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The Architectural Tools in Reducing Energy Consumption of Residential Buildings in Hot Countries

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Abstract

This research identifies several architectural elements at different levels from design up to construction for saving energy in residential buildings by reducing the energy consumption. These architectural elements contribute to an inefficient use of energy. Finally, the paper puts a set of recommendations, design-related and otherwise, for enhancing the sustainability of residential buildings in hot countries, depending on the analytical study of 5 case studies from Middle East countries.

Keywords: Energy consumption, saving energy, architectural elements

1. Introduction

Due to the increasing in the population, growth of the economy, and widely utilization of technology, energy consumption has increased dramatically, which has led to an increase in global warming. Studies found that; a third of this energy consumption is in homes (Fig. 1), and the energy consumed is non-renewable energy such as gas and fossil fuels, so we need to move for utilizing the renewable. This paper discusses the different ways of saving energy and reducing energy consumption in buildings to limit the energy utilization in residential buildings in architectural design phase and during construction.

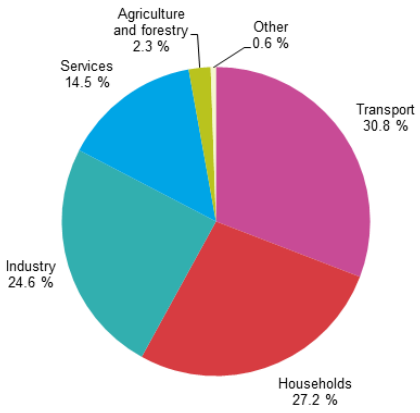


Fig. 1. Final energy consumption by sector

Architectural Tools for Reducing Energy Consumption

The main architectural tools improving the microclimate inside the buildings, and hence reducing the energy consumption which led to save energy are the following:

The courtyard

The using of the courtyard as an architectural design element in buildings is common to almost architects of hot countries. The Courtyard can be used in almost buildings in the hot and dry climatic regions of the world. So, the application of courtyard is most suitable in the tropical regions. However, it is also applicable to all climatic regions. We can define the courtyard as a covered outside space but open to the element at its apex. Also can be defined as a space that is open to the heavens, a rectangular or square in shape and bordered by a group of buildings (in a group buildings) or the most important rooms in the same building.

The main function of courtyards were as meeting area for specific functions such as gardening, working, sleeping, playing, cooking, or even in some cases as places to breeding birds. The importance of such a space was by their being located in central sites within the urban fabric or building. Surrounded by arcades and colonnades, paved, landscaped with water bodies, various plants, shade, and light, they all played an important role in our social and working life. Also the courtyard can be used as a place for facilitating the healing process due to its natural healing environment, and courtyard also can contribute in a major way by modifying the climatic setting and thereby inducing mental and physiological sensation of its end users.

In residential design, the courtyard is in rectangular or square form, but circular, curvilinear and other forms may evolve. The courtyard form can be adapted to by using the numerous eco-friendly aspects such as scenery, site limitations, and building orientation, to generate new shapes such as; U, L, T or Y. (Fig. 2)

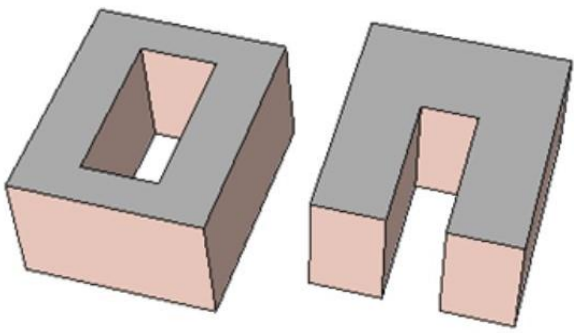


Fig. 2. Fully enclosed and a semi-enclosed courtyard

Building Orientation

Building orientation plays very important role in saving energy, in which the southern building elevation should be oriented towards the equator in the northern hemisphere (and the northern façade towards the north in the southern hemisphere.

