AREE - Aqaba Residence Energy Efficiency

The Complete Experience

The Center for the Study of the Built Environment (CSBE)

October 2011

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Acknowledgment

The content of this report was developed with the help of the project architect and manager Florentine Visser.

Introduction

The Aqaba Residence Energy Efficiency (AREE) project is an environmentally-friendly pilot project built in Aqaba's 9th District. This project encourages better design and construction practices that promote passive and active energy efficiency, water efficiency, and environmentally friendly construction materials and techniques. One of the main purposes of the project is to demonstrate the cost effectiveness of energy efficient design, construction techniques, and installations for a typical residential building, particularly in a hot, dry climate.

The building is developed by the Emtairah Consulting Corporation Amman, Jordan, and was designed by Florentine Visser, a Dutch architect and consultant for sustainable designs, who specializes in hot climate areas. The design was based on one of the winning entries from the Aqaba Housing Competition,[1] a design competition organized in 2004 by the Center for the Study of the Built Environment (CSBE).The engineering design is by Mohammad Abu-Afefeh in Aqaba. Construction began in early 2007 and was completed in June 2008. The cooling system was installed in May 2009.

The AREE building was selected by the EU-funded MED ENEC[2] project as one of 10 Pilot Projects that aim at promoting energy efficiency in buildings in the Mediterranean region.

The building accommodates 420 m² of residential space. The building focuses on reducing electricity costs for cooling, reducing water consumption, and reducing the environmental impact of construction materials where possible. This was achieved through careful consideration of the following aspects of the building construction process:

1. Thoughtful design: The architectural design carefully considered issues of orientation, floor plan layout, architectural detailing, and the use of architectural features and landscaping to best utilize the natural forces of sun and wind to achieve passive heating and cooling, shading, and natural ventilation, as well as to minimize water consumption.

2. Building technology, construction techniques, and materials: Improved construction detailing and the use of insulation in walls and roofs help create a well-insulated building envelop and minimize the energy demands for

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[1] For additional information on the Aqaba Housing Competition, see, http://www.csbe.org/competitions/aqaba_housing/announcement.htm.

[2] For additional information on the MED ENEC Project, see, http://www.med-enec.eu/.

indoor climate comfort. Energy costs related to the manufacture and transportation of building materials were also taken into account during the selection of those materials.

3. Electro-mechanical systems: the building applied technologies that range from the low-tech to the contemporary state of the art, and that optimize the use of renewable energy and water resources. These include the installation of an experimental solar powered cooling system, and the installation of a graywater recycling system. The installation of electricity generating photovoltaic panels was also considered. In addition, modern technologies that minimize energy and water consumption were used, as with energy efficient lighting fixtures and water saving fittings.

4. Building use – the behavioral aspect: The building occupants play an important role in achieving energy and water saving. This includes the operation of shading devices for windows and doors to block the hot sun, the operation of opening to achieve natural and night ventilation, the use of outdoor spaces, and setting indoor temperature controls. All these can provide a positive contribution to achieving energy savings.

This report will present, in detail, the design considerations, construction techniques, and systems utilized in this building. The report will also share some of the challenges and lessons learned during the execution of the building. After its completion, the building was monitored for over a year to assess its energy performance, and a monitoring report was prepared. A summary of this monitoring report is provided at the end of this essay.

Project Sponsors

Tariq Emtairah, Emtairah Consulting Corporation, Amman, Jordan
MED ENEC: EU-funded project on Energy Efficiency in the Construction Sector – supported the development of an energy efficient design for the building including the installation of certain construction items, the installation of the cooling system, monitoring, dissemination, and selected project management components.
Aqaba Special Economic Zone Authority (ASEZA) – supported the installation of the water efficient garden and the graywater system, and the opening event.
Philips Electronics, Netherlands – supported the installation of energy efficient lighting.

Project Team

Developer:
    Tariq Emtairah, Emtairah Consulting Corporation, Amman

Design
    Architect and project manager: Florentine Visser
    Engineering office: Mohammad Abu-Afefeh, Aqaba
    Landscape: Matilda Nilsson, BIOTOPIA, Sweden
    Thermal performance calculations: Tala Awadallah, Royal Scientific Society, Amman

Construction:
    Construction manager (skeleton): Khaled Abu-Aishah
    Owner representative: Ismail Emtairah
    Finishings coordinator: Jameel al-Homsi
    Skeleton contractor: Mohammad Abdul-Aziz & Partner
    Plastering: Ghalil Abdel-Hamid Mahmood Ghazafy
    Graywater installation: Jameel al-Homsi, supervised by Heba Abu-al-Rub, JoHUD
    Drip irrigation: Mazen Darwish

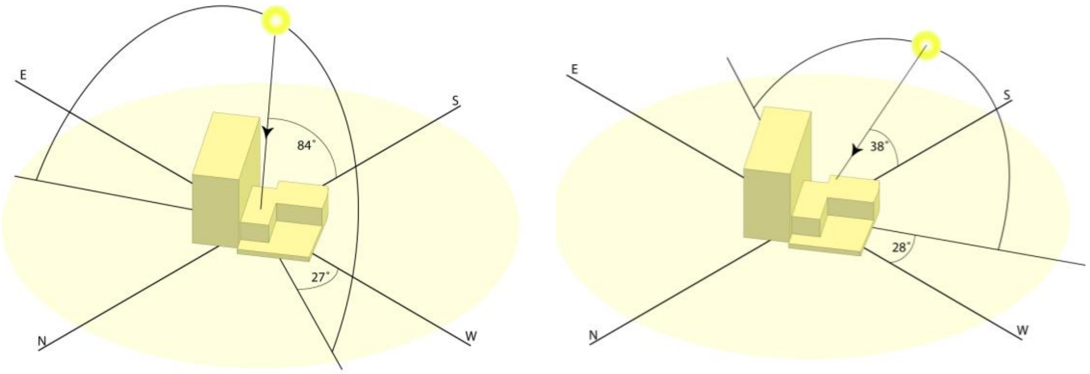
Suppliers
    Adsorption Cooling System: Millennium Energy Industries, Amman
    Furniture: Indoor Home Furniture, Amman
    Lighting: Unilight, Philips Electronics, The Netherlands
    Plant Suppliers: ASEZA Nurseries, Ministry of Agriculture Nurseries, and Dagdel, Aqaba
Dissemination:
    Center for the Study of the Built Environment (CSBE), Amman

Monitoring:
    Building monitoring: Hans Rosenlund, CEC, Sweden
    Cooling installation monitoring: National Energy Research Center (NERC), Amman

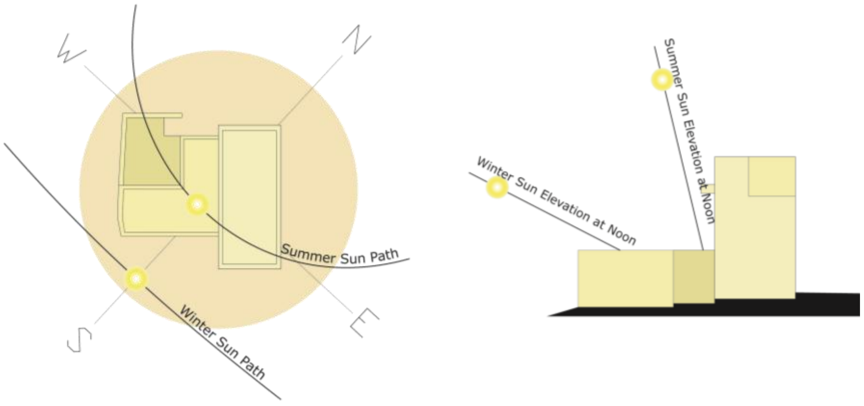
1. Thoughtful Design

1.1 Orientation

The design aimed at orienting the long sides of the building masses along an east-west axis so that its long sides would face north and south. Southern exposures provide the optimum solution in terms of maximizing the sun's rays. However, the shape of the land plot and existing zoning regulations in that area did not allow for a true southern exposure.



Summer Sun Path **Winter Sun Path**



Horizontal Sun Path **Vertical Sun Angles**

Fig. 1: AREE’s orientation in comparison to the sun's path during the summer and winter.

1.2 Compact Mass

The compactness of the building's volumes minimizes the outer surface of the building envelope that can absorb heat. A compact floor plan reduces the use of materials and provides for a more efficient structural design.

The building presents a compact volume to the largest extent possible while addressing programmatic needs and aesthetic values.

1.3 Layout

The development of floor plans carefully placed the house's different functions in order to save as much heating and cooling energy as possible (see fig. 2). Service rooms and areas such as the garage on the ground floor, and the corridors on the first and second floors (fig. 2 in yellow) were placed in the zones most susceptible to heat gain during the summer. This way, they serve as buffer zones for internal rooms. They do not need to be cooled or heated since they are only transitional spaces through which people pass, but do not stay in for long periods.

For the same reason, the bathrooms (fig. 2 in orange), which are only used for short periods of time, were placed in the southwestern side of the building, which is its warmest.

The bathrooms and kitchen (fig. 2 in orange) are grouped closely together – both vertically and horizontally. This minimizes the plumbing work needed to provide hot and cold water and sewage lines. It also minimizes the heat lost as hot water moves through these pipes.

Bedrooms (fig. 2 in blue) were placed in the northeastern part of the house, where they are less exposed to the sun, to prevent them from overheating during the summer.

The living room (fig. 2 in red), which is located on the ground floor, is placed at the southernmost tip of the house, and is protected from the west by the garage and storeroom. The southern side offers a unique location where the low sun can heat it during the cool winter days, while the high sun can be easily shaded off during the hot summer days.

The indoor living-room is designed for active use in the winter, while a shaded ‘outdoor living room’ located above the garage was designed as a summer living-room. This room simulates the cooling effect of a Bedouin tent. It creates an attractive outdoor space with a beautiful view towards the sea. The cooling breeze from the north encourages outdoor living. Since it is extensively used in the summer, the need to cool interior spaces is limited. Parts of this outdoor room may even be used for outdoor sleeping, which traditionally has been carried out to benefit from Aqaba's cool nights.

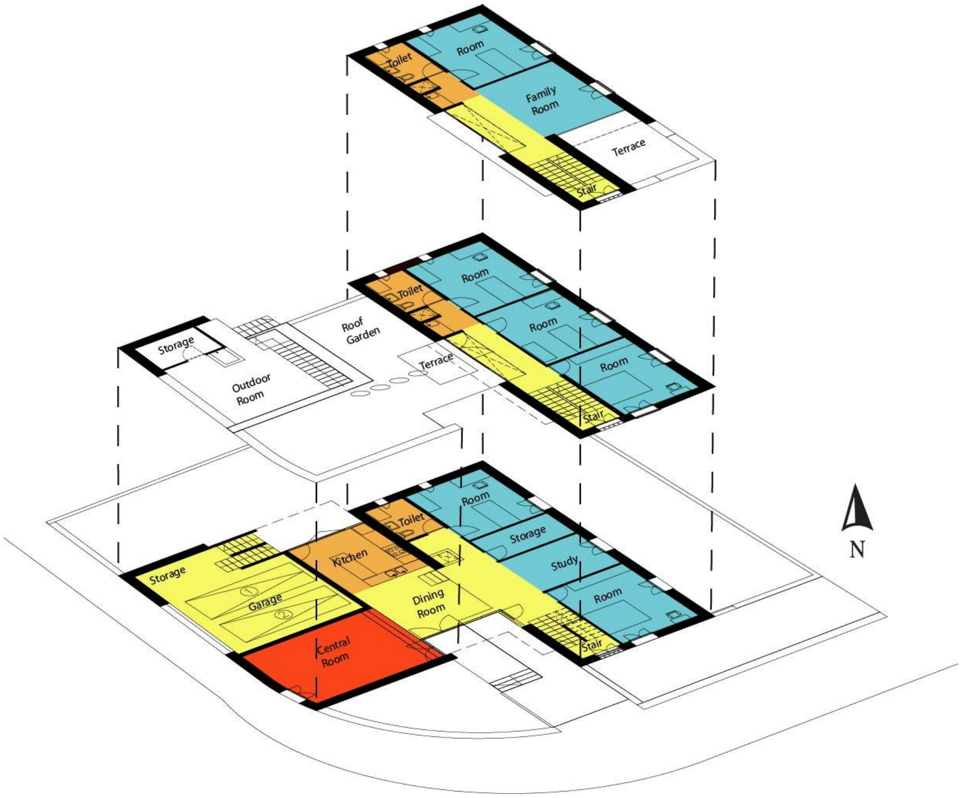


Fig. 2: Layout plan of AREE’s three floors.

