Architecture Department
Faculty of Engineering
Ain shams University

Passive Cooling Techniques for Enhancing the Building Sustainability Development

Presented by
Arch. Hala Mohammad Ali Hammad
B.S.C. Architecture; Ainshams University; 2004

A Thesis Submitted in a Partial Fulfillment
of the Requirements of
M. SC. DEGREE IN ARCHITECTURE

Under the supervision of:

Prof. Dr. Yasser Mohamed Mansour
Prof. of Architecture - Department of Architecture
Faculty of Engineering- Ainshams University

Prof. Dr. Khaled Mohamed Ragehb Dewidar
Prof. of Architecture - Department of Architecture
Faculty of Engineering- Ainshams University

Prof. Dr. Hanan Mostafa Kamal Sabry
Prof. of aAchitecture - Department of Architecture
Faculty of Engineering- Ainshams University

Ain Shams University
2009

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Prof. Dr. Hanan Mostafa Kamal Sabry Prof. of architecture Department of Architecture Faculty of Engineering Ainshams University	

RESEARCHER IDENTIFICATION

Researcher Name: Hala Mohammad Ali Hammad

Birth Date: 20th of October 1982

Scientific Degree: B.Sc. Architecture- Ain Shams University 2004

Present Job: Teaching Assistant in Architectural department- Ain Shams University

For Contact: Halahammad_eng@Hotmail.com

STATEMENT

This thesis is submitted to Ain Shams University for the degree of Master of Science in architecture.
The work included in this thesis was accomplished by the author at the department of Architecture Ain Shams University during the period from may 2005 to October 2009
No part of this thesis has been submitted for a degree or a qualification in other university or institute.

Name: Hala Mohammad Ali Hammad
Signature:

A C K N O W L E D G E M E N T S

First of all I am thankful to my supervisor Prof. Dr. Yasser Mohamed Mansour, Prof. of Architecture – Department of Architecture for his critical viewpoint on the subject and the study. Prof. Dr. Khaled Mohamed Ragehb Dewidar and to Prof. Dr. Hanan Mostafa Kamal Sabry for their guidance to me and their support to my study and belief in me. Finally I am grateful to my family for supporting me to realize this study, special thanks to my husband Khaled Hassan for supporting me and guiding me to different collection of data for completing my research.

1-1 Introduction

The concept of sustainability in building design and construction has evolved over many years. The initial idea of building sustainability to architect is to know how to transact with non renewable resources like energy, materials, and water, and how to reduce the building's impact on the surrounding environment, taking into account the building environmental, social, and economical factors. Sustainable building target is not only to achieve the building ecologically but also to create a harmony between the structure and its surrounding nature. This chapter introduces a brief explanation for the main concepts and principals for developing the sustainable building. Moreover, it explains the main principals of a passive design building and its efficiency in developing the sustainability of any building.

1-2 Main Objectives of Sustainability in Buildings

Sustainable building key is to design a building for more productive and healthier environments. The main objective of sustainability is that to design a building that responds to today's human needs without imposing additional costs upon future generations taking into consideration the impact on the surrounding environment[1]. This main objective could be achieved by realizing the following secondary objectives:

1. Insisting on the right of humanity and nature to co-exist in a healthy, supportive, diverse, and sustainable condition.
2. Considering all aspects of human settlement including community, industry, and trade in terms of existing and evolving connections between spiritual and material consciousness.
3. Creating safe objects to long-term value, means not to trouble future generations with requirements for maintenance and prevent careless creations of products, processes, or standards.
4. Eliminating the concept of waste, means to evaluate the full life-cycle of products and processes to approach the state of natural systems in which there is no waste.
5. Relying on renewable natural energy flows.
6. Understanding the limitations of design.
7. Seeking constant improvements by sharing knowledge, encouraging direct and open communication between manufacturers, and

[1] U.S. General services administration, 2002, GSA office of Government wide Policy, *Office of Real Property, Real property sustainable development guide.PDF,*, p3.

reestablishing a long-term relationship between users' cultures, sustainable considerations, natural processes, and human activities[2].