By facing the longer axis of the building elevation in the east/west direction, the longer dimension of the building faces will be more likely to gain the maximum solar energy and radiation. So, functions and spaces which are most frequently used, such as kitchen and living room, must be located into this part of the building.

This orientation is also advantageous for summer cooling conditions because it minimizes the east-west elevation to morning and afternoon sunlight. (Fig. 3)

Shading elements

Shading elements are important tools in a passive buildings because they help in reducing overheating during the summer season. Therefore, it is very important that the devices are properly designed in size and orientation. The southern building elevation through which the sun mostly comes inside the building must be correctly shaded, or equipped by sized the shading elements, in order to prevent overheating and to keep the building cool during summer. However, a careful design of the shading element must be designed in order to guarantee that the size and sloped (if necessary) can achieve the need to let the sun in during the winter and to shade the building during the summer. The type of shade and its slope degree is always depending on the position of the sun and the geometry of the building. (Fig. 4)

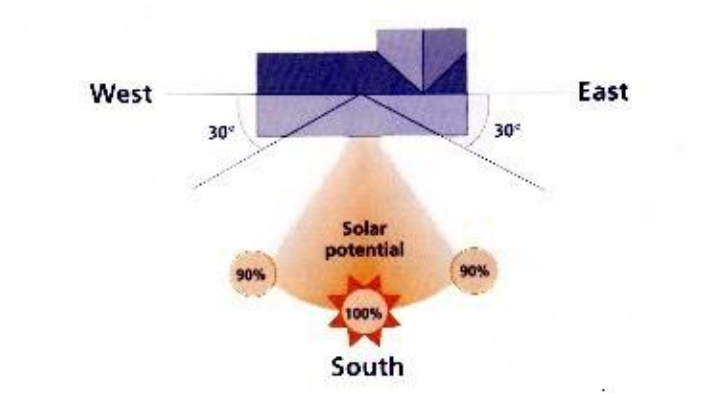


Fig. 3. Best building orientation in hot countries

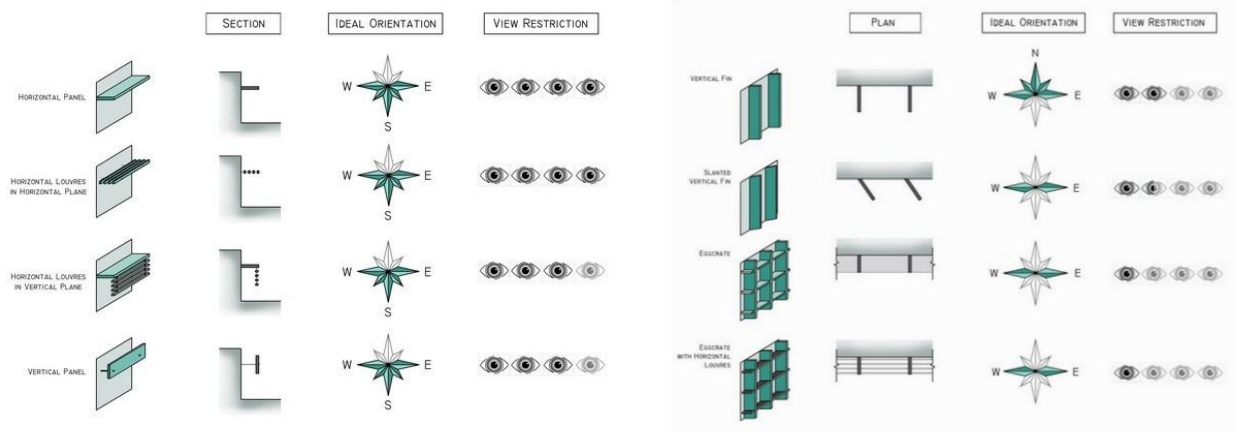


Fig. 4. Examples of shading design and window locations

Using insulation materials

The building insulation is a very important factor in warm climate and also in cold climate, less energy will be required to heat buildings in cold conditions or cool buildings in warm condition which results in a good interior temperature during the whole year. So a well-insulated building is helping in reducing heat loss during the winter and keeping the house in a cold conditions during the summer monthes. Insulated materials, so called because they are poor conductors of heat, form a barrier between interior and exterior spaces, by means between warmed interior and cool exterior, and cool interior and hot exterior according to the season.