1.4 Placement of Openings

The ground floor in figure 3 shows how openings were carefully placed opposite each other to maximize the effects of cross ventilation. This also applies within the rooms themselves, where windows and doors are placed opposite each other.

Even if the doors and windows of the rooms are closed for privacy, both the internal doors and external windows are designed to include small openings at their top to maintain cross ventilation.

Within the house, openings were generally provided along opposite elevations.

The placement of openings was also thought of within the context of the house's different levels. The staircase was placed in a way that allows it to function as a wind tower. It, together with the double height corridor space on that extends across the first and second floors, allow the hot air in the house to rise and thus create a vertical hot air draft, thus improving natural ventilation in the house. The design takes advantage of the fact that hot air rises over cool air. For that reason, a set of small windows were placed at the top of the staircase to induce the upward movement of hot air and direct it outside the building.

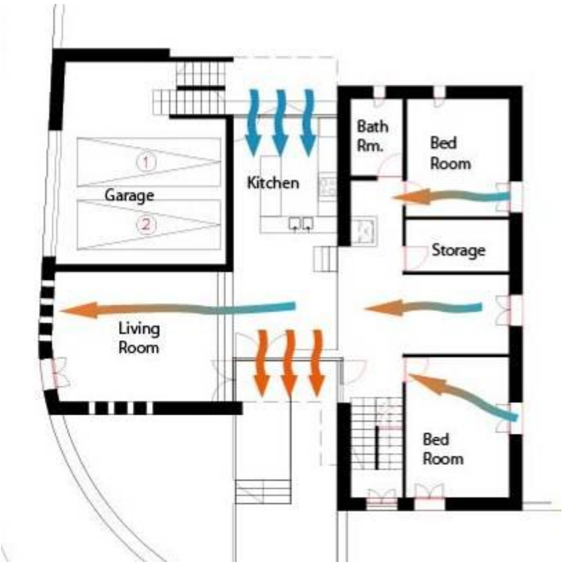


Fig. 3: Ground floor plan showing induced cross ventilation.

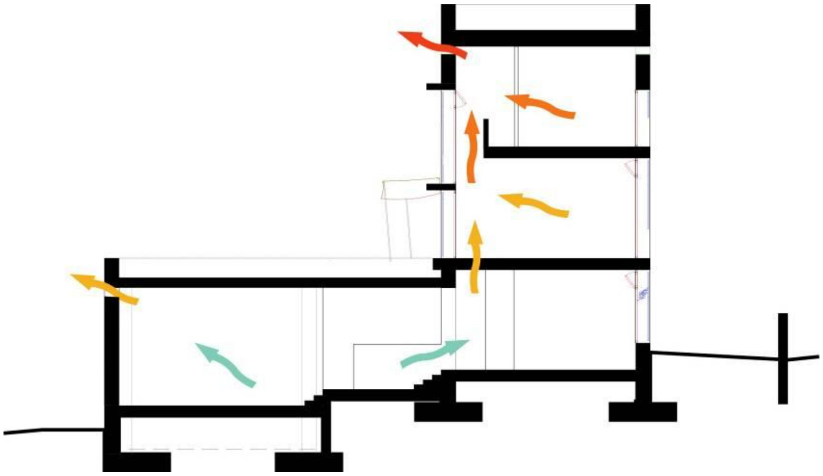


Fig. 4: Section showing how the hot air rises and exits the house.

Fig. 5: The small latches at the uppermost part of the building induce the rising hot air within the building to exit it.

On the ground floor, the cool northern wind is captured from the kitchen entrance, and is further cooled by a small water pool underneath the kitchen entrance.

Narrow vertical windows were used throughout the building. The shaded narrow windows allow little direct sunlight to enter during the hot months, while the glazed area is just large enough to allow natural daylight to enter deep into the rooms during the day. Windows are located along the building's northern and southern sides, whereas eastern and western windows are avoided because they allow the hot sun to enter during the summer days. When it was necessary to use them, they were made extremely small in size.

The only exception to the use of small and narrow windows is a big glazed window that runs over two stories along the southern façade. This glazed area serves as a sun collector during the winter, while a wooden lattice shades it in the summer, preventing direct sunlight to enter.

1.5 Architectural Features and Landscaping Elements

The design incorporates elements that help contribute to the energy efficiency of the house, and enhance indoor thermal comfort. These elements include the following:

1.5.1 Shading elements

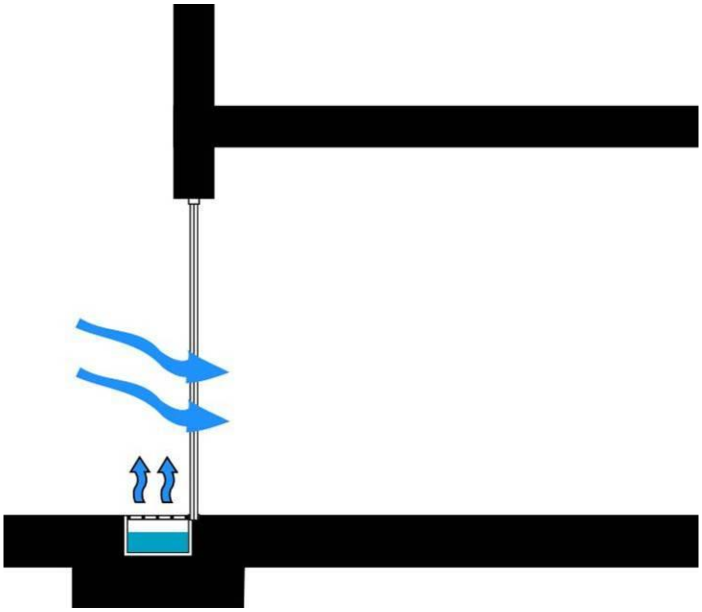
The Design incorporates movable and fixed shading elements that are used to shade the walls and windows. The shading of external walls helps prevent the absorption of heat into the building mass, while movable external shading of windows prevents direct sunlight from entering into the building during the summer at the times when the sun angle is low (in the afternoon for example). The following are several types of shading that have been used for this building:

- Horizontal cantilevers.
- External vertical sliding shades for windows.
- Fixed decorative open concrete blocks in front of the eastern staircase window that allow for air movement yet prevent direct sunlight from entering.
- Fixed shading structures for the outdoor spaces and in front of large windows such as the kitchen and dining area windows.

Figs. 6-9: Images of different shading elements used in the building to shade external walls and openings.

1.5.2 Evaporative cooling pool

The pool is located just below the kitchen door entrance, which opens towards the north. It takes advantage of the northern breezes and cools them further before they enter the house.



Figs. 10-11: Section and image showing the evaporative pool and its cooling effect on the air that enters the kitchen door.

1.5.3 Subsoil cooling

The design uses the three different levels of the ground floor offered by the slightly sloping site for installing several subsoil pipes. The subsoil pipes capture the cool air at the building's northern façade and take it underground, where it is further cooled by the subsoil temperatures, and leads them to an outlet in the living room.

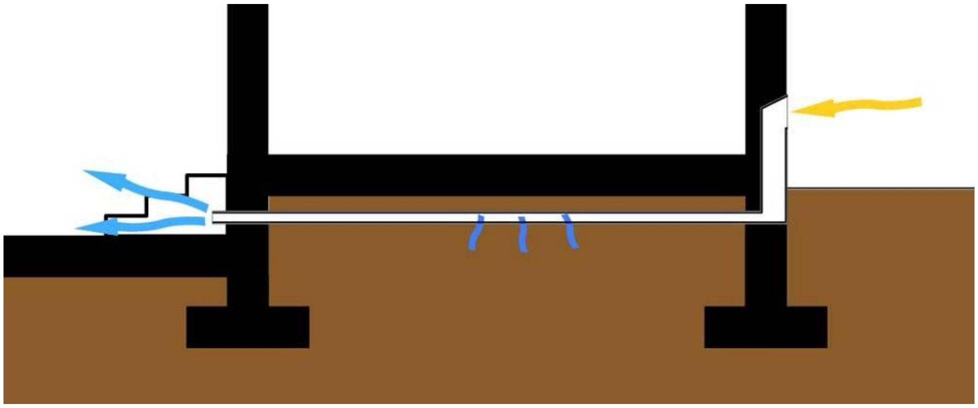


Fig. 12: Section showing the use of underground pipes for cooling.

Fig. 13: Image showing the inlet for the underground pipe while under construction.

1.5.4 Landscaping[3]

The landscape design for the project was developed by BIOTOPIA, Sweden (http://eng.biotopia.se; phone: +46 (0)708 456020; e-mail: biotopia@gmail.com)

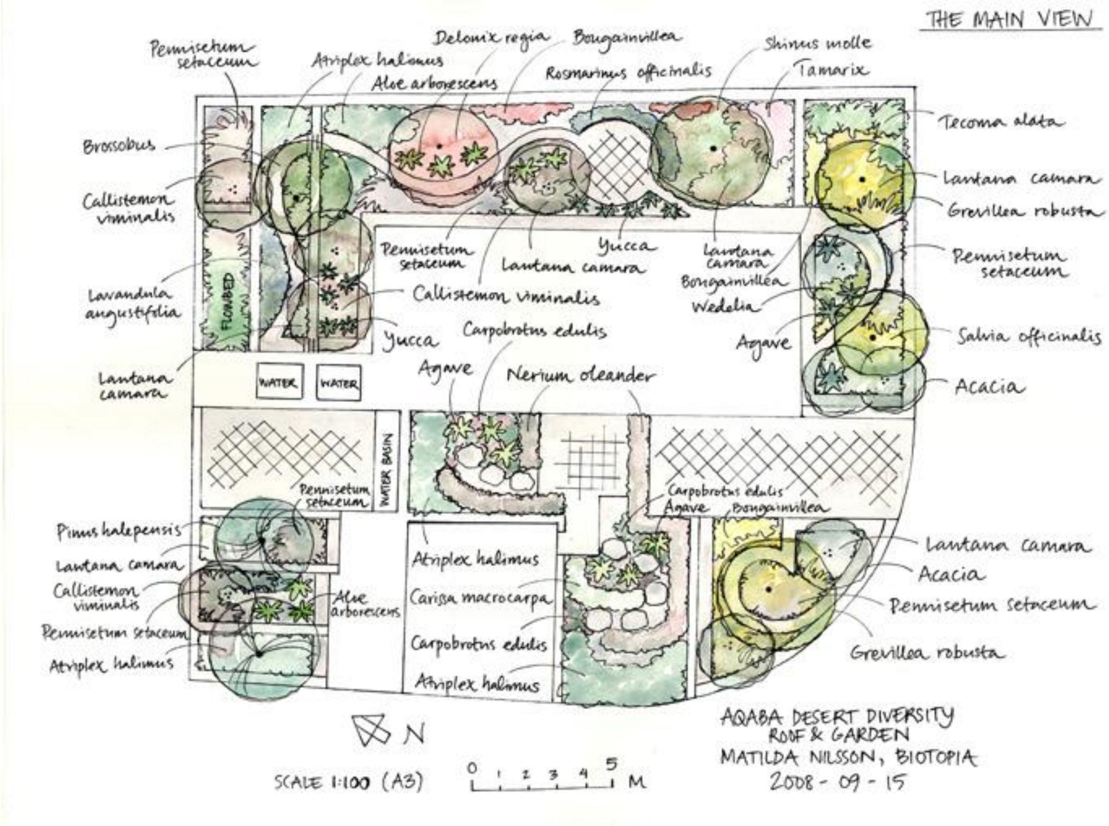


Fig. 14: Landscaping site plan.

