Building envelope design as a passive cooling technique

E.M. Okba
Fayoum Branch, Cairo University, Egypt

ABSTRACT

Envelope design as a means of passive cooling is the integrated design of building form and materials as a total system to achieve optimum comfort and energy savings.

This paper aims at highlighting the role of envelope design in determining the efficiency of passive cooling in the building. The paper consists of two major parts. First, the theoretical part, illustrates the main elements of design for passive cooling, and particularly the elements related to envelope design. Second, the applied study of the paper analyzes the envelope design techniques in two different examples of Egyptian touristic projects on the red sea coast.

The paper has developed a checklist for envelope design techniques to provide architects with the principles and design strategies for envelope design as a passive cooling technique. It also has examined using a special computer program a simulated model representing a composition of modular hotel room units to determine the influence of changing orientation and building shape as elements of the building envelope on the needed cooling energy.

1. INTRODUCTION

Passive cooling is considered an alternative to mechanical cooling that requires complicated refrigeration systems.

The building envelope is a critical component of any facility since it both protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's roof, walls, windows, doors, construction details and ground surfaces the envelope controls the flow of energy between the interior and exterior of the building.

The building envelope can be considered the selective pathway for a building to work with the climate- responding to heating, cooling, ventilating, and natural lighting needs (U.S.D.O.E, 2004).

2. APPROACHES OF PASSIVE COOLING

There are four key approaches for achieving thermal comfort in cooling applications: envelope design, natural cooling sources, hybrid cooling systems, and adapting lifestyle.

Envelope design as a means of passive cooling is the integrated design of building form and materials as a total system to achieve optimum comfort and energy savings. An optimal design of the building envelope may provide significant reductions in cooling loads-which in turn can allow downsizing of mechanical equipment

Natural cooling sources including air movements, evaporative cooling, and earth coupled thermal mass can also provide thermal comfort.

Hybrid cooling systems are whole building cooling solutions employing a variety of cooling options (including air-conditioning) in the most efficient and effective way. They take maximum advantage of passive cooling when available and make efficient use of mechanical cooling systems during extreme periods.

Adapting lifestyle involves adopting living, sleeping, cooking and activity patterns to adapt to and work with the climate rather than using mechanical cooling to emulate an alternative climate.

The general design principles of passive cooling are the reduction or elimination of external heat gains during the day with sound envelope design, and allow lower nighttime temperatures and air movement to cool the building and its occupants (Willrah, 2000).

3. EFFECT OF CLIMATE ON BUILDING FORM

Climate, in particular, produces certain easily observed effects on building form. For example, the proportion of window area to wall area becomes less as one moves toward the equator. In warm areas, people shun the glare and heat of the sun, as demonstrated by the decreasing size of the windows. In the subtropical and tropical zones, more distinctive changes in architectural form occur to meet the problems caused by excessive heat.

In Egypt, Iraq, India, and Pakistan, deep loggias, projecting balconies, and overhangs casting long shadows on the walls of buildings are found. Wooden or marble lattices fill large openings to subdue the glare of the sun while permitting the breeze to pass through. Such arrangements characterize the architecture of hot zones, and evoke comfort as well as aesthetic satisfaction with the visible endeavors of man to protect himself against the excessive heat. Today a great variety of devices such as sunbreakers or brise-soleil have been added to the vocabulary of architectural features in these zones.

It is also noticed that the gabled roof decreases in pitch as the rate of precipitation decreases. In Northern Europe and most districts subjected to heavy snow, gables are steep, while in the sunnier lands of the south, the pitch steadily decreases. In the hot countries of the North African coast the roofs become quite flat, in some areas providing a comfortable place to sleep. Still further south, in the tropical rainfall zone, the roofs are again steep to provide protection from the torrential downpours typical of the region.

4. EFFECT OF BUILDING MATERIALS ON INDOOR CIMATE

The materials surrounding the occupants of a building are of prime importance for protection against heat and cold. Great care must be taken in the choice of the wall and roof materials and their thickness with respect to their physical properties, such as thermal conductivity, resistivity and transmission, and optical reflectivity.