1-3 Historical Background of Sustainable Building

The concern of the building ecological sustainability has followed a widespread rise in environmental awareness due to the energy crisis of 1973. It considered the turning point in the development of energy efficient buildings. Cooling and daylighting were the two major concerns for every building at the beginning of the 20th Century. This resulted in designing a new building type with new characteristics that kept its design utilizations but different in its principals. The main objective was to reduce fuel bills by reduction in the artificial lighting and mechanical air-conditioners usage. After these events, the interest in sustainable architecture has increased which make the western architects recognize the economic and health benefits of conserving energy and directed to recognizing sustainable architecture.

For the Middle East especially in Egypt, idea of sustainability is not new, since 1940 the Egyptian architect Hassan Fathy was leader in dealing with the local materials, limited resources, and architecture for the poor people. Fathy used traditional building techniques and local materials to create environmentally conscious architectural solutions and to enable the poor to control the building process for their homes. It seems that Hassan Fathy was strongly against Western techniques and materials like reinforced concrete and steel as he found it was inappropriate for Egypt's climate. His structures were cheap, cool in summer and the walls were heat-retaining in winter. His buildings designs depend mainly on natural ventilation, orientation, wind patterns and local materials, as well as, he has concerned the traditional construction methods and energy- conservation techniques.

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[2] Leslie Starr Hart, 1994, *Guiding Principles of Sustainable Design,* Published by Gordon Press Publishers, Denver, Colorado, p19.

Figure 1-traditional sustainable architecture: Akil Sami House, Dahshur, Egypt[3]
Example of Fathy´s sustainable architecture: using local limestone and the courtyard with wooden pergola.

The previous historical view considered a guide to architects to develop the environmental, social, and economical sustainability in buildings to achieve perfect solutions for human needs. New sustainable design techniques are now using an alternative approach to the traditional design to incorporate these new changes in architect mind-set with the sustainability considerations. The new design approach should recognize the impacts on natural and cultural resources of the local, regional, and global environments[4].

1-4 Cyclic Development of Building Sustainability

Sustainable development is the challenge of meeting growing human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality for future life and development. Building's sustainability is a relationship, or balancing between many factors social, environmental and economic constraints (figure 1-2). If sustainable design principles are incorporated into building projects, benefits could include resource and energy efficiency, healthy buildings and materials, ecological and social sensitive land

[3] digital library, Hassan Fathy, accessed 2006, http://archnet.org/library/images/thumbnails.jsp?location_id=5161

[4] Leslie Starr Hart, 1994, *Guiding Principles of Sustainable Design,* Published by Gordon Press Publishers, Denver, Colorado, p20.

use, transportation efficiency, and strengthened local economies and communities[5].