The design aimed at using landscaping as much as possible as a climate control tool. Shady trees were planted towards the west to shade off the unwanted hot afternoon sun. In addition, a roof garden is installed on top of the building's lower mass. The plants, as well as the soil of the roof garden, provide the roof with an extra layer of insulation. In addition, plants provide the roof with shade. The roof garden provides a nice outdoor sitting area as well.

Other landscape installations on the roofs and in external living spaces, such as pergolas, have been designed to provide as much shade as possible.

Moreover, the garden is designed following water conserving garden design principles, and using drought resistant plants. Drought tolerant plants can cope with little water and still look good. Also, the plants are watered with

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[3] Information about the landscaping concept was provided by the landscape consultant BIOTOPIA. For additional information and pictures, see, http://aree-garden.biotopia.se/index.html.

graywater coming from the house. The durable plants chosen tolerate higher pH levels and some chemical residue. Many of the plants are local or from similar arid regions, and most of them are evergreen, thus providing greenery throughout the year.

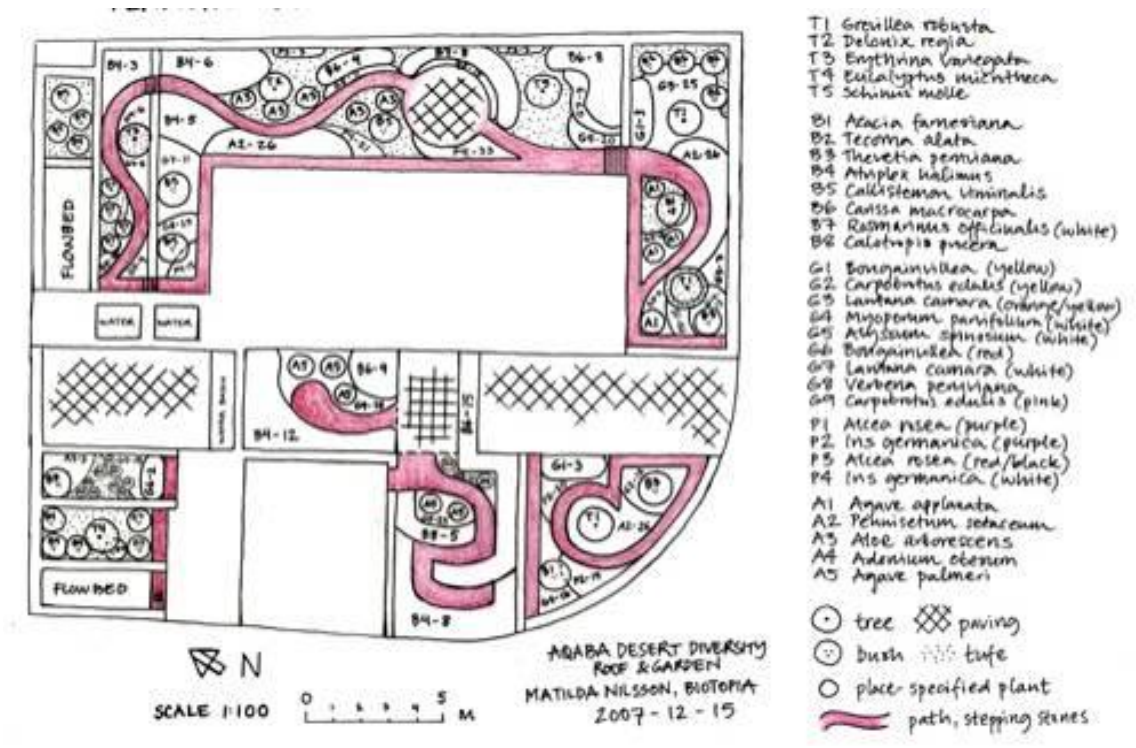

Fig. 15: Landscaping planting plan.

The landscape design identified 3 different landscaping zones. Each zone has specific features and characteristics that are tightly linked to the role of landscaping in increasing the building's energy efficiency, while minimizing the need for water and maintaining an appealing look. These zones are:

- The entrance: Plants that are tolerant of heat and full sun exposure are used here. They are in color shades of warm yellow, orange and deep purple to create an aesthetically pleasing entrance. The terraces: The partial shade available for the terraces provides excellent conditions for the growth of herbs and ornamental plants.

- The roof garden: Here, the ground cover *Carpobrptus Edulis* is particularly effective, completely covering the soil after only one year. Steppingstones allow for easier maintenance. *Nerium oleander* and Agave give height and also color as they bloom. *Nerium oleander* is intended to grow and densify quickly, thus providing the patio with shade and privacy from the street.

These plants were planted in a soil mixture of sand, *tuf* stone, and local yellow and red soil with some clay content. The soil surface was covered with *tuf* to control water evaporation. *Tuf* also provides for an aesthetically pleasing ground cover.

Figs. 16-17: Images of the landscaping at the entrance.

Figs. 18-19: Images of the landscaping in the terraces.

Figs. 20-21: Images of the landscaping of the roof garden.

Within a year after the construction of the garden, tests showed that indoor temperatures decreased, particularly under the roof garden. The graywater irrigation system also has worked well. The water is reaching the plants through the reed bed system, with good results. No plants have shown any severe problems, except for some species growing too fast because of excess watering. This is mostly an aesthetic matter that was solved through pruning during the second year after planting. Another common problem with plants grown on sandy soils, especially when watered with graywater, is the lack of iron and micro nutrients. The garden was fertilized with micronutrients during the third year after planting because a few yellow leaves started appearing. This is a common symptom of micronutrient deficiency.

2. Building Technologies, Construction Techniques, Detailing, and Materials

2.1 Walls and Wall Materials

2.1.1 Wall Types

The typical wall formation in Jordan basically consists (from the inside out) of a 10 cm plastered hollow cement block wall, 5 cm of insulation, and a 7 cm stone cladding attached to a 7-10 cm concrete layer.

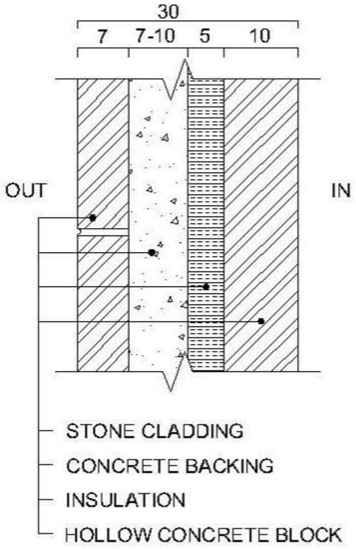

Fig. 22: Typical wall section used in construction in Jordan.

The building's structural design aimed at upgrading conventional wall sections and experimenting with new ideas, keeping in mind the use of locally produced materials as much as possible. Three different wall sections were used in the building's construction:

Wall 1 – Hollow concrete block cavity wall with plaster finish mixed with straw. The cavity is filled with rockwool for insulation, as well as sand and straw to increase the thermal capacity[4] (thermal mass) of the walls (Total U-value = 0.34 W/M^{2}K).[5]

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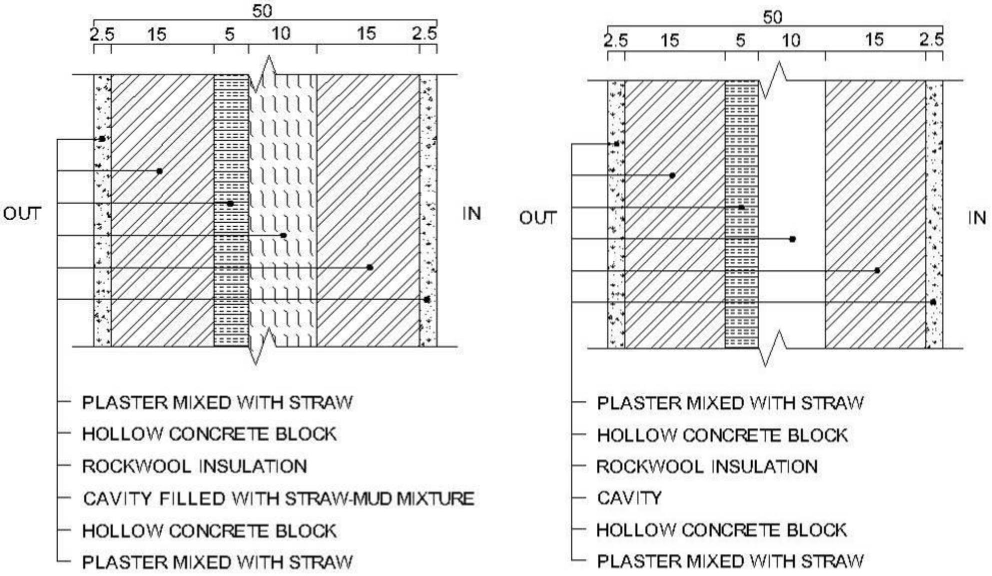
[4] The thermal capacity of a wall measures the ability of the wall to store heat. Increasing the thermal capacity of a wall increases the time gap during which outdoor heat is transferred to the interior.

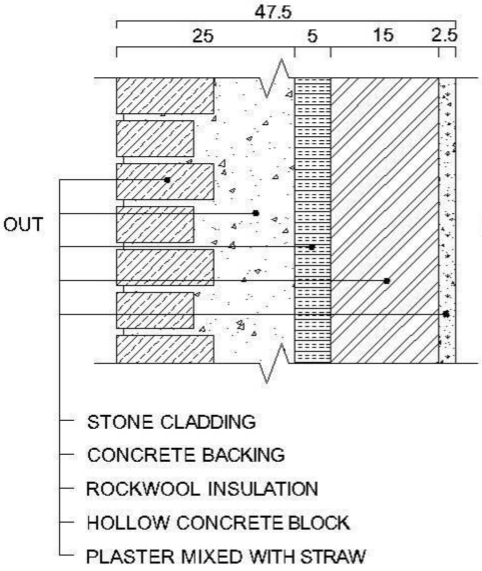
[5] The U-value (the Heat Transfer Coefficient) is a measure of the rate of heat loss or gain through a material or assembly of materials. U-values gauge how well a material allows heat to pass through The lower the U-value, the higher is the material's energy efficiency.

Wall 2 – Hollow concrete block cavity wall with rockwool for insulation and a plaster finish mixed with straw. (Total U-value = 0.39 W/M^{2}K)

Wall 3 – Cavity wall with stone cladding on one side and plaster finish on the other. (Total U-value = 0.50 W/M^{2}K)



Wall 1 section **Wall 2 section**



Wall 3 section

Fig. 23: Sections of the three types of walls used in the building.

2.1.2 Concrete blocks

3 different types of concrete blocks were examined to choose the best sustainable option:
Type 1: Hollow blocks made with perlite aggregate (from Greece), U-value = 2.00 W/M^{2}K.
Type 2: Hollow blocks made with volcanic aggregate (from Mafraq, Jordan), U-value = 3.13 W/M^{2}K.
Type 3: Typical hollow blocks (made in Jordan, and available in most Jordanian markets), U-value = 5.55 W/M^{2}K.