The rate of heat flow transmitted through exterior wall from the outside hot air to the inside air is proportional to the air temperature difference, area of the wall, and rate of global heat transmittance that can be determined from an analysis of the components of the total resistance to heat flow

The total resistance is composed of the resistance to heat flow through the material, the interfacial resistance at the external surface, and the interfacial resistance at the internal surfaces. Since the interfacial resistances are determined primarily by temperature conditions over which the builder has little control, his principal effect on the heat transmittance is on changing the resistance to heat flow through the wall material (Fathy, 1986).

5. COMPONENTS OF BUILDING ENVELOPE AND PASSIVE COOLING

The building envelope, or "skin," consists of structural materials and finishes that enclose space, separating inside from outside. This includes walls, roofs, windows, doors, openings and floor surfaces. The envelope must balance requirements for ventilation and daylight while providing thermal and moisture protection appropriate to the climatic conditions of the site. Envelope design is a major factor in determining the amount of energy a building will use in its operation (U.S.D.O.E, 2004).

One of the most important factors affecting envelope design is climate. Hot/dry, hot/moist, temperate, or cold climates will suggest different design strategies. Specific designs and materials can take advantage of or provide solutions for the given climate.

A second important factor in envelope design is what occurs inside the building. If the activity and equipment inside the building generate a significant amount of heat, the thermal loads may be primarily internal (from people and equipment) rather than external (from the sun). This affects the rate at which a building gains or loses heat. Building volume and sitting also have significant impacts upon the efficiency and requirements of the building envelope. Careful study is required to arrive at a building footprint and orientation that work with the building envelope to maximize energy benefit.

Openings are located in the envelope to provide physical access to a building, create views to the outside, admit daylight and/or solar energy for heating, and supply natural ventilation. The form, size, and location of the openings vary depending upon the role they play in the building envelope. Window glazing can be used to affect heating and cooling requirements and occupant comfort by controlling the type and amount of light that passes through windows.

Decisions about construction details play a crucial role in design of the building envelope. Building materials conduct heat at different rates. Components of the envelope such as foundation walls, sills, studs, joists, and connectors, among others, can create paths for the transfer of thermal energy, known as thermal bridges that conduct heat across the wall assembly. Also ground surfaces surrounding the building play an important role in the efficiency of building envelope (Watson and Labs, 1983).

5.1 Walls and Roofs

For buildings dominated by cooling loads, it makes sense to provide exterior finishes with light colors and high reflectivity or wall-shading devices that reduce solar gain considering the impact of decisions upon neighboring buildings. A highly reflective envelope may result in a smaller cooling load, but glare from the surface can significantly increase loads on and complaints from adjacent building occupants.

Reflective roofing products help reduce cooling loads because the roof is exposed to the sun for the entire operating day.

Wall shading can reduce solar heat gain significantly using roof overhangs, window shades, awnings, a canopy of mature trees, or other vegetative plantings, such as trellises with deciduous vines.

In new construction, providing architectural features that shade walls and glazing should be considered. In existing buildings, vegetative shading options are generally more feasible.

Building walls, roofs, and floors of adequate thermal resistance is essential to provide human comfort and energy efficiency. Passive evaporative cooling design can also be used on roofs through roof spray or roof ponds, and Insulating materials in walls and roofs are very beneficial for energy saving and efficiency.

Incorporating solar controls on the building exterior can also have a significant impact to reduce heat gain (Ballinger et al., 1992).

5.2 Windows, Doors, and Openings

Size and position of doors, windows, and vents in the building envelope based on careful consideration of daylighting, heating, and ventilating strategies.

The form, size, and location of openings may vary depending on how they affect the building envelope. A window that provides a view need not open, yet a window intended for ventilation must do so. High windows for daylighting are preferable because, if properly designed, they bring light deeper into the interior and eliminate glare.

Vestibules at building entrances should be designed to avoid the loss of cooled or heated air to the exterior. The negative impact of door openings upon cooling loads can be reduced with airlocks. Members of the design team should coordinate their efforts to integrate optimal design features. For passive solar design, this includes the professionals responsible for the interactive disciplines of building envelope, daylighting, orientation, architectural design, massing, HVAC, and electrical systems.

Shaded openings in the envelope during hot weather will reduce the penetration of direct sunlight to the interior of the building. Overhangs or deciduous plant materials on southern orientations can shade exterior walls to reduce heat gain during warmer seasons.