There are many types of insulation materials which might be

used in a passive design, such as cellulose, cotton, fiberglass, polyurethane, mineral wool, perlite and sheep's wool.

Glazing openings type

Glazed openings play an important role in a passive design and saving energy because they serve as solar collectors bringing in light and heat while also providing natural ventilation. The way of openings are positioned, in relation to the landscape elements around the building, the wind directions and the movement of the sun can effectively increase the energy efficient and provide a good internal comfort in buildings.

The main role regarding openings in the passive design is the southern position because it allows openings to collect warm solar energy when heat is needed in winter, or vice versa to let fresh air in when is needed in summer. The Location of the glazed surfaces on the southern of building elevation helps in achieving the maximum solar radiations and reduce them in the northern elevations helps for the insulation of the building against winter cold.

Also the type of glazing used in openings is a key feature considering insulation issues. So it is recommend using double glazing (has two layers of glass with a gap between them) or triple (has tree layer of glass, with argon or krypton gas filled between glazing layers, and low-conductance edge spaces) which helps in reducing heat losses through the openings.

Using Wind catcher

Wind catcher is one of the traditional systems for providing natural ventilation inside the buildings without utilization of conventional energy. It had been used for over three thousand years in Middle East countries in different types of buildings, especially in residential buildings. Wind catcher is usually a tall construction element which has height between 3 and 33m placed on the building roof for achieving the natural ventilation. There are two main categories for wind catcher; unidirectional and multidirectional wind catcher. In other ways called one-sided wind catcher and the latter is classified under three sorts: two, three and four-sided wind catcher which usually have square plan, hexahedral and octahedral wind catcher. (Fig. 5)

There are two main functions of the wind catcher: the first is to related to opening which should bring the fresh air inside the building, while the second function is related to the exit of wind catcher which should absorbs hot and polluted air from the building (the suction functions) and thus works such as a sucked and ventilation system.

Building Mass

Massing and arrangement of the building blocks help achieving thermal and visual comfort. Building blocks channelize or obstruct the wind flow between buildings; also they act as shading elements for surrounding buildings. Building blocks arrangement, design and form can influence the wind flow and velocity. Massing of blocks can also help regulate the summer wind and achieve ventilation, and obstruct wind flow in winter season. (Fig. 6)