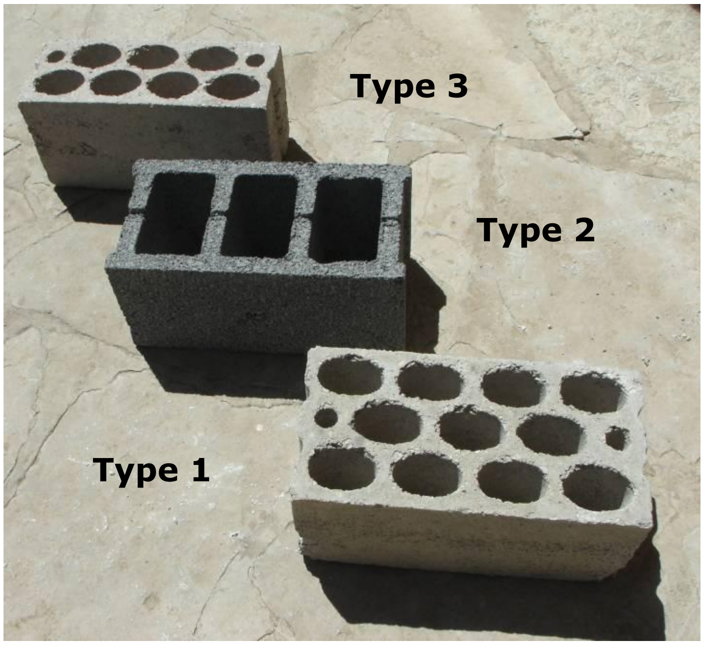


Fig. 24: Image showing the three concrete block types mentioned above.

After comparing the three types, type 1 was found to have the least U-value, followed by type 2. Type 1, however, has a large amount of latent energy embedded in it since the aggregate has to be imported, and thus includes considerable energy consumption needed for shipping and transportation. For this reason, type 2 was chosen. Soon after construction was initiated, there was a shortage of type 2 blocks in the market. This forced the construction team to use type 1 instead.

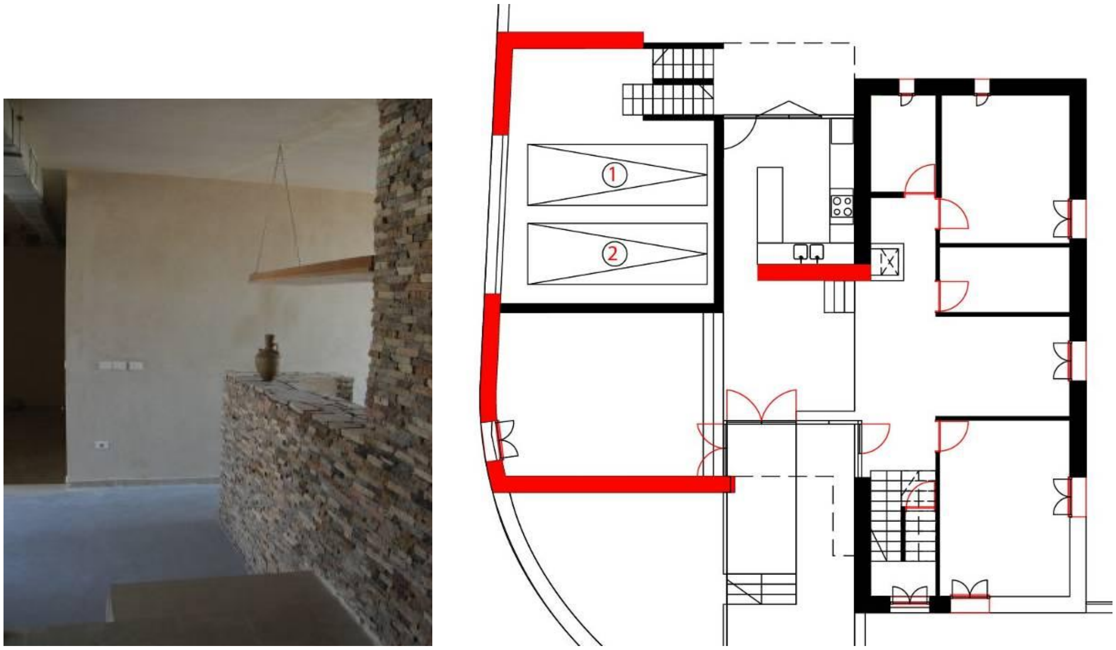
2.1.3 Masonry

Stone cladding is typical in external wall construction in Jordan. The stone used in the construction of the building consisted of stone scrap and leftovers collected from stone workshops. This choice was based on the need to minimize the environmental impact of stone quarries and to show that recycled materials can have an aesthetic value. The result is a beautiful façade with a collage of different stone colors.

The un-wanted leftover material initially was obtained for free. However, once the workshop providing the stones learned that their waste was used as a construction material, they started charging for it.

Fig. 25: Image showing the stone cladding pattern produced using leftovers from stone workshops.

Stone was used on the southern façade as well as for a few of the internal walls at the ground floor level. The high thermal capacity of the stone helps offset heat gain during the day and radiates it at night, when the temperatures are cooler.



Figs. 26-27: Image of an internal stone wall, and the ground floor plan showing the location of stone walls (in red).

2.1.4 Plaster

Plaster was mixed with straw and pigment as an experiment aimed at decreasing the U-value of the conventional plaster finish made solely from cement and then covered with paint. By adding straw to the plaster mixture, the amount of needed cement decreases by 25%, and the U-value for the plaster is improved by 400%. However, since the thickness of the plaster on the wall is very small, this addition of the straw to the mixture has little impact on the wall's total U-value. Yet, the straw gives a nice aging quality to the wall, and the addition of the pigment to the mixture reduces the labor costs resulting from adding yet another coat of paint on top of the plaster.

Fig. 28: Image of a plastered wall using the straw-mud mixture.

2.1.5 Insulation

Rockwool, polystyrene, and a sand-straw mixture were used for insulation within the walls. Each of these has its pros and cons:

- Rockwool has very low U-value, and is a very good insulator. However, it is very susceptible to water and water vapor, and should be very carefully installed and water insulated. If dampness reaches the rockwool, its insulating effect will disappear. This of course is less of a concern in the hot dry climate of Aqaba.
  Rockwool was generally used where wall construction was dry (i.e. between two walls constructed with concrete blocks) to avoid exposure of the rockwool to the wet concrete.

- Extruded polystyrene is the best type of polystyrene that may be used for insulation. It can be easily applied and is not affected by dampness. However, it is not manufactured in Jordan, but is imported from Saudi Arabia. It is also less environmentally friendly than rockwool, which requires less manufacturing efforts. Polystyrene was used in the building where construction was wet; i.e. in the stone-clad facades with concrete backing.

A main construction challenge was the application of insulation materials. The ideal situation for installing insulation requires the external envelope of the building to be constructed as two separated layers, with the insulation in between. However, as Aqaba is located in an earthquake susceptible region, achieving the necessary structural stability requires that the height of the building be divided with structural beams at each floor level. Therefore, in order to avoid thermal bridges[6] at the junctions between the walls and the structural system, the insulation has to wrap around these structural elements. This proved to be hard to execute, and the construction team had a difficult time fixing the insulation to the exterior of the building as it kept falling off.

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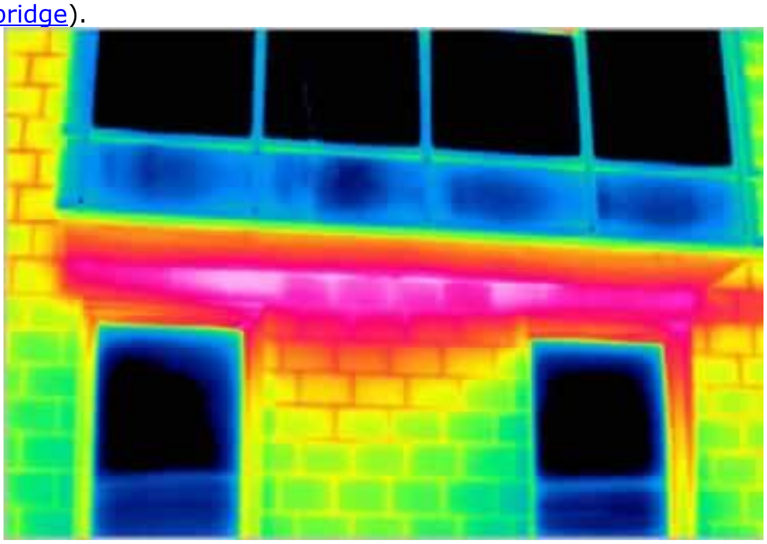
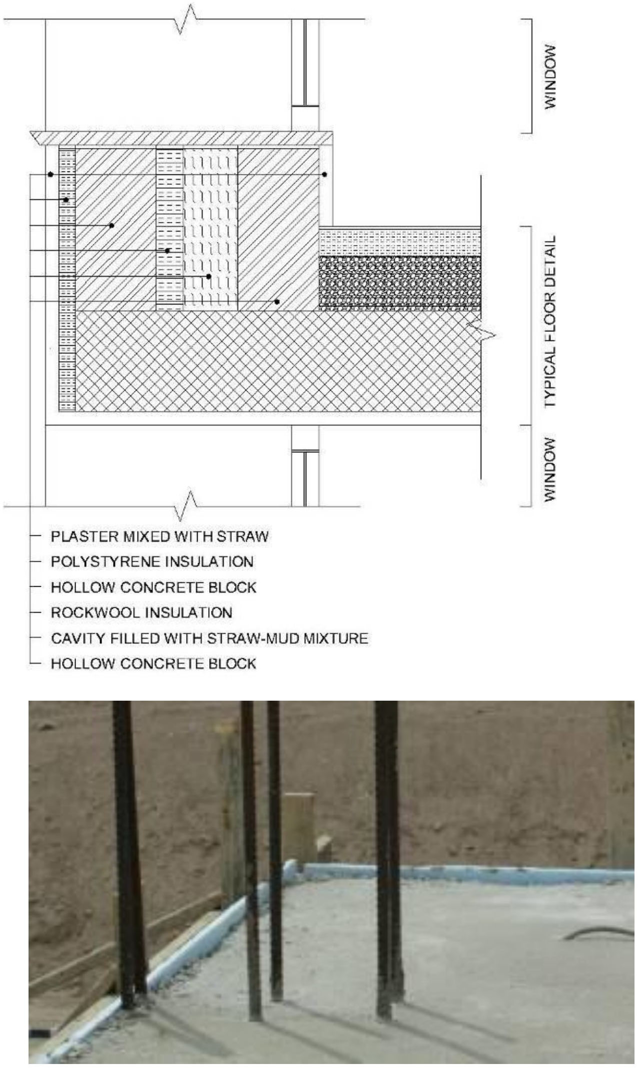
[6] Thermal bridges are junctions where insulation is not continuous, thus resulting in heat loss. In a building that is not properly insulated, thermal bridges represent low comparative losses (usually below 20%) as total losses via the walls and roof are very high (about >1W/m2K). However, when the walls and roof are well insulated, the percentage of loss due to thermal bridges becomes high (more than 30%), but overall losses remain very low (less than 0.3 W/m2K). That is why in low energy consumption buildings, it is important to have very high thermal resistances for walls and roofs. This means that heat loss as a result of thermal bridges remains low. (Source: http://www.isover.com/Q-A/Implementation/What-is-a-thermal-bridge).



An infrared image of a thermal bridge (in red) formed by the structural beam below the balcony window. (Source: http://www.rensolutions.co.uk/thermal_bridge.php)



Figs. 29-30: External edges of floor slabs insulated by polystyrene strips are used to avoid the formation of thermal bridges.

Another issue relating to the application of insulation is the necessity of carefully installing it so as not to leave any gaps. This entailed careful supervision of the construction team by the contractor and the architect, since this is not the conventional work procedure in Jordan.

Fig. 31: Image showing the overlapping of insulation material to insure equal distribution.