Glazing systems have a huge impact on energy consumption. Appropriate glazing choices vary greatly, depending on the location of the facility, the uses of the building, and (in some cases) even the glazing's placement on the building. In hot climates, the primary strategy is to control heat gain by keeping solar energy from entering the interior space while allowing reasonable visible light transmittance for views and daylighting.

Solar screens that intercept solar radiation, or films that prevent infrared and ultraviolet transmission while allowing good visibility, are useful retrofits for hot climates. In colder climates, the focus shifts from keeping solar energy out of the space to reducing heat loss to the outdoors and (in some cases) allowing desirable solar radiation to enter. Cooling energy can also be lost through openings' frame. Doors and windows with air -tight frames can help eliminate sources of convective losses (Koenigsberger, 1974).

5.3 Construction details

Good specifications of construction materials and details can reduce heat transfer. Heat transfer across the building envelope occurs as either conductive, radiant, or convective losses or gains. Building materials conduct heat at different rates. Metals have a high rate of thermal conductance. Masonry has a lower rate of conductance; the rate for wood is lower still. Insulating materials, either filled in between framing members or applied to the envelope, resist heat flow through the enclosing wall and ceiling assemblies.

It is important to consider the following principles in construction detailing:

- To reduce thermal transfer from conduction, develop details that eliminate or minimize thermal bridges.
- To reduce thermal transfer from convection, develop details that minimize opportunities for air infiltration or ex-filtration. Plug, caulk, or putty all holes in sills, studs, and joists. Consider sealants with low environmental impact that do not compromise indoor air quality (Watson and Labs, 1983).

5.4 Ground surfaces

The use of earth berms and sod roofs can reduce heat transmission and radiant loads on the building envelope. Burying part of a building will minimize solar gain and wind-driven air infiltration. It will also lessen thermal transfer caused by extremely high or low temperatures.

It is important to coordinate building strategy with landscaping decisions as follows:

- Landscape and other elements such as overhangs should be integral to a building's performance.
- Decisions about the envelope need to be coordinated with existing and new landscaping schemes on a year-round basis.
- Reduce paved areas to lessen heat buildup around the building that will add to the load on the building envelope.
- Consider selection of a paving color with a high reflectance to minimize heat gain, with considering glare factors (Ballinger et al., 1992).

6. CASE STUDIES IN EGYPT

6.1 Discussion of envelope design techniques in touristic projects

Two touristic projects located in Hurghada along the red sea in Egypt were selected as case studies. Both of them use envelope design as a passive cooling technique.

The first project is El Gonna's Golf Resort, designed by Michael Graves and located in El Gouna, built on clusters of islands and surrounded by turquoise lagoons. El Gouna (located 32 km north of Hurghada) spreads over 10 million sqm of unspoiled terrain with 10 km of pristine beachfront. The project consists of a golf course with a hotel and housing area, and a clubhouse (Ismail, 1999).

The second project is Serena Beach Resort, designed by architects, Rami El Dahan, and Soheir Farid, The project is located at 6 km distance north the city of Quseir on the red sea beach and includes 180 hotel rooms clustered around inner yards and connected with a clear path, the main building, cafeteria, restaurants, a health club, a gym, and a diving center (Alam Al Bena'a, 1999).

In El Gona's Golf Resort, Graves has used the traditional rural Egyptian architecture, and has proven that this sort of architecture can support the demands of modern requirements.

The vernacular manner allows for variations in height, skyline, and colors. This gives the complex a distinct character (Fig. 1).

The project utilizes the following envelope

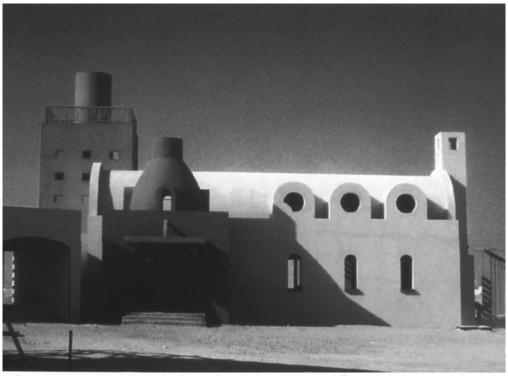


Figure 1: Hotel unit in El Gouna's Golf Resort.

design techniques to achieve passive cooling:

- In what concerns walls and roofs: the project utilizes domes and vaults in designing the envelope skin of the buildings, which gives more thermal comfort, by more effective cross ventilation (high windows in end walls of vaults), and better ventilation by increased stack effect (skylight openings in domes), and also produce more shading.
- In what concerns windows, doors, and openings: The project uses small size openings to reduce heat gain.
- In what concerns construction details: the project use thick walls with high capacitance.
- In what concerns surrounding surfaces: It provides Shading by vegetation, and uses green areas to reduce indirect heat radiation.