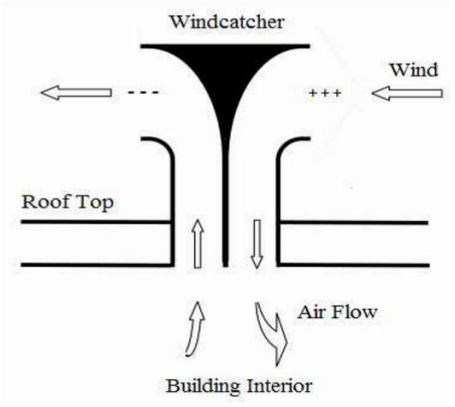


Fig. 5. Wind effect of Wind-catcher

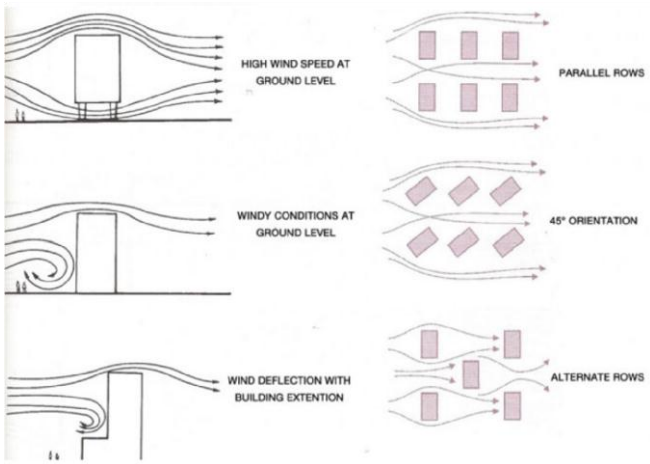


Fig. 6. Massing of building blocks influence wind pattern

Water Bodies and Vegetation

Water and vegetation play very important role in enhancing the micro climate inside buildings at different levels: building-scale, street level or urban and semi-urban level. By manipulating the benefits from their evapotranspiration process and morphological characteristics, trees whether isolated or planted in-groups and water bodies are the best urban cooling systems. The use of vegetation can contribute many thermal benefits, for instance providing shade effect, lowering ground and air temperature, reduced solar infiltration, ventilation effect, minimize glare from reflection and providing building with cold water.

Analytical study

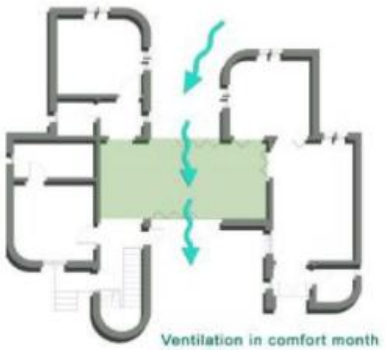
Following is an analytical study for 5 successful examples of using architectural elements for reducing energy consumption, these examples reflect the role and the way of improving the microclimate inside the residential building.

Project name: **SQU Eco house-Oman**

Project information:

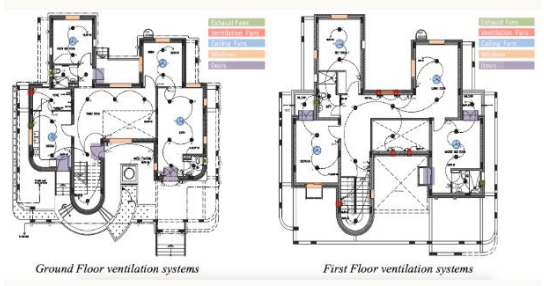
This house project is one of the research-based attempts to design, construct and operated an energy-efficient building in Oman. The project is created based on collaboration between academic, governmental and industrial local bodies.

The house area is around 280 m^2 with two-story and a total height of 8.6m. The house was designed to suit the modern Omani family life pattern, like respecting social norms, also to reflect the Omani vernacular architecture



Achieving the ways of saving energy:

- Using two courtyards, in north and south courtyards, for creating better air flow in the building and enhancing the indoor-outdoor connectivity.
- Using developed shading system which supported by a double-shell system.
- window openings are teamed up to maximize nature ventilation
- Using the Landscape elements to utilize and moderate the microclimate of the site, provide shading, and control air in the needed places
- Using good insulated and compacted externals walls, containing of three layers: external layer of 100mm thermal blocks, 50mm insulated cavity, external layer of 100mm thermal blocks.
- Using the fully shaded roof which incorporates a 100mm thermal insulation layers
- Using PV panels at the roof top of the house to supply all the needed power during day time also provide shading to the roof to reduce solar gain.

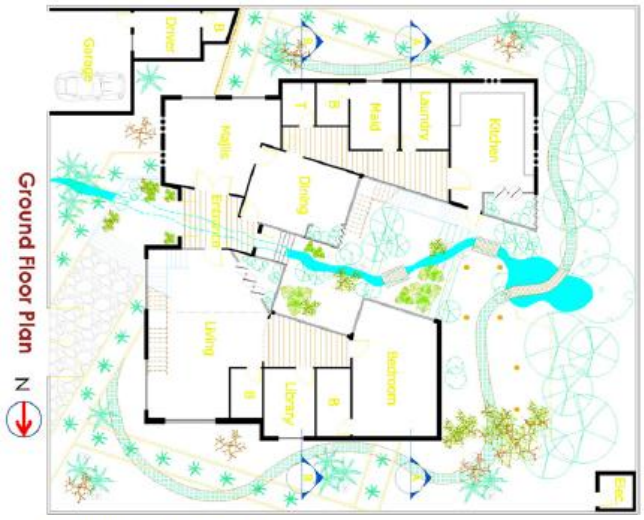


Project name: **AL_ Fareej house in Abu Dhabi Emirate**

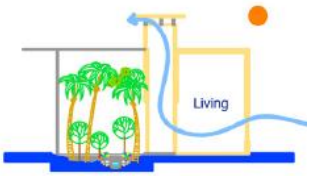
Project information:

This project is a result of Plan Abu Dhabi 2030, under the direction of Abu Dhabi Urban Planning Council, ensuring important factors such as sustainability, infrastructure capacity, community planning and quality of life to create cities and houses which help to save more energy.

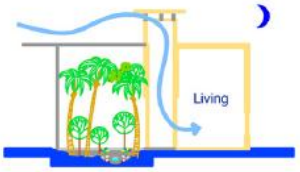
The design of the Fareej form has integrated different passive architectural items derived from the Emirati vernacular architecture. The main house form is configured around a central courtyard. This form configuration is deeply rooted in the traditional architecture of the Arab Gulf house due to social, cultural, and ritual needs.



Courtyard - Ventilation/Wind



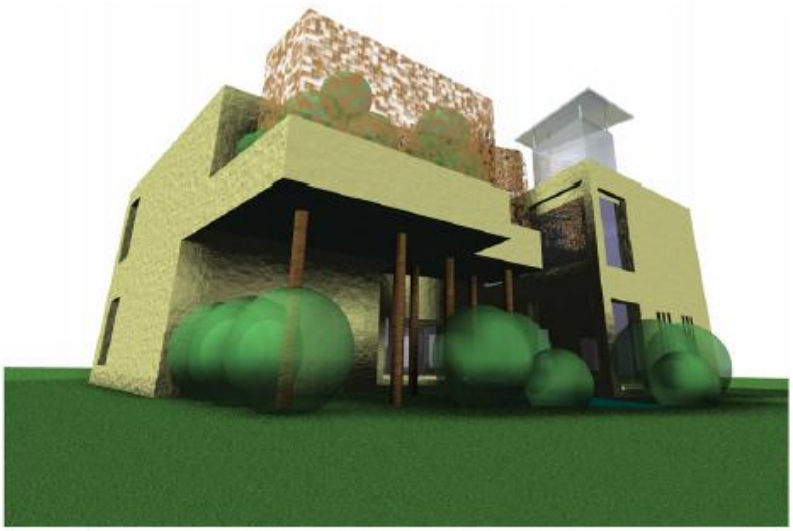
Daytime - Stack Effect



Nighttime - Wind Catcher

Achieving the ways of saving energy:

- The design of the building form has integrated different passive architectural items which cractarize the Emirati vernacular architecture.
- Using central courtyard which located in the middle of the house mass
- Using two wind towers at the begging and toward the end of the north south axis, to confine the winds and cool the house in return.
- Using three roof gardens that integrate the house further with nature and aid in passive cooling. In hot climate, a green roof acts as a buffer that protects the building from extreme solar radiation, and Moreover, a green roof reduces the requirements for traditional insulation
- The main system used of plants irrigation is drip irrigation (mainly for roof gardens) besides a bio swale for the house central courtyard



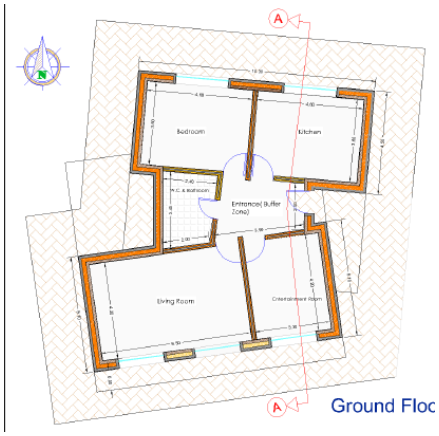
Project name: **Eco house-Iran**

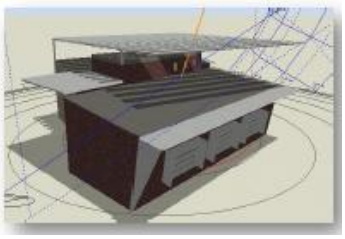
Project information:

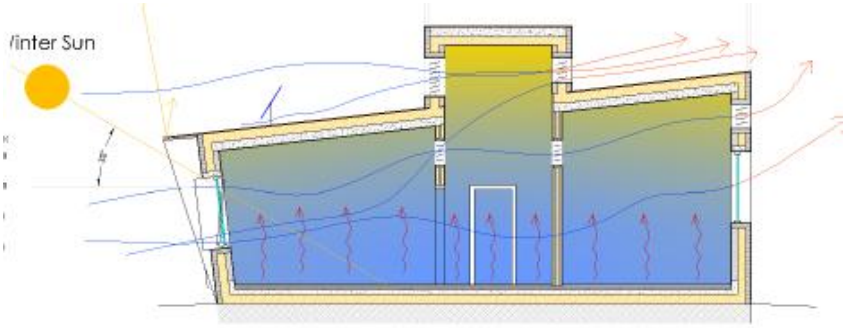
This house project - Eco-house - is designed by Ali Khiabanian and Mohammad jodeiri abbasi in central Iran. The house is a three story building, and it is considered as an example to solve most of the environmental problems such as overheating in summer and enhance indoor air quality in addition to reducing fuel consumption. The total building area is 95.5m². A typical House is designed according to Tehran's Standards in terms of material and form.

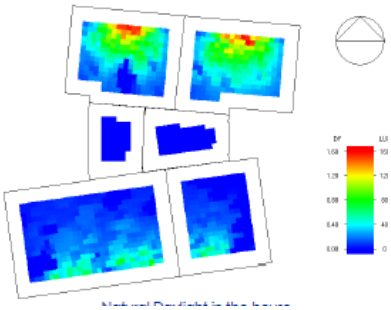
Achieving the ways of saving energy:

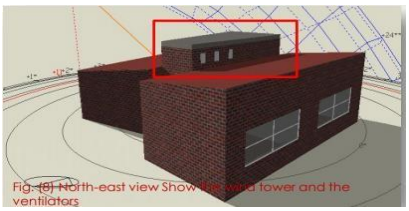
- Using developed tower for cooling and natural ventilation.
- Using treble wall and colored glass in order to prevent dust enter into the house
- Using canopy and minimum wall openings to control sunlight inside the building.
- The integration of Green roof with the building to achieve the cool the roof and consequently and to prevent direct sun light away from the roof.
- Using Solar power collector
- Using renewable materials
- The central mass of the building works as a wind tower containing small windows work as ventilators on the high level of the north façade to help the hot air for escaping and promote natural ventilation in summer
- Using different types of shading elements; Fixed Horizontal shading which shades the walls especially the south and west facing walls, Horizontal Roof Canopy helps to shade large part of the building roof which is the most exposed element of the sun and the main reason for overheating inside the house.
- Achieving the natural ventilation
- Using Photovoltaic panels in the south facing roof to provide the building with heat and electricity