The last challenge affecting insulation involved wet construction. The conventional wall construction process in Jordan starts with building the internal block wall first, followed by applying the insulation, building a few rows of stone, and then pouring the concrete backing between the stone work and the insulation. The pouring of concrete compresses the insulation, thus lowering its insulating capacity, and also may result in breaking the damp proofing material that covers the insulation. A preferred way to construct the wall would be to use wood framing to build the outer layer of the wall, then fixing the insulation to it, after which the internal block wall would be built (see diagrams below).

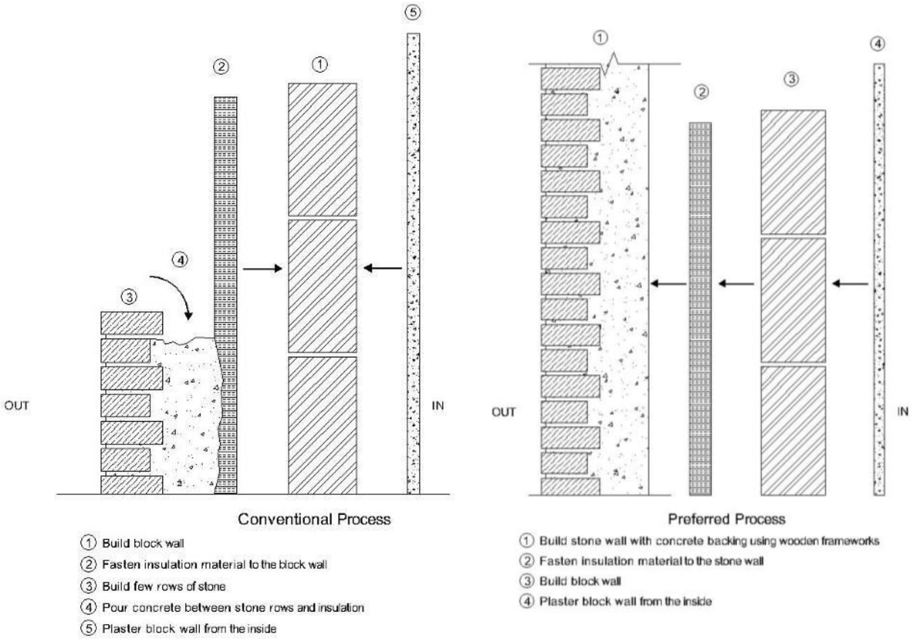


Fig. 32: Diagram showing the difference between conventional and preferred processes of wet wall construction.

Of course this process is more costly than conventional methods. However, it will not compromise the insulation capacity of the rockwool in the long run. Because of the extra cost involved, the building contractor refused to adopt this process. Polystyrene insulation therefore was used for the wet wall construction.

Figs. 33-34: Polystyrene is used here for insulation in wet construction (left), while rockwool is used for insulation in dry construction (right).

2.2 Roof

In climatic zones where the sun is almost perpendicular to the earth’s surface during the summer, the roof is the most heat-absorbing surface in a building. That is why special attention was given to its insulation. A 5 cm insulating layer was applied to the roofs’ construction. A layer of stabilized sand mixed with a small portion of cement was used instead of a concrete screed layer. The sand has lower thermal conductivity and a high thermal mass, which help improve the roof's insulation.

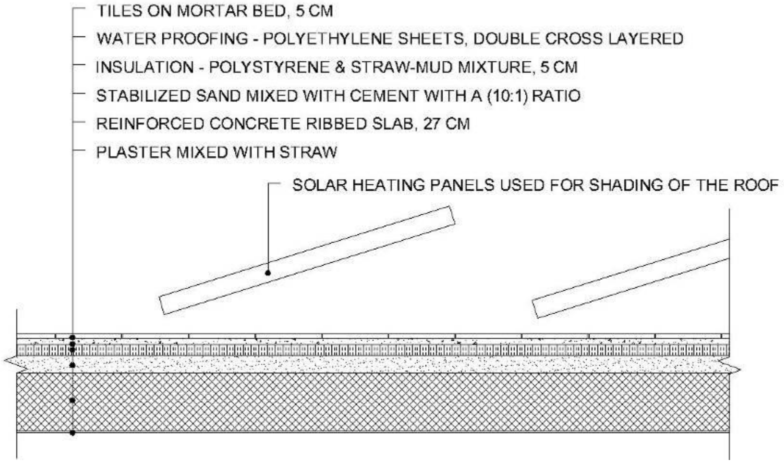


Fig. 35: Section showing the building's roof construction.

Waterproofing the building usually is achieved by using bitumen sheets. However, bitumen sheets cannot be installed on top of the insulation. They therefore were substituted for polyethylene sheets, which is sufficient in Aqaba, where average annual rainfall is only 30 mm.

Fig. 36: Image of polyethylene sheets spread over the roof.

As mentioned earlier, part of the roof was used as a roof garden. The extra layer of soil on top of the roof increases its thermal mass and helps offset heat gain. The plants on the roof garden and the solar heating panels also shade the roof.

Fig. 37: View of the roof garden.

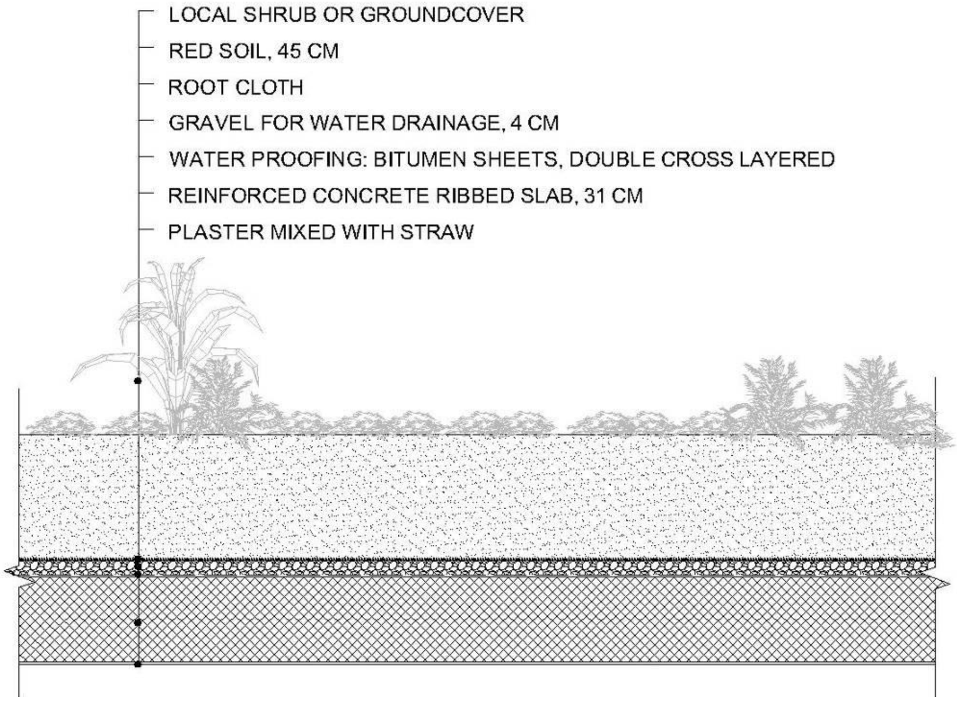


Fig. 38: Section showing the construction detail for the roof garden.

2.3 Floor Slabs

Conventional reinforced ribbed concrete slabs were used for all internal floor slabs (see fig. 39). These were finished with an epoxy layer placed on a 5 cm concrete screed, which in turn is placed on a 10 cm gravel layer. In Aqaba, it is not necessary to insulate the ground floor slab since the earth's high thermal mass makes it cooler than its surroundings.

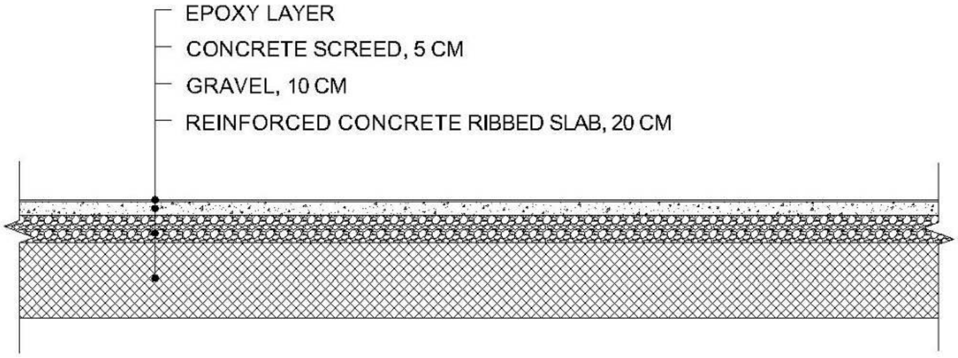


Fig. 39: Section showing the construction detail of the floor slab.

2.4 Windows

As mentioned earlier, the building's windows are longitudinal in shape to allow daylight to enter, while minimizing the duration of the sun's penetration through them. The only exception to this rule is the large glazed window on the southern façade of the building, which is intended to function as a heat collector that heats the house during the winter. This window is well shaded during the summer to prevent direct sunlight from entering the building.

All of the windows have external movable wooden shades in order to control direct sunlight as needed.

Windows throughout the building are double glazed. Double glazing in windows lowers their U-value from 5.9 to 2.9 W/m^{2}K. Double glazing also decreases the window’s transmittance[7] of solar radiation from 83% to 69%.

Large longitudinal windows used in the rooms included a small opening at their upper parts. These windows, together with the windows above the internal room doors, allow constant air flow even when doors and windows are closed.

Windows were designed with steel window frames rather than aluminum ones, which require a more involved manufacturing process. Foam strips were used around the steel frames to insure air-tightness. Wooden frames for the movable shading screens also function as insulators for the steel windows.

Each window is placed along the internal side of the wall. This maximizes the benefits of the shade provided by the thickness of the building skin.

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[7] Transmittance: represents the percentage of solar radiation that passes through a transparent material. Solar radiation reaching a window is reflected, absorbed by the window, or transmitted.

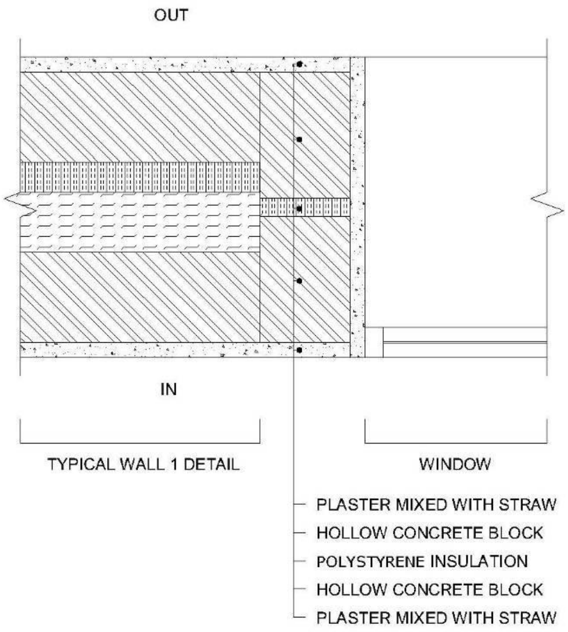

Fig. 40: Horizontal sectional detail of the meeting points of walls and windows showing the methodology used to ensure continuity in the insulation.

Fig. 41: Windows were fixed along the inner sides of the outer walls to maximize shade.

2.5 Furniture[8]

Producing 100% environmentally friendly local furniture cannot be obtained in Jordan today. Because demand by consumers for environmental furniture is extremely low, it is very hard to find suppliers who are interested in providing eco-friendly materials for making furniture.

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[8] Information on environmentally friendly furniture was provided by Indoor Home Furniture, which supplied the furniture for the project.

Furthermore, furniture manufacturers do not have clear regulations regarding their working environment. Toxic fumes and residues often are released during the manufacturing process through the use of varnishes and adhesives that contain formaldehyde, which can be harmful to both workers and the environment.