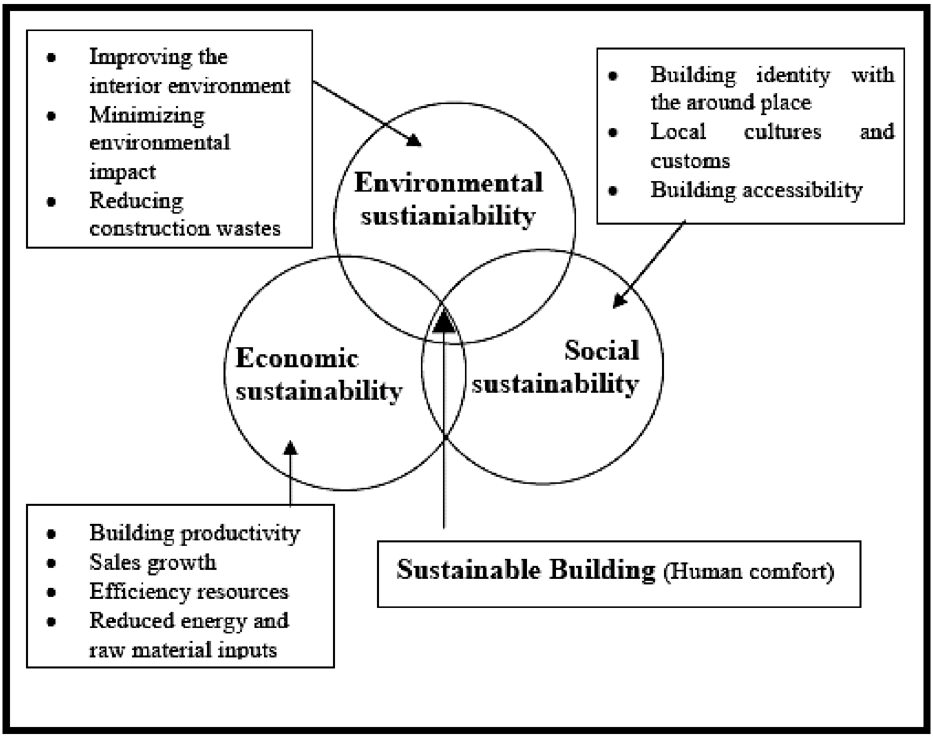

Figure 1- Cyclic sustainable development[6]

The next sections discuses the economic, environmental and social aspects which are essential to the building sustainability development.

1-4-1 Economic Sustainability Development

Economics is an important aspect which guides to building's sustainability development, as it explains the production, distribution, and consumption of goods and services. The exchange of goods and services has a significant impact on the environment, since the environment serves the source of raw materials input for constructing the building[7]. Economic sustainability

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[5] Public Technology inc, 1996, *Sustainable Building Technical Manual Green Building Design, Construction, and Operations. PDF*, p5.

[6] Sustainable Architecture, accessed 2006 http://www.arch.hku.hk/research/BEER/sustain.htm#1.3

[7] Public Technology inc, 1996, *Sustainable Building Technical Manual Green Building Design, Construction, and OperationsPDF.*, p 4.

development requires that the architect should recognize the limits of the resources in the environment. The architect should minimize the consumption of all resources, renewable and nonrenewable resources in building construction. Once this is done sustainable development will be revealed to achieve more economically benefits than current development patterns.

1-4-2 Environmental Sustainability Development

Environmental sustainability of the building means to protect the environment from impact of the building, while meeting human needs in a manner that assures a healthy environment for future generations. The main principals that form the environmental sustainability of the building are:

- *Improve the interior environment:* creating a healthful interior environment by controlling pollutants, better light quality, better ventilation quality, and avoiding noise. And to ensure that materials and building systems do not emit toxic gases into the interior atmosphere.
- *Minimizing environmental impact:* the architect should carefully design a building that minimizes environmental impact, maintains the surrounding bio-diversity, and oriented to maximize natural energy flows available from the sun and wind while minimizing unwanted solar gain and glare.
- *Reducing construction wastes*: The sustainable building design strategy should focuses on reducing construction wastes by recycling and reusing the construction wastes.

1-4-3 Social Sustainability Development

It considered an important aspect in developing the sustainable building, as more than 70% of a person's lifespan is spent indoors. This creates an importance to build environments that sustain occupants' safety, healthy, and physiological comfort. Moreover, architect should preserve local cultures, customs, and creating a sense of place, using local materials and architectural elements to design a building which responses to the regional climate.

1-5 Sustainable Building Principals

It is an important point to evaluate the sustainable building principals during the early phases of building design in order to be able to evaluate the initial decisions to improve the building sustainability. These principals are:

sustainable site selection, energy conservation, water conservation, materials conservation, indoor environmental quality, and waste management. The next section presents an overview on: energy efficiency, site selection, and indoor environmental quality as the important principals affecting the building internal cooling loads which considered the main idea of this research.

1-5-1 Energy Conservation

The sustainable building ideally uses a very little energy and depends mainly on renewable energy resources in cooling, ventilating, and lighting processes. So, creating a low energy profile is a major goal for designing sustainable buildings that produce energy more than it consumes. Cleaner and efficient technologies are required to further develop and expand the role of alternative energy sources.