In Serena Beach Resort, The integration of the project with the existing environment is the most positive aspect of the design. The structure of the buildings is simple and uses the traditional technique of load bearing stonewalls. The designers used traditional materials where possible: stone, plaster, mortar and they utilized sand stone for walls extracted from the nearby mountains (Fig. 2).

The project utilizes the following envelope design techniques for passive cooling:

- In what concerns walls and roofs: the project utilizes the advantages of domes and vaults in reducing heat gain. Also it uses the variation of heights however the project consists of only one floor to produce more shades on walls and roofs.
- In what concerns windows, doors, and openings: The project Shades them from direct sun, especially on east, west, and south facades, it also uses small size openings
- In what concerns construction details: it uses thick walls with high capacitance for not permitting the external heat to penetrate to the inside of the buildings. The sand stone-walls are excellent insulators, and provide a high time lag.
- In what concerns surrounding surfaces: It provides Shading by vegetation, and lessen heat buildup around the building through green areas, and light color paving.

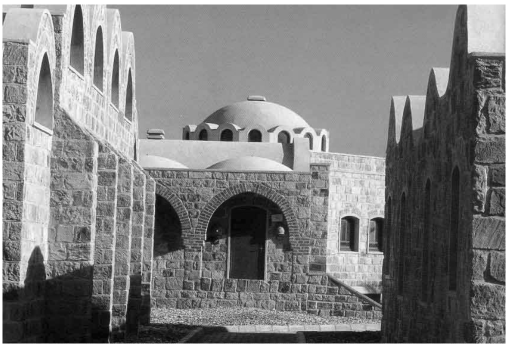


Figure 2: Hotel units in Serena Beach Resort.

7. PROPOSED ENVELOPE DESIGN CHECKLIST

The Previous discussion of key notions and principles allow the formulation of Envelope Design Checklist for Passive Cooling (Table 1).

The Envelope Design Checklist for Passive Cooling is formulated based on the main elements of envelope design.

8. EXAMINATION OF THE INFLUENCE OF ORIENTATION AND BUILDING SHAPE ON THE COOLING ENERGY

Both of orientation and building shape have a great influence on thermal conditions and the needed energy for cooling indoor space. The orientation has an important role in protecting building from direct solar radiation in the overheated periods when cooling is needed, but its influence differs upon the building shape

An examination was done by the author with the assistance of department of materials' nature in Housing and Building Research Center (HBRC) to examine this influence in case of touristic projects in Hurghada, which consist of hotel room units gathered in different ways of composition. Weather data of Hurghada hour by hour were obtained from the Internet web site: www.wunderground.com (the weather underground Inc., 2005).

A simulated modular design unit is chosen representing a one-floor hotel room unit with axes dimensions 4.8m * 6.0m provided with a front window. Six different ways in composing eleven rooms of this modular design unit are examined considering fixing the plot area of each composition while changing the orientation of each composition. The examined compositions are considered the most widespread compositions in touristic projects, which are I-L-T-Z-H-U shapes.

The needed cooling energy to reach thermal comfort conditions (dbt=24o C, R.H.= 50%) for each case are calculated while considering all other design thermal factors such as u-values, infiltration, and heat emitted from lighting and appliances as constants for all cases with a special schedules of operation for room guests, lighting and appliances. The calculations are made by an hourly analysis program (HAP-E20-II), which is used for thermal load estimation and energy analysis (Medhat, 2004)

Table 1: Envelope design checklist for passive cooling.