Environmentally friendly furniture was designed and supplied to the project by Indoor Home Furniture (www.indoor-furniture.com; tel. +962 6 4624536). The environmental concept for their furniture design may be summarized as follows:

Design and building:
- Maintain a simple, functional approach and avoid unnecessary details.
- Try to minimize the quantity of materials used.
- Build pieces that can be disassembled so that it is easier to reuse them in the future.
- Try to make furniture pieces that are multi-functional.

Wood
- Use fast-growing softwoods such as pine and cedar, since FSC[9] certified wood is not locally available. Also, try to make use of small leftover pieces or reclaimed old pieces of furniture.
- Substitute manufactured boards such as plywood, particle board, or MDF with traditionally made panels of soft woods. Most of these large industries still depend on abusive logging, which contributes to habitat destruction.

Paint
- Use either natural finishes such as linseed oil, teak oil, bee wax, or water based materials that do not release harmful fumes.

Fabric
- Depend on locally produced handmade fabrics that are made from natural cotton or wool.
- Try to make use of small leftover pieces of fabric.

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[9] FSC (Forest Stewardship Council) is an independent, non-governmental, not-for-profit organization established to promote the responsible management of the world's forests. FSC Certified Wood ensures that the wood used comes from responsibly harvested and verified sources. For additional information on FSC Certified Forest Products, see http://www.fsc.org.

Figs. 42-43: Images of the furniture used in the building.[10]

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[10] Images are by Joseph Zakarian. Source: Nicholas Seely, "Home of the Future," *JO Magazine*, Nov. 2008.

3. Electro-Mechanical Systems

3.1 Domestic Hot Water Supply

During the summer in Aqaba, there is hardly any need for water heating. In the winter, domestic hot water is supplied by a system of panels that collect solar energy to heat the water. The system is composed of 11 Azuro Paradigma panels, each with 24 evacuated tubes. These solar collectors are placed on the main roof.

Each panel is 2 m x 1.6 m in cross sectional area, and occupies a roof area of 2 x 1.50 m. There are 3 rows of panels. One row of 5 collectors faces the Southeast, and is tilted at an angle of 6 degrees. Each of the other 2 rows of 3 collectors faces the southwest, and is tilted at an angle of 17 degrees. This is to maximize the benefit of solar energy throughout the year.

The collectors are placed in a manner so as not to shade each other during the summer or winter, and also to provide maintenance space in between. The total area that the collectors occupy is about 32 m^2.

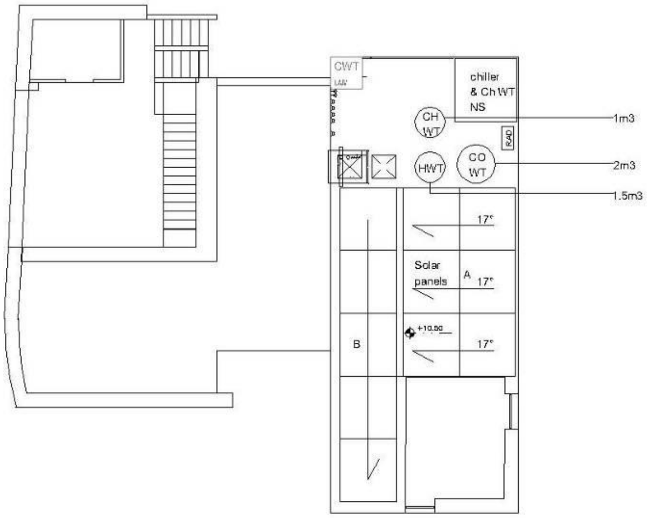

Fig. 44: Diagram showing the distribution of collectors on the roof.


Fig. 45: Solar collecting panels on the roof.

In order to prevent overheating, the collector fields have pressure valves that feed back into the hot water tank, and also a heat dissipater with an outlet to the roof floor.

These solar panels also serve as a basis for the building's cooling system, as will be explained later.

3.2 Heating System

Thermal modeling of the building design showed that there was hardly a need for heating. Therefore no heating system has been installed.
In case of extreme cold winters in Aqaba, heating may be provided using movable gas heaters.

3.3 Cooling System

The strong sun of Aqaba is available throughout the year, and it is the best energy source to use, even for cooling purposes. The building features an experimental solar adsorptive cooling system in order to utilize the abundantly available solar energy for cooling purposes. The amount of solar energy that be collected during the hot summer months exceed what is needed by the solar cooling system, as shown in the diagram below.

The solar-driven adsorption[11] cooling system developed by Millennium Energy Industries (MEI) in Amman, and is installed on the top roof. This experimental technology uses the solar hot water system as an energy resource for the adsorption chiller, which delivers cooling at a high efficiency rate. The hot water generated by the evacuated tube solar collectors to provide domestic hot water is also used to secure hot water for night cooling. The hot water drives the adsorption chiller to produce cold water, which runs through a conventional distribution system of individual fancoils and air handling units (as with conventional air-conditioning units with ducts from the cold water tank to provide cooling at night).

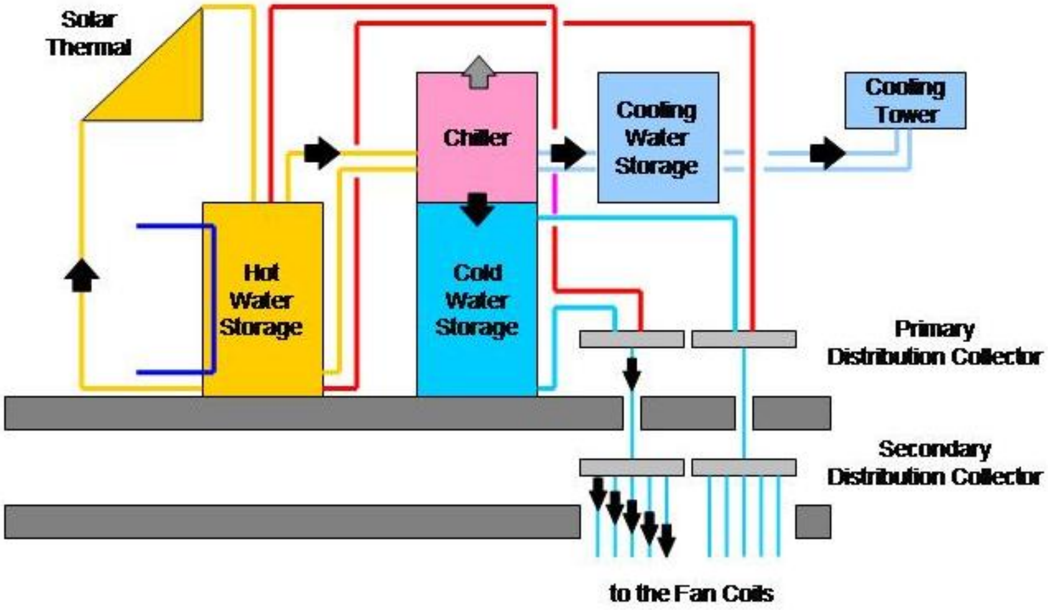

Fig. 46: Adsorption chiller cooling system installed at AREE.

The adsorption chiller is more energy efficient than the more common absorption chiller, since it can provide cooling with a water input temperature of 65 instead of 90°C. It also is more environmentally friendly, since it uses silica gel and a zeolite coating technology rather than ammonia. It also minimizes crystallization of water in the system, and thus requires less maintenance.

A third party chiller (Sortech ACS 15) was installed by MEI as a temporary substitute system during the intermediate period during which the adsorption chiller was not ready.

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[11] Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or a liquid, forming a molecular or atomic film. It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution.

3.4 Photovoltaic (PV) Cells

According to Jordan's National Energy Resource Center (NERC), the economic feasibility of installing PV systems in urban areas in the country has yet to be established. That has been confirmed by the EU-funded MED ENEC program's financial engineering section. Calculations suggest that the payback period for the investment in such a system can reach 14.8 years. This is mainly due to relatively low price of electricity in Jordan. It should be noted, however, that the price is expected to rise in the near future.

Photovoltaic systems generally are used as part of a hybrid electricity generating system that is connected to the power grid. PV cells placed on top of a residence can produce more energy than it needs. It therefore would be more efficient if the surplus energy can be sold to the electricity provider. In the mean time, the electricity located in the power grid would be needed at times when solar energy is not sufficient for the house, such as during nighttime or when there is cloud cover. Such a setup was suggested for the building, where a PV system was planned based on a solar power potential of 6 $KWh/m^2/day$ average. However, since the idea of connecting to the power grid so far has not been applied in Jordan, particularly for private residences, the idea was abandoned.

Attempts have been made to obtain additional support for installing a PV system as a demonstration, but with no success. European suppliers still do not see Jordan as a potential market, and therefore are not yet willing to fund such a system.

It therefore was decided that the additional investment in a PV system was not a priority. In case external funding is secured in the future, however, the option to install a PV system for generating electricity remains available.

3.6 Energy Efficient Fixtures

3.6.1 Lighting[12]

Philips Electronics – the international Dutch-based company - supported AREE with a state-of-the-art portfolio of lamps, gear, optics, luminaries, and controls. The objective of the lighting design was to create the most energy-efficient solution for the building, and to achieve significant reductions in energy consumption, Co_2 emission, and other harmful substances.

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[12] Information for this section was provided by Philips Electronics.

Outdoor lighting: Good outdoor lighting can improve safety and emphasize architectural features. It also encourages users and visitors to socialize and spend time outdoors instead of staying inside the house, thus increasing the use of air conditioning. The lighting concept for the building is based on color change with LED lights (Philips LEDline2). The mixing of RGV colors makes it possible to create almost any given lighting color.

Although LED lights are more expensive, their value lies in their very low running and maintenance costs – one LED has an average lifetime of 50,000 hours and consumes a mere 1-3 watts compared to 60-100 watts needed for normal bulbs, and 8-28 watts needed for energy saving CFL (Compact Florescent Lamps) bulbs.

Fig. 47: AREE at night.

Indoor Lighting: A selection of controls used in the building has helped reduce the cost of energy and maintenance. For example, in the bedrooms, study, kitchen, family area, and corridors, the system ensures that light is controlled according to the amount of daylight available. The controls allow lights on the window side of the room to adjust automatically as the amount of daylight in a space decreases or increases, all without disturbing the occupants. This solution ensures comfortable lighting levels. The application of this system results in substantial energy savings at the window side (up to 70%), and it can always be switched off when the spaces are not in use.

3.6.2 Electrical Appliances

The building owner tried to choose the most energy efficient appliances available in the market. However, there is a lack of information available to the consumer in the Jordanian retail market on this matter. There is no standard rating system for energy performance for electrical appliances in Jordan, although some appliances have European ratings placed on them. In addition, none of the retailers in Aqaba could provide any useful information on the comparative energy use of different brands.

