Costs

The investment costs for the realized building (standard finishing) amounted to 155 000 Euro. This investment represents an increase of about 48 000 Euro compared to a conventional building (standard materials). Figure 11 presents the life cycle costing and pay-back potential from these additional investments. The payback is described in two scenarios. The first scenario includes the additional costs for all measures including the solar cooling installations: This is called the 'realized project' (Figure 11, top). The second scenario comprises only the additional investments due to design and construction technology. This is called the 'replicable version' for large dissemination (Figure 11, bottom).

What we conclude from these calculations is that investments in passive design elements and improved building materials, alone, yield good pay-back potential over the life time of the project. The incremental costs are around 11 per cent more than the conventional and the pay-back period in this case is about 3.3 years from the energy savings. This compares well with recent trends in high performance buildings across Europe where on average the incremental costs add up to 10% for buildings with less than 45 Kwh/m^{2}a of total primary energy use for space and water heating and electricity (Hastings, 2007). In the case of Jordan, however, for a broad dissemination of the realized scenario (with solar cooling installation) building costs and payback have to be further reduced.

The computer simulations point out some possible further improvements. In combination with costless saving options, like hybrid ventilation and extended comfort zone, increased thermal insulation may save running costs and also

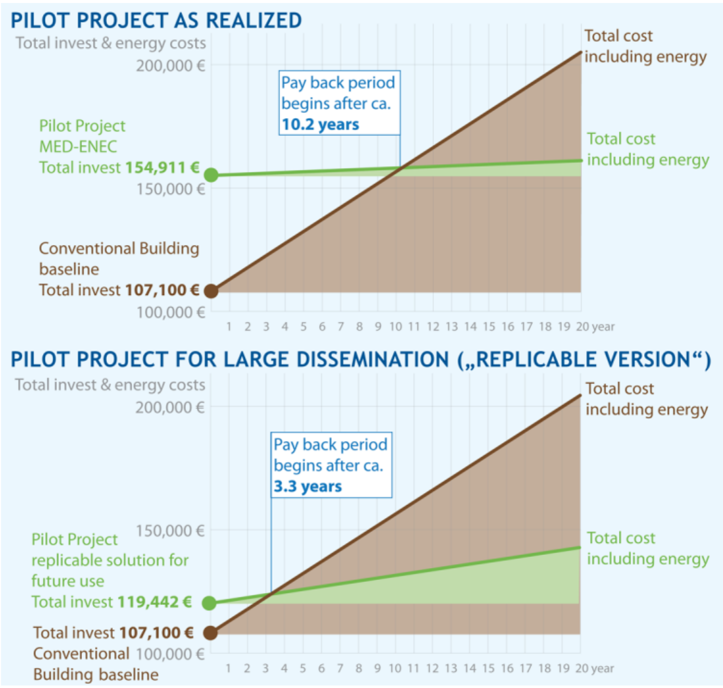

Figure 11: Life cycle costing including total energy costs.
Top: the realized project. Bottom: the 'replicable version'. *Source: MED-ENEC*

decrease investment levels for the cooling equipment. However, any detailed cost estimates for these alternatives have not been made.

5 Lessons Learnt from the Construction Process

Our account of the lessons from the construction process is derived from the periodic project management reports to the funding partners as well as direct observations from the authors' team, as two of the authors have been extensively involved in the project management. Here we will focus primarily on observations related to the execution of the energy concept.

During the design phase, several rounds of discussion took place with the local authorities to get approval for the architectural drawings. In the first design proposal, the main building volume had a better climatic orientation; however that had to be adjusted to comply with setback rules for corner plots. Therefore the final orientation of the realized building is not optimal. Another example is the noted efforts needed to work with local engineering consultants and construction contractors to seal thermal bridges, which should have been a simple problem to solve in the view of the architect. For those actors, AREE had more unusual construction detailing, particularly the ones that are related to elimination of thermal bridges. These details were new to the workers, and to great extend also for the engineers involved in the engineering drawings.

This has lead to several errors in execution which increased the delivery time and costs related to the execution of the energy concept. Finally, the project team faced supply chain problems with the choice of materials for AREE such as the alternative wall blocks with a higher thermal resistance than standard ones.

Given the experience from AREE, an optimist might say that building green in Jordan does not have to be neither costly nor technically inaccessible. An alternative reading of the pilot project experience may also suggest that Jordan, and in particular Aqaba city, is locked-into an inefficient built environment and ineffective building value chain. The challenges of introducing alternative building technologies are more systemic than what they appear on the surface.