	DESIGN CHECKLIST
Walls & Roofs	- Control shape, form and orientation
	- Provide shading for walls and roofs
	- Use reflective materials and light colors
	- Use insulating materials with adequate thermal resistance
	- Select thermal mass construction /materials for hot dry areas
	- Select low mass materials construction/ for hot humid areas
	- Use roof spray or roof ponds for evaporative cooling to reduce heat gain
	- Incorporate solar controls on the building exterior
Windows, Doors and Openings	- Control form, size, and location
	- Avoid negative impact of door opening upon cooling loads with airlocks
	- Provide protection through insulation
	- Provide shading devices for openings
	- Orient door and window openings to facilitate natural ventilation in summer
	- Use overhangs or deciduous plant materials to shade windows
	- Select the proper glazing to reduce heat
	- Provide windows and doors with air-tight frames
	- Use solar monitors for ”stack effect” ventilation
Construction Details	- Specify construction materials and details that reduce heat transfer
	- Provide insulating materials to resist heat
	- Develop details that eliminate or minimize thermal bridges
	- Develop details that minimize opportunities for air infiltration
Ground Surfaces	- Use earth berms and sod roof to reduce heat transmission and radiant loads
	- Coordinate with existing and new landscape and other elements
	- Reduced paved areas to lessen heat buildup around the building

Table 2 shows the results of the calculations. It can be noticed that the case of I-shape with north-south orientation represents the best shape of composition and the best orientation of hotel room units as it records the lowst average needed energy for cooling during the worst ten months along year.

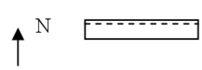
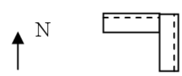
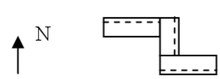
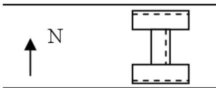
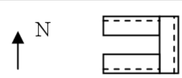
9. CONCLUSION

Envelope design is a major factor in determining the amount of energy a building will use in its operation, and decisions about its components play a crucial role in energy costs needed for cooling, in addition to realizing the required passive cooling.

There is always an interplay relationship between building form, materials, and climate, and each of them affects the thermal comfort of human being.

Members of the design team should coordinate their efforts to integrate optimal design fea-

Table 1: The lowest cooling power consumption per hotel room unit for different shapes and orientations of the most widespread compositions in touristic projects.

The best orientation for different shapes	Power consumption / Hotel room unit
	2.65 k. w. hour
	2.76 k. w. hour
	2.75 k. w. hour
	2.753 k. w. hour
	2.755 k. w. hour
	2.757 k. w. hour

------- Window position

tures for every building type to reach the lowest energy for realizing thermal comfort for its occupants, and Careful study is required to arrive at a building footprint, shape, form, and orientation that work with the building envelope components to maximize energy benefit, and to achieve energy savings.

The paper is highly recommending the proposed envelope design checklist for passive cooling to be used by the architects for providing them with the principles and design strategies for envelope design as a passive cooling technique.

The paper recommends that examinations could be done using different computer programs on simulated models for different building types to examine the influence of changing each element of the building envelope to reach the best case recording the lowest needed cooling energy during the overheated periods.

REFERENCES

Alam Al Bena'a, 1999. Serena Beach Resort, Center of Planning and Architectural Studies CPAS, Issue No. (215) September, Cairo, Egypt.

Ballinger, J., et al., 1992. Energy Efficient Australian Housing, 2nd. Edition, AGPS, Canberra.

Fathy, H., 1986. Natural Energy and Vernacular Architecture, Chicago: The United Nations University Press.

Ismail, A., 1999. Local Focus: El Gouna's Golf Resort, Medina Magazine Issue No. (10) November, Cairo, Egypt.

Koenigsberger, O., 1974. Manual of Tropical Housing and Building Design, U.K.: Longman Group.

Medhat, A., 2004. Optimizing Energy efficiencies of cooling systems at hot & dry climates, Proceedings, International Conference "Future Vision and challenges for urban development", Housing and Building Research center (HBRC), Cairo, Egypt

The weather underground, inc., (2005), www.wunderground.com

U.S. Department of Energy (U.S.D.O.E), 2004. Energy Efficiency and Renewable Energy: Building Envelope, www.eere.energy.gov.

Watson, D. and K. Labs, 1983. Climatic Building Design 'Energy Efficient Building Principles and Practice', New York, Mc Graw-Hill Book, Inc.

Willrah, H., 2000. Energy Efficient building Design Resource Book, Brisbane Institute of TAFE.