3.7 Water Saving Fixtures

The building water outlets in the kitchen and bathrooms use water saving fixtures. This includes sinks, shower heads, and toilet flushing systems. These water saving fixtures have the following flow rates:

Showers	6 L / minutes
Toilets	6 L / flush
Faucets	5 L / minutes

The diagram below shows the estimated percent water saved in each of the different household tasks:

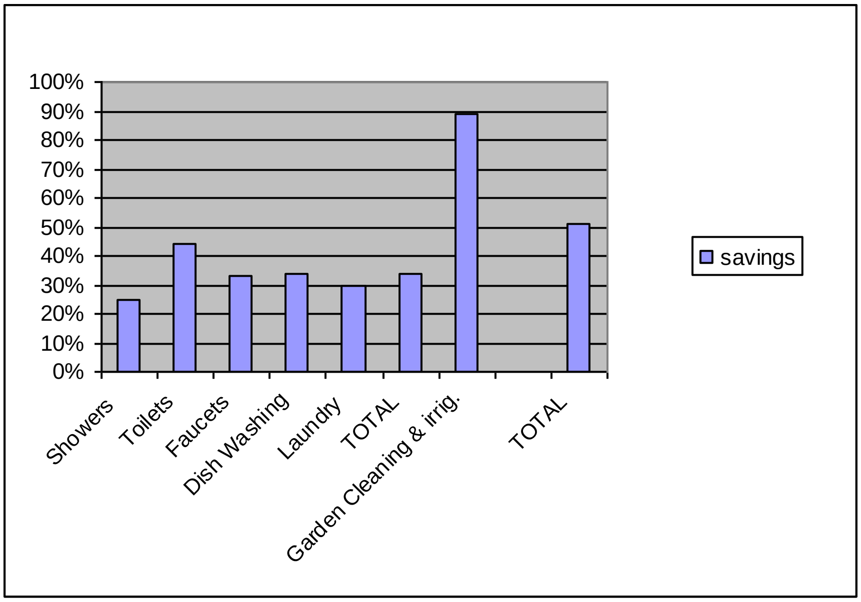

Fig. 48: Estimated water savings in the building for different household tasks.

3.4 Graywater Recycling and Reuse

The building's graywater system is an integral part of the design. It is a low cost graywater recycling system that is best suited for residences. The graywater system is designed to use and accommodate the waste water of seven house occupants.

The graywater filtering system is integrated in the garden's landscape design as an artificial wetland. The filtering system design was based on a low tech, low cost graywater system developed by the Jordanian NGO JOHUD.[13] As illustrated in the diagram below, waste water coming from the showers and sinks of three bathrooms and from two kitchenette sinks is collected in a small settling tank that has a fishnet to filter solid objects. Settled water then goes through a constructed three stage wetland flowerbed planted with bamboo. The bamboo roots system helps filter the water. The filtered water then goes through a charcoal filter to remove odors, and then finally ends up in a storage tank with a submerged pump. The treated graywater is then used for irrigation. The kitchen sink and washing machine have not been connected to the system to reduce the contaminants from the graywater and to avoid additional pumping because the slope between the kitchen and the garden is insufficient.

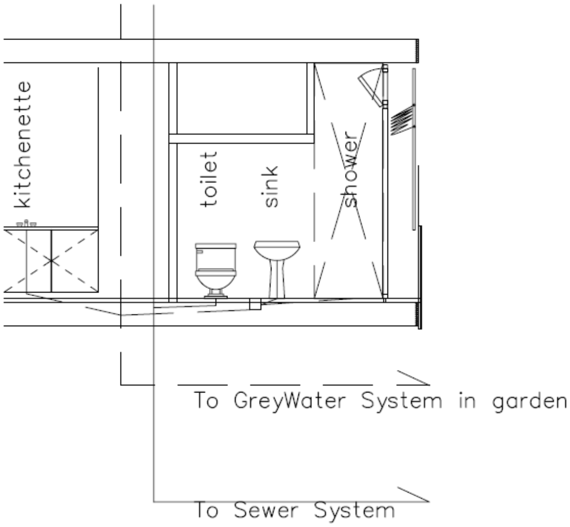

Fig. 49: Graywater collection system.

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[13] Technical assistance for developing and installing the graywater system was provided by Engineer Heba Abu Rub.

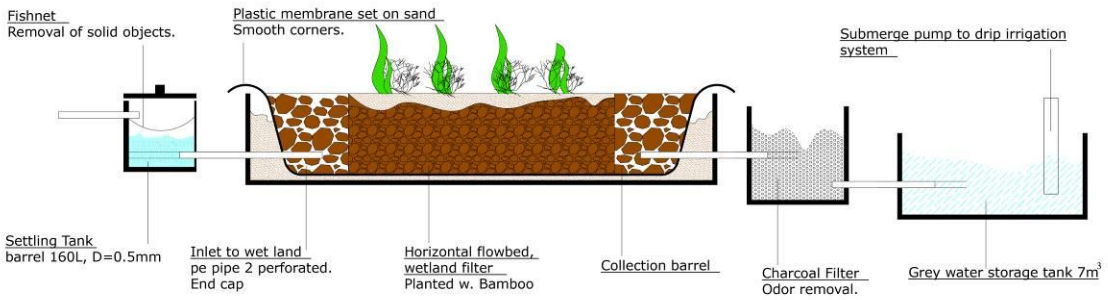

Fig. 50: Graywater filtering system.

Fig. 51: Artificial wet land with bamboo (left) and settling barrel (bottom right).

It is generally not recommended to store graywater as this can cause an odor problem. In this case, however, and because of the irregular inflow of the graywater, a water tank was needed to collect it. The relative high quality of inflow water allows for its temporary storage in a concrete basin. Water testing has shown that the quality of the filtered graywater falls within the 'Jordanian Standard for Reclaimed Graywater for Irrigation in Rural Areas.'

The system was easy to install. It was installed by an experienced plumber with the technical assistance of an experienced engineer. Many of the required materials were available locally in Aqaba, so the system was cheap to install, with the exception of the PE (Poly Ethylene) lining and the settling barrel, which had to be brought in from Amman.

4. Behavioral Aspects

The behavior of the users of an environmentally friendly building strongly influences its performance. For example, it is up to the users to turn off the lights during the day or when a room is not being used, to close the windows when the air conditioning is on, or to turn off the faucet when it is not being used.

There are certain behavioral aspects in dry-hot climates that can greatly contribute to enhancing the building's environmental performance. One of these is what is called 'night ventilation,' which depends on benefitting from the cooler air during the night for natural ventilation, but closing up the building during the hotter periods of the day. This can lower internal room temperatures by at least 2-3 degrees. Moreover, the cooling sensation felt by air movement can be substituted by the use of a fan. Even if air-conditioning is to be used during the day, the cooling load would be reduced since the air that is being cooled is already cooler than if the outdoor daytime air is let in. Increased use of outdoor areas is another way of decreasing the cooling loads of a building in hot dry climates.

Another energy efficient behavior is to accept a higher temperature range in the summer and a lower temperature range during winter. Comfort levels can be reached during the winter by dressing warmly, instead of increased heating of the space.

The design of the building encourages many of these behaviors and catered for them in its design. Multiple attractive outdoor areas that have varied views and shading, and that are open to see breezes aim to encourage the use of outdoor spaces, especially during the night and morning. Natural ventilation is encouraged by designing openings in a way that allows for cross ventilation in the house, minimizing the need for air-conditioning. At the same time, manually controlled windows and vents allow users to manipulate the internal atmosphere according to external temperature fluctuations and personal preferences.

5. Life Cycle Cost-Analysis[14]

Prior to the start of the construction phase, a detailed analysis of the estimated project budget was carried out. This analysis was later compared to different design and construction options. The first comparison was with the estimated cost of a conventional equivalent building built in Aqaba (Case A). Case B was a conventional building design, but incorporating improved design and construction techniques. Case D was an extreme case where the house would consume zero energy. This, however, required significant extra investment to cover the cost of the required PV cells, solar cooling, and other technologies. Case C - that of the implemented project - consists of case B’s improved design and construction, combined with solar cooling. The diagrams below show the results of some of these comparisons:

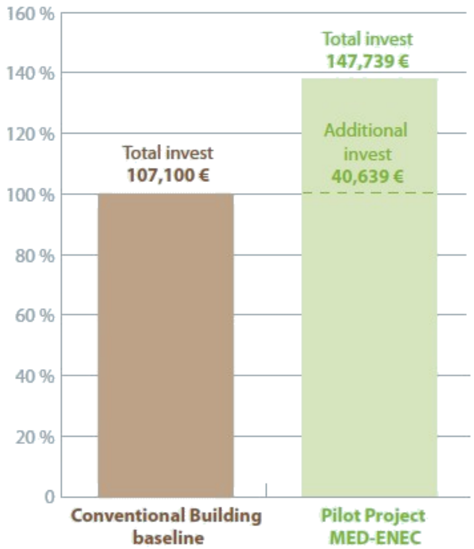

Fig. 52: Diagram comparing the project’s total budget to the baseline case.

All these cases were subjected to a life cycle analysis where the extra investment in each case was balanced with the estimated savings in energy bills for the house. The table below details this comparison. The numbers are then used to estimate the payback period for each additional investment.

	Unit	JOD Conventional Building	Pilot Project Options		
			Case 2 Replicable	C Built Project	D ‘0-Energy’

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[14] Life Cycle Cost Analysis (LCCA) is an economic evaluation technique that determines the total cost of owning and operating a facility over period of time. The analysis is applied in decisions regarding construction or improvements to a facility.

		Base Line Case	measures		
E-Primary consumption	kWh/m^2.a	407 1)	142 1)	59 1)	15 1)
	%		65	85	96
E-end Consumption[15]	kWh/m^2.a	107 1)	33 1)	14 1)	4 1)
	%		69	87	97
Cost Energy Consumption	€	3760	1150	482	125
	%		69	87	97
Construction Cost	€	107.100	126.600	154.900	197.100
Incremental Construction Cost	€		19.500	47.800	73.000
	%	0	18	45	67
Payback	yrs		3.3	10.2	13.8

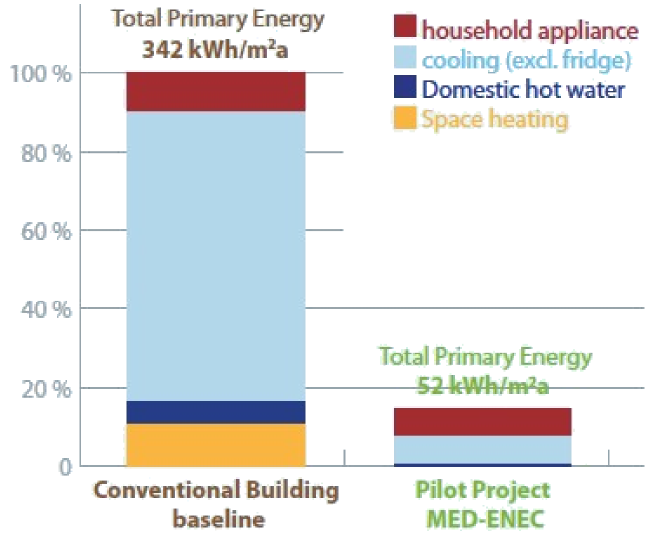
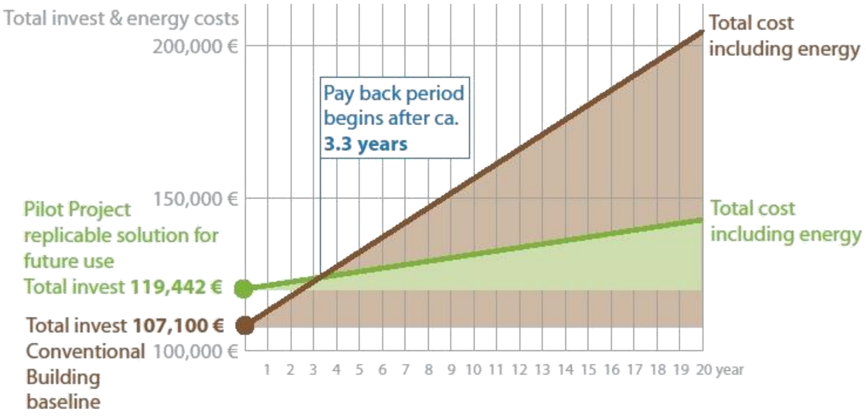


Fig. 53: Diagram comparing different design and construction options with the baseline case.



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[15] For Total Building Area, 420m2. Cooled area is 340m2.

Fig. 54: Diagram calculating estimated payback period for case B – low cost measures.