That is why it is important for owners and design teams to consider some issues for energy-efficient and sustainable design from the moment the decision is made to construct a building until the building usage. There are three Energy efficient strategies that can enhance the building sustainability development. These strategies could form an energy efficient pyramid (figure 1-3) with its base is the energy conservation by building passive design, and then comes the usage of energy efficient systems and then usage of alternative sources of energy comes at its top.

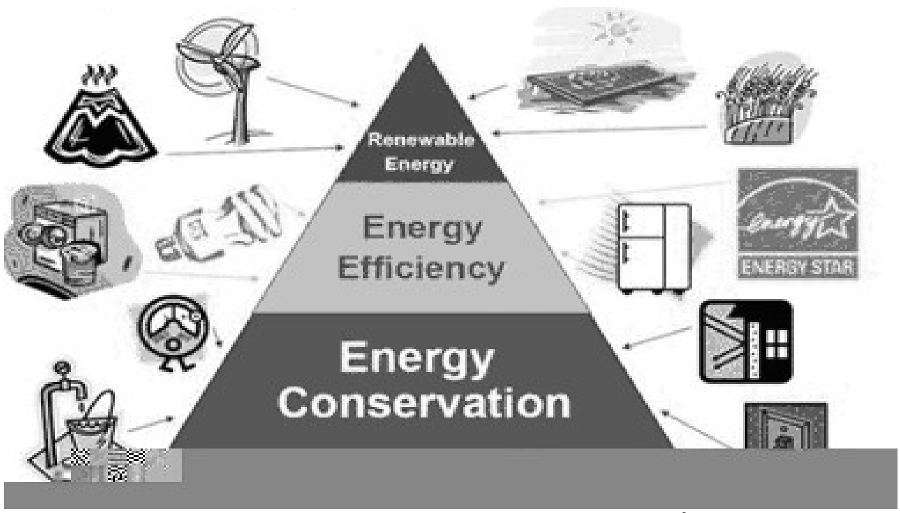

Figure 1- The sustainable Energy Pyramid[8]

8 nwcommunityenergy.org, Conservation and Efficiency, accessed 2008. http://www.nwcommunityenergy.org/biogeo/efficiency

1-5-1-1 Energy conservation: building passive design

Passive design means designing buildings and spaces that take into consideration the local climate conditions, such as natural light, temperature, humidity, solar radiation and wind. It creates climate-responsive and energy conserving structures that can be powered with renewable energy sources. Passive design is a key element of sustainable building which aims at maximizing occupancy comfort while minimizing energy usage and other impacts on the environment. This means to make the most free and natural sources of energy (such as the sun and the wind energy) can provide free heating, cooling, ventilation and lighting[9].

Passive design requires an understanding of the relationships between building components and surrounding environment. Moreover, it requires understanding the ways in which design elements and various building materials contribute to various goals. For example, sky lights permits natural light all over the day and additional heat gain for passive heating in winter while it may cause overheating in summer. Thus, the key to a successful passive design is to think about a building as a package of design features and building components that work together to provide comfort during any season (figure 1-4). That means the supply of fresh air, heat, coolness, and light to achieve a pleasant indoor environment[10]