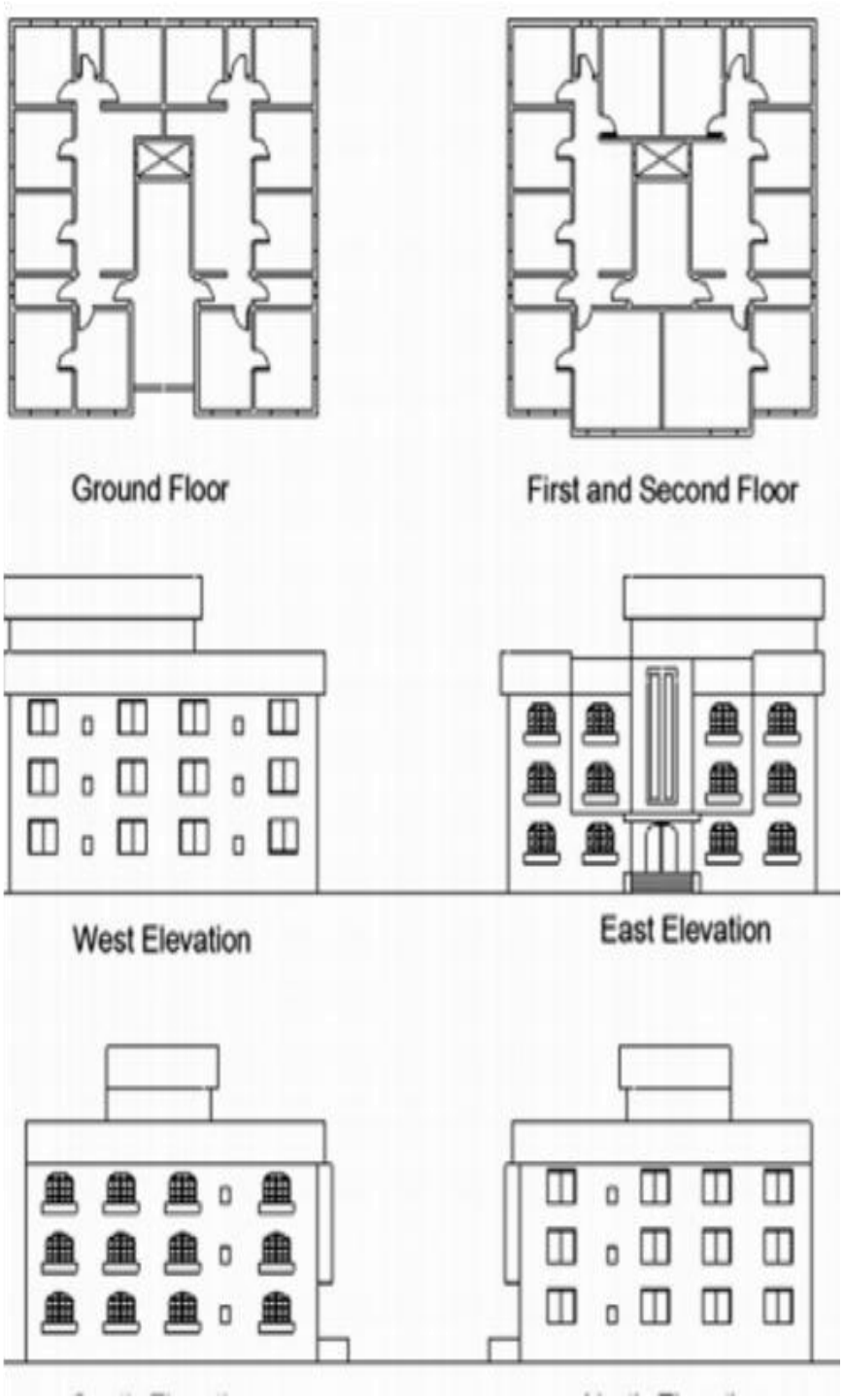
Project name: **Residential Building in Jeddah City, KSA**

Project information:

The case study building consists of three stories and six apartments. The built floor area is 420 m2 and a total land area of 625 m2. The apartments are elongated and symmetrical around a staircase with a mid-axis perpendicular to the street.

Achieving the ways of saving energy:

- Enhancing the insulation of the external walls and the roof of the building,
- Using double-glazed windows and fitting shading devices).
- The air gaps in the external walls were replaced by foam insulation with a thickness of 100 mm. As a result, the U-value (i.e. thermal transmittance) for the external walls has decreased from 0.58 to 0.33 W/m2 004B.
- layer of polyurethane insulation (thickness of 100 mm) was added to the roof
- Using thermal mass or thermal design, which represents the capacity of a material to store heat.
- Using High thermal isolated walls, whilst not necessarily have good insulation properties, and have the ability to provide better indoor comfort through delaying and reducing the impact of outdoor temperature changes on conditioned indoor environments
- Using appropriate external shading systems