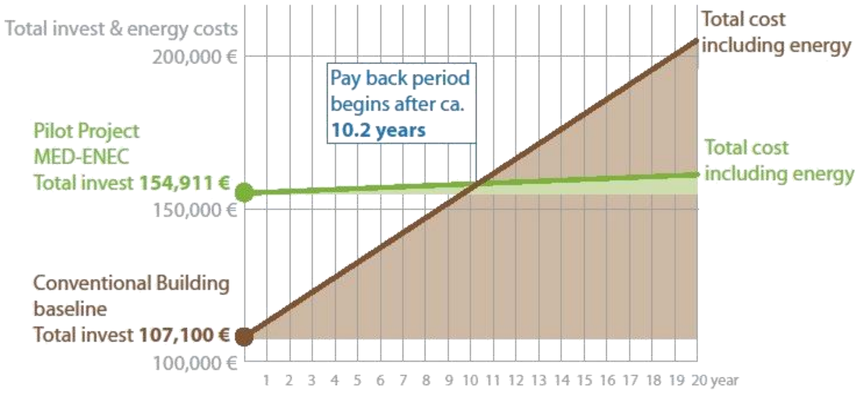

Fig. 55: Diagram calculating estimated payback period for case C – the project as implemented.

From these table and diagrams, it can be shown that the improvements in design and behavior and construction (case B) are highly affordable with a payback period of only 3.3 years. Case C had a much longer payback period of 10.2 years. However, since case C is a pilot project and the cooling system offers great potentials, the MED ENEC project decided to fund it. This is mainly due to Jordan's relatively low electricity prices. However, it could become much more feasible if energy prices rise, which is expected. Finally Case D was not found to be feasible with an estimated payback of 13.8 years.

6. Implementation Challenges and Lessons Learned

The implementation of this project created certain challenges in communication and coordination since it did not fit with the local contractors' 'business as usual' model. This is mainly due to the introduction of additional construction details not commonly addressed in standard construction in the region. The main challenges faced during the project's implimentation are listed below:

1. Communication and Reporting:
    - Communication with contractors is an ongoing process that requires additional supervision compared to a regular project.
    - Communication relating to the project is mainly verbal. There is no reporting and documentation of decisions.
    - The architect's limited knowledge of Arabic and the contractors' limited knowledge of English made it difficult and time consuming to communicate the project's ideas.
    - A lack of capacity among the contractor and workers to understand drawings. This is partly because of language issues and partially because they are not used to working with drawings. The architect had to be available on site as much as possible, and had to explain the details on site. This required considerable planning for the coordination of upcoming work. Drawings were needed for all details and were to be executed accordingly. The finishing coordinator made an effort to check many of the details with the architect. The architect ended up taking a bigger role than that of designer only. In spite of this, the quality of finishes was not satisfactory.
2. Availability of Materials
    - Some plumbing materials for the solar cooling system and the graywater system were not available in Aqaba, which resulted in increased costs.
    - The components used in the solar cooling device are unique and not widely used or known in Jordan or worldwide. It was very hard to locate the right suppliers and the right components for its application. The supplier had to redesigning the condenser for the new type of refrigerant to overcome this issue and also to improve its performance.

3. Lack of Technical Experience and Knowledge:
    - The lack of knowledge by local contractors and builders of the effects of thermal bridges meant that the architect had to take on the role of tutor who would explain the importance of properly addressing this issue and also had to work with the finishing coordinator to find possible solutions.
    - Local suppliers did not know much about the insulation qualities of the materials they sell. The architect therefore had to specify

materials according to thickness and density in order to obtain the needed insulation value.

4. Project Management and Time Scheduling:
    - The weak planning skills of finishing partners made it difficult to get a realistic estimation of the needed time to complete the building. The agreement with the finishing coordinator had to be terminated due to the slow progress of the finishing work and its low quality. The owner's representative had to take over his role.
    - The solar cooling system was far more experimental than initially expected. The development of the system took a much longer period than anticipated. As a result, the cooling system supplier and the developer agreed to install a third party adsorption chiller.

Within such constraints, high levels of planning were not always possible.

Without the EU-Funded MED ENEC project, it is doubtful if the cooling system could have been developed the way it has. The development of this solar cooling system is an achievement supported by MED ENEC, and ended up not only benefiting the project, but more importantly, the development of locally manufacturing of cooling solutions based on renewable energy. These can be disseminated to the whole Middle East region in the future.

Another lesson learned is that changing existing construction practices requires tremendous effort and continuous adaptation. Ideally, the costs of such effort and adaptation should have been budgeted from the beginning.

The project team realized that the pilot project details posed a challenge for traditional construction workers, builders, and contractors. This required additional effort from the architect to explain and educate, and to play a more proactive role with all parties to get the message across.

In order to ensure timely delivery, or at least receive compensation for the delays caused by (sub)contractors or third parties, the project could have benefited from legal advice on contracting and supply agreements.

7. Summary of Monitoring Results

The building was monitored over a period of more than one year, mainly by a data logging system. The monitoring study was prepared by Hans Rosenlund of CEC Design, Sweden (Alltidhultsvägen 11, SE-29391 Olofström, Sweden; Tel +46 (0)755 07 57 07; Mob +46 (0)730 53 0909; mail@cecdesign.se; www.cecdesign.se).

At the time of data logging, the building was not regularly occupied. User influence on the building’s performance therefore could not be estimated. Also, the solar cooling system was never used regularly. An evaluation of its energy efficiency therefore was not possible through measurements.

Fig. 56: Data logger mounted in storage room.

The monitoring showed a typical performance for a heavy building with stable indoor temperatures when kept closed. Measurements showed that in the winter, the building keeps indoor temperatures close to comfort levels when kept closed. If occupied, this would raise the levels further through internal heat and shading management. The building's thermal inertia is also able to overcome shorter periods of extreme weather. It therefore may be concluded that its passive winter performance is satisfactory.

During the hottest part of the summer, however, passive climatization efforts, while not ineffective, failed to keep temperatures down to comfortable levels. The ground floor and northern rooms were cooler than the top floors and southern rooms. One problem was the large, south-west corridor windows, which captured a lot of solar radiation and passed it on, especially to the bedroom behind it, and, by chimney effect, to the upper corridor.

Measurements also showed that the green roof works very well and keeps the living room ceiling temperatures stable and relatively low in the summer and high in the winter. However, the different wall construction types used do not seem to have had any real effect on indoor climate. It also was found that the subsoil cooling system does not work.

Parallel to data logging, a detailed computer simulation model was developed to serve as a reference to the measurements and to enable predictions of improvements to the design. The model comprised 17 thermal zones – one for each room. A 'typical' occupation pattern was imposed on the model, with internal heat, ventilation, heating, and cooling set-points etc.

The baseline simulation model (as built) confirms that the building shows good passive performance in the winter, since practically no energy for heating/cooling is needed from December to March. In the summer, the energy use for cooling (with a conventional air-conditioner) is 24 kWh/m² (relating to the total apartment area of 248 m²). This represents a saving of 80% compared to an assumed normal level in Aqaba. Replacing the building structure with conventional Jordanian materials would have raised the energy use to 29 kWh/m². Thus, the material choice represents a saving of 18%, with the rest resulting from the building design and user behavior. However, it is impossible to exactly specify the contribution of each. Thus, provided that user behavior is 'disciplined', the building performs in a very energy efficient way – even with conventional air-conditioning.

A series of additional simulations investigated possible improvements to the design:

- Hybrid ventilation, where cool night air is utilized for cooling in the intermediate period of April, May, and October. This strategy can save 10% energy on cooling.
- Increasing the insulation layer, essentially from 50 mm to 150 mm, can bring about a 10% savings in energy.
- Accepting a wider comfort zone, up to 27°C instead of 24°C, can save 38% in energy consumption compared to the baseline case. This is a costless strategy that also brings down the investment cost for the cooling system, since the peak power need decreases by 25%.

Combining these improvements can result in bringing down the annual energy need to 2.9 MWh, or 12 kWh/m². Heating need is eliminated, and the cooling season is shortened. The savings in energy consumption would be 52% compared to the base case, and 98% in comparison to estimated use in normal Aqaba households.

All these scenarios are summarized in Figure 57, where it is seen how hybrid ventilation affects energy use in the spring and autumn, while insulation mostly affects energy use in the hot period. Also, adopting an wider comfort zone results in savings throughout the cooling season, and even shortens it.

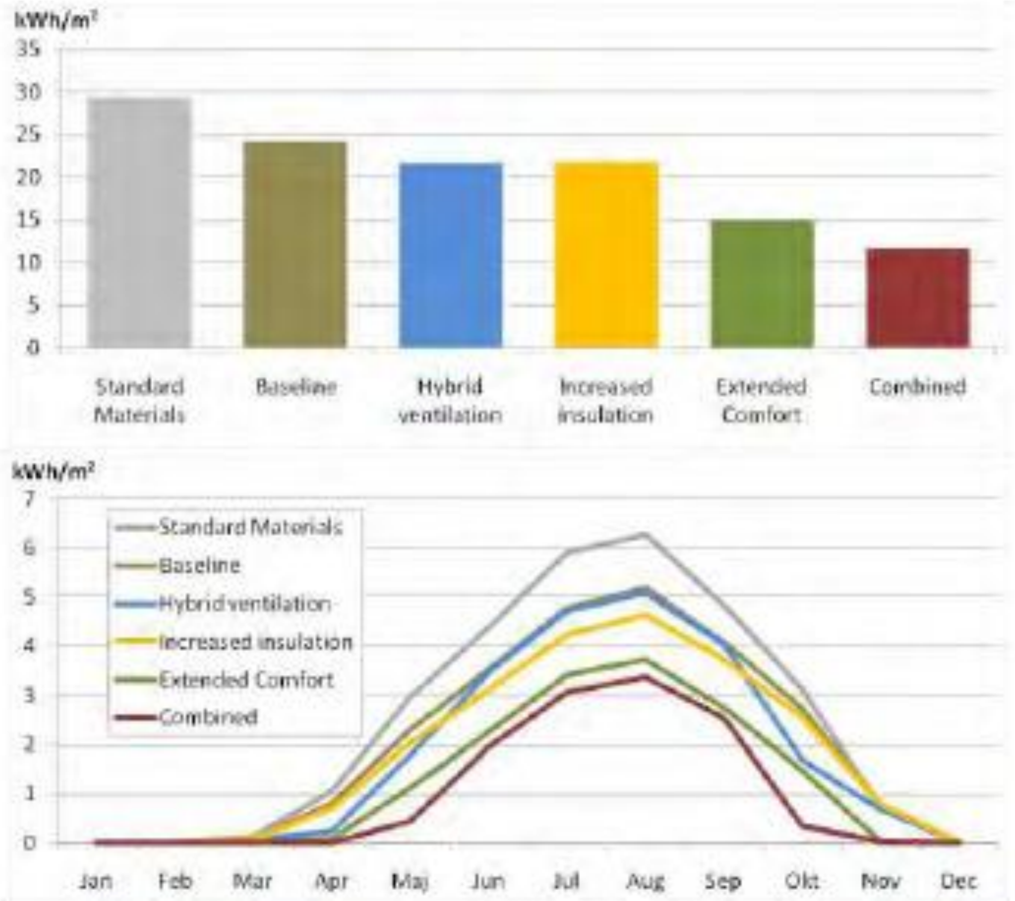

Figure 57: Required cooling energy for the simulated cases. Top: Annually, per area. Bottom: Monthly totals.

The estimates above do not take into consideration the decrease in energy efficiency resulting from the solar cooling system which was to be installed but was never operational during the monitoring period. If working properly and according to specifications, the reduction in energy consumption would be a further 55%, which translates to 11 kWh/m² for the building as designed, or 5 kWh/m² if a combination of all proposed improvements were incorporated.

This means that if the suggested improvements are implemented and the solar cooling system is installed, the building can almost be classified as passive.[16]

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[16] Note: All web sites referenced in this report were last accessed on September 20, 2011.