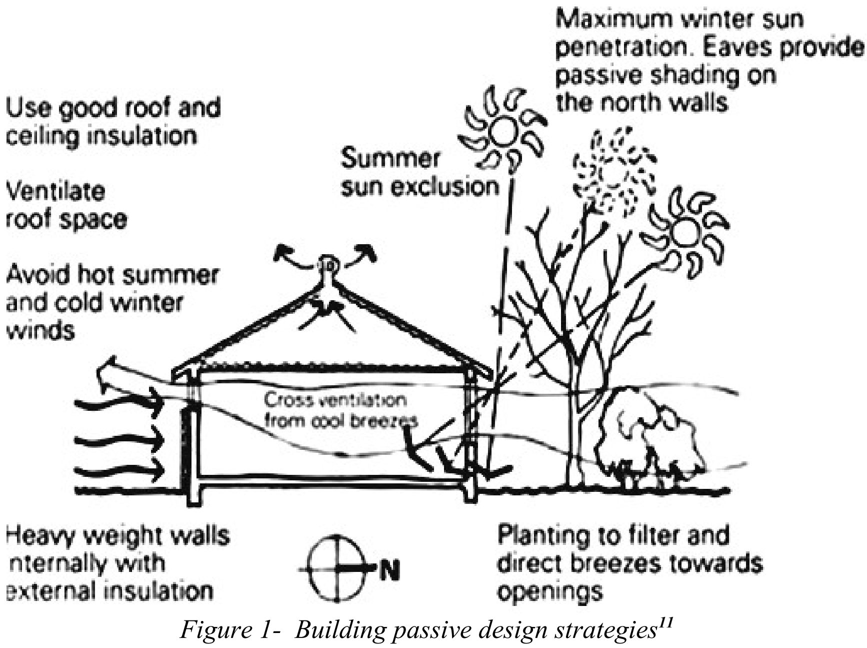

Figure 1- Building passive design strategies[11]

[9] Level, The authority on sustainable building, Passive Design: Introduction, accessed 2008. http://www.level.org.nz/passive-design/

[10] Daniel D. Chiras, 2002, *The Solar House*, Published by Chelsea Green Publishing, p9.

[11] surf coast shire, Passive Cooling – a brief introduction, pdf, accessed 2007

a) Passive design features

Passive design features are elements that are permanently attached to or part of the building design such as building orientation, double skin envelope, sun-shading device, large overhang etc. Passive techniques as alternative to conventional building design that bring important energy, environment, financial, operational and qualitative benefits as it will lead to decrease cooling, heating, and electric loads on the building and could improve the building sustainability[12]. The next section discusses briefly these passive design features.

- *Passive Heating:* Passive heating strategies can maintain stable temperatures on year-round without any need for supplementary heating. As well as, passive heating is by far the most environmentally friendly way to interior space heating. Other forms of heating such as gas and electricity generate greenhouse gases and other harmful emissions when produced by burning fossil fuels. Passive solar heating in particular makes use of the building components to collect, store, and distribute solar heat gains to reduce the demand for space heating. It does not require the use of mechanical equipment because the heat flow is by natural means (radiation, convection, and conductance) and the thermal storage is in the structure itself[13]. It is better to incorporate passive solar heating into a building during the initial design. The whole building approach evaluates it in the context of building envelope design. Window design, especially glazing choices, is a critical factor for determining the effectiveness of passive solar heating.

- *Passive Cooling:* passive cooling strategies could decrease the internal cooling loads through the building envelope by minimizing heat gain from the external environment and facilitating heat loss. Passive cooling techniques radiation, evaporation, ventilation, shading, and insulation) are considered alternative to mechanical cooling to reduce energy consumption, costs, and impact on the environment. This section will be discussed deeply in chapter two, three, and four.

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http://www.surfcoast.vic.gov.au/Planning/Documents/Sustainable%20building%20design/Passive_Cooling.pdf

[12]Level, The authority on sustainable building, Principles of passive design, accessed 2008 http://www.level.org.nz/passive-design/principles-of-passive-design/

[13] Judy Fosdick, Passive Solar Heating, accessed, 2008 http://www.wbdg.org/resources/psheating.php?r=minimize_consumption

- *Daylighting:* it is one of the important aspects for achieving energy efficiency and building sustainability development. It could be used as an alternative to electrical lighting in commercial buildings in daytime. At the same time, daylighting helps to creating a visually stimulating and productive environment for building occupants, while reducing as much as one-third of total building energy costs[14]. The need for sun light to be a part of the design determines the possibilities for reducing the solar loads by using appropriate natural daylighting techniques.

b) *Benefits of passive design*
   - Increase the user comfort: Properly designed, passive buildings are bright and sunny and in harmony with climate and nature. It produces a high degree of temperature stability and thermal comfort.
   - Increase the user productivity: passive design creates delightful places to live and work, it can contribute to increased satisfaction and productivity.
   - Reduce emissions: By relying on renewable and non-polluting energy sources (solar, wind, and geothermal energy resources), so passive solar design does not generate greenhouse gases and slows fossil fuel depletion.