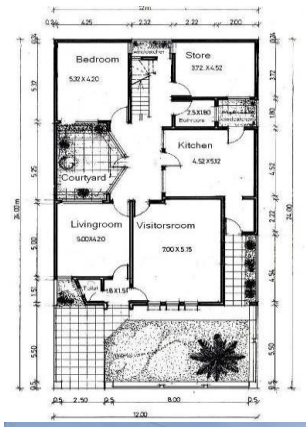
Project name: **Residential house-Iraq**

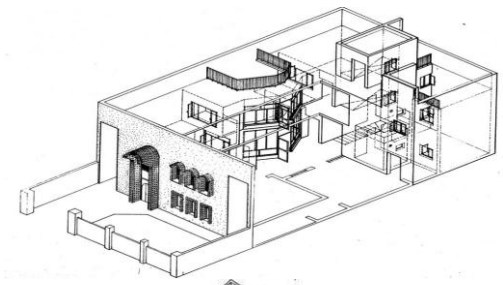
Project information:

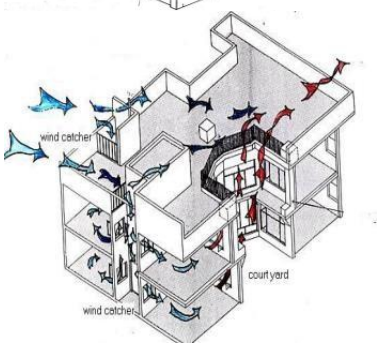
This presented model had been won a prize of the Iraqi Energy Consultative Committee in a competition for the best environmental design. The design style for this building was applied on a 2-storey residential house with the construction area 380 m2, constructed on land plot area 288 m2, with eastern frontage. The building consists of 5 bed-rooms, 1 room for reception, living space, office room, kitchen, store-room, 4 bathrooms, and interior garden area as court.

Achieving the ways of saving energy:

- Using two wind catchers for achieving the natural ventilation.
- Using internal and external garden as a green area.
- Using 25cm thick walls, which were built with Thermo stone blocks, whose high thermal insulation and used structurally as bearing walls.
- Using reinforced concrete roof with 15 cm thickness, which covered with waterproofing material for insulation.
- Using the concept of adjacent in heritage houses, in building design to be on the outer perimeter of the land plot, which help to shield the outer building walls from exposure, solar energy and outer hot air.
- Using porous bricks in courtyard floors, which help making the floor looks like a cold pool.
- The courtyard walls in all directions are elevated to the ceiling level, which makes air motion within the courtyard with normal speed. The courtyard then maintains low temperature day time, when wind catchers and windows are kept closed.
- Reducing the wall temperature by using creeping and low – condensed indoor plants, which effectively shadowed the walls from sun rays.
- Using Sun breaker (shading elements) built of bricks as part of the architectural facade of the building, which has shading efficiency greater than 80% summer time and shading efficiency 30% winter time.
- Placing the windows at the inner edges of the internal walls thickness in order to raise their thermal performance and air.
- Using small external windows, in summer, the sun rays enter to less than 1m inside, and for short periods. The winter sun was made to reach the west – facing rooms on ground floor and overloading the courtyard by the property of reflecting sun rays from 10mm glass in the first – floor.







CONCLUSIONS

All over the world, especially in sustainability pioneering countries, reducing household energy makes a great deal of economic sense. This study, which has examined in detail 5 residential buildings from hot countries, not only shows that such a building severely lacks the means to ensure energy efficiency, but that it also demonstrates how a few design and operational changes could have had a significant impact on the sustainability performance of the building. The architectural tools which help save energy in residential buildings considered in this paper, were: courtyard: building orientation: shading elements; insulation materials; glazing opening type; wind catcher; building mass and water bodies and vegetation. These mentioned architectural tools are reducing the energy consumption by improving the microclimate inside the residential buildings.

Using wind catchers in conjunction with courtyard in buildings reduces the need for reliance on air cooling and air moving-equipment day and night for long periods of the year, and achieving the benefit of cooling buildings' inner skin and human body during moderate summer nights. Also, wind catchers help in enhancement natural ventilation, keeping fresh air inside building and make living conditions inside healthier.

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