The experience from the pilot project points to challenges within the overall building system. These challenges can be as far-reaching as zoning rules working against energy efficiency, the local construction industry practices and norms, knowledge and capacity problems among the chain of actors in building projects and supply chain bottlenecks for alternative materials. On the other hand, one could argue that these challenges are not unique to Jordan and more symptoms of characteristics inherent in the construction work. The project-based orientation as opposed to a process orientation, among other factors, has been frequently noted as one of the barriers for the diffusion of new and energy efficient techniques in the literature on innovations and buildings (Shove, 1998), (Gann & Salter, 2000), (Taylor & Levitt, 2005), (Beerepoot, 2007).

6 Conclusions

As demonstrated with this pilot project, there are several low-cost measures that could well improve the energy efficiency of the built environment in Aqaba. Passive design elements such as orientation, appropriate sizing of windows and shading, combined with behavioral elements can reduce net energy demand up to 70% compared to the common practice scenario. With additional investments in improved envelope construction such as the use of insulation, double glazed windows and tighter control over thermal bridges, the payback on energy saving can be less than 3.5 years, which was the case with AREE. At the same time we need to acknowledge that not all passive measures in AREE worked well for the Aqaba climate. Generally with the hot summer conditions in Aqaba, passive climatization measures, similar to the ones used in AREE, alone are not sufficient for creating indoor comfort; additional active cooling *is* needed. However, occupants' wise 'management' of active and passive climatization systems, and their ability to adapt to extended comfort zones, strongly influence the total energy use for climatization of their residence.

To demonstrate the potential of renewable cooling technologies, a solar powered adsorption cooling system was installed. The costs associated with such systems still make them very unattractive for the private residential market. The challenge even goes further in terms of lack of locally based capacity for the installation, maintenance and operation of such systems.

Acknowledgements: The energy saving measures in this project including the monitoring were enabled by a grant from MED-ENEC, an EU-funded project to promote energy efficiency in construction in the Mediterranean. ASEZA provided funding for the realization of water efficiency measures including the garden concept. Energy efficient lighting was granted to the project by Philips.

7 References

ASEZA. (2007). *Aqaba Special Economic Zone Authority Strategic Plan 2007–2010*. Retrieved February 18, 2010, from ASEZA: http://www.aqabazone.com/files/bro-eng.pdf

Beerepoot, M. (2007). Public energy performance policy and the effect on diffusion of solar thermal systems in buildings: a Dutch experience. *Renewable Energy , 32* (11), 1882–1897.

Biggs, C. (2005). *Building What? The Challenge of Introducing Alternative Building Practices into the Aqaba Built Environment.* Lund University, International Institute for Industrial Environmental Economics - IIIEE. Lund, Sweden: Lund University.

Biotopia. (n.d.). *AREE - The garden*. Retrieved February 18, 2010, from Biotopia: http://aree-garden.biotopia.se

Commision of the European Communities. (2005). *Green paper on energy efficiency or doing more with less.* Brussels.

DesignBuilder Ltd. (n.d.). *DesignBuilder*. (DesignBuilder Ltd) Retrieved 11 06, 2009, from DesignBuilder: http://designbuilder.co.uk

DOS. (2007). *Population and Housing*. (Department of Statistics) Retrieved 2009, from The Hashemite Kingdom of Jordan Department of Statistics (DOS): http://www.dos.gov.jo

Gann, D., & Salter, A. (2000). Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy , 29*, 955–972.

Hastings, R. (2007). Introduction. In R. Hastings, & M. Wall, *Sustainable Solar Housing 2: Exemplary Buildings and Technologies (1–7).* London: Earthscan.

JOHUD. (n.d.). *MEDWA project: sustainable water management*. Retrieved February 18, 2010, from JOHUD: http://johud.org.jo/MEDWA-water-project.html

Shove, E. (1998). Gaps, barriers and conceptual chasms: theories of technology transfer and energy in buildings. *Energy Policy , 26* (15), 1105–1112.

Taylor, J., & Levitt, R. (2005). Inter-organizational knowledge flow and innovation diffusion in project-based industries. *System Sciences 2005: Proceedings of the 38th Hawaii Conference*, (p. 247c). Hawaii.

UNEP DTIE. (2007). *Buildings and climate change: status, challenges and opportunities.* Paris: UNEP.

US Department of Energy. (n.d.). *EnergyPlus*. (US Department of Energy) Retrieved 11 06, 2009, from EnergyPlus: http://apps1.eere.energy.gov/buildings/energyplus/