1-5-1-2 Energy conservation: electric systems

Electrical and mechanical systems are responsible for more than 50% of a building's annual energy costs[15]. For sustainable building, designer should select the high efficient electrical and mechanical systems which consume less energy than other, for example:

a) *Regular and compact fluorescent lighting:* they use 75% less electricity; heir average life is 10 times longer than incandescent and could reduce maintenance and transportation costs[16]. For example: Halogen lamps, Metal halide lamps, High-Intensity Discharge Lamps (HID), and light

[14] Gregg D. Ander, FAIA, Daylighting
http://www.wbdg.org/resources/daylighting.php

[15] Kibert, Charles J., 2005, *Sustainable Construction: Green Building Design and Delivery*, John Wiley and sons, Hoboken, New Jersey, p17.

[16] Leslie Starr Hart, 1994, *Guiding Principles of Sustainable Design,* Published by Gordon Press Publishers, Denver, Colorado, p26.

emitting diodes (LED) lighting are considered innovative energy efficient electrical lighting systems.

b) *Electric controls in lighting and ventilation systems:* it includes dimmer controls, switchers, photosensors, occupancy sensors, and motion sensors. These controls reduce the energy which could be wasted by lights that are left on when not needed.

c) *Heating, ventilation, and air-conditioning (HVAC) systems:* they should be selected for the greatest efficiency at the most commonly experienced temperatures. The initial price of these equipments may be higher than that of less efficient equipment, but this will be offset by future running cost savings.

1-5-1-3 Energy conservation: Alternative sources of energy

Solar, wind, water, biogas and geothermal energy systems could be used as alternative sources for generating electricity to reduce or eliminate the need for external energy sources. These natural resources could be used for functions such as lighting, cooling, water heating, and electric power production as well. The designer should maximize the use of the renewable energy resources available on the site for design an efficient passive design[17]. Alternative energy generation techniques are so many depending on the available source on the site. Following, briefly explanation of two of the clean renewable energy generator resources that could be available on the building site:

a) Photovoltaic (PV) cells

One of the most promising systems of converting this solar radiation into usable energy is the Photovoltaic cell. Photovoltaic system is a solar power technology that uses solar cells or solar photovoltaic arrays to convert sunlight into electricity. Its low maintenance, high reliability, and widespread support make it an attractive option for remote energy generation. It could be used as cladding to exterior facades (figure 1-5) as this system design is flexible and could be easily expanded[18].

[17] Ibid

[18] Ibid

Figure 1- PV panels on Brundtland Centre facade, Toftlund, Denmark, Krohn & Hartvig Rassmussen[19]

b) *Wind generators*

Wind energy offers many advantages and is the fastest growing renewable energy source in the world. Wind generators could be a good choice for remote applications and small power demands such as pumping water. Its major maintenance should be performed by the dealer[20]. It is a clean fuel source and does not pollute the air unlike power that rely on combustion of fossil fuel. Wind turbines innovative technologies allow it to be utilized in building design.

1-5-2 Sustainable Site Selection and Planning

Creating a sustainable building starts with a proper site selection. The location, orientation, and landscaping affect the local ecosystems, transportation methods, infrastructures, and energy consumption[21]. The architect should decide the appropriate site to take the maximum advantage of solar access, existing vegetation, and natural geological features. The important considerations the architect should take into account before selecting an efficient site to maintain the sustainable developments are: *Site analysis, Infrastructure efficiency, Cultural and historical Context, and Sustainable site planning*

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[19] Deo Prasad and Mark Snow, 2005, *Designing with solar power – A source book for Building Integrated Photovoltaics* (BiPV) , published by the images publishing group ply ltd and earthscan, p 70.

[20] John Twidell, Anthony D. Weir, *Renewable Energy Resources*, Taylor & Francis 2006.

[21] Kibert, Charles J., *Sustainable Construction: Green Building Design and Delivery*, John Wiley and sons, Hoboken, New Jersey, 2005.

1-5-2-1 Sustainable site: Site analysis

It refers to looking on the site context before planning and designing the project, as it will affects on choosing the building shape, materials, and structural systems. The site analysis determines the site characteristics that influence the building design (form, shape, materials, dimensions ratio, structural systems, mechanical systems, access and service, solar orientation, and elevations). It includes the natural factors presented on site and the site topography.

a) *Natural Factors*

Sustainable design should seek harmony with its environment; design should not be static but always evolving and adapting to interact more intimately with its surroundings. When nature is incorporated into designs, spaces will be more comfortable, interesting, and efficient[22]. Site climate, temperature, sun directions, wind directions, humidity, and existing vegetation are the natural factors on site which should be known by architect in the early design stage to develop the sustainability of the building. These natural factors around in the environment affects on man behavior as well (figure 1-7).

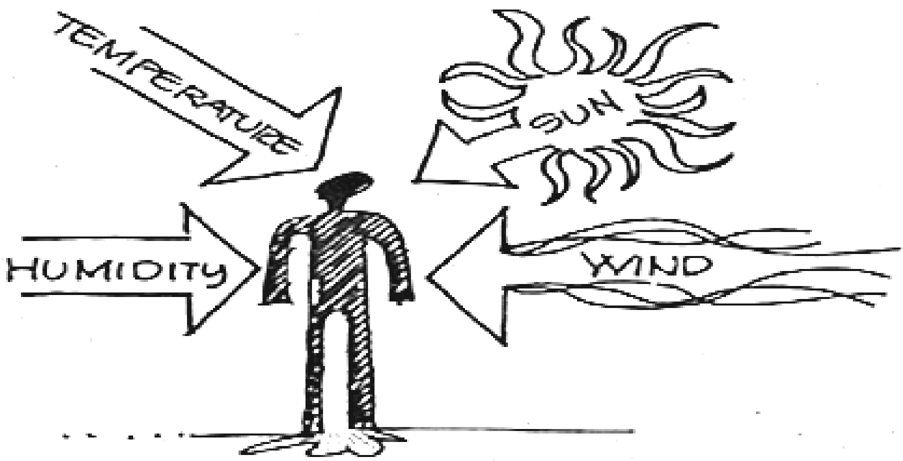

Figure 1- natural factors in site affecting the building design[23]

- *Temperature*

Knowing the site temperature is an important parameter for designing a sustainable building, it affects on the building design from cold regions than that in hot regions. Also building construction will differentiate with temperature difference, for

[22] Leslie Starr Hart, 1994, *Guiding Principles of Sustainable Design,* Published by Gordon Press Publishers Denver, Colorado*, p*

[23] Ibid

example, in regions having hot day and cold night, heavy construction is efficient to yield relatively constant indoor temperatures. In hot regions the architect could find some architectural solutions to overcome this high temperature by: maximizing exposure for natural ventilation, isolating heat-generating functions such as kitchens and laundries from living areas, and by providing shaded outdoor.

- *Sun*

Sun directions in the site could help the architect to orient the building, for example, in order to maximize building exposure to the sun, the building openings should be faced to the south for providing passive heating. In hot climates the architect could orient the building surfaces away from hot late western sun such that to reflect all sun radiations to prevent over heating for example he can use overhangs, vegetation, louvers, screens, and shutters to shade walls and openings on east and south directions. Thus, the orientation of the building involves how the building will relate to climatic and weather conditions and how the sun radiations could be maximized in winter and minimized in summer.

- *Wind*

Wind direction in the site is an important issue which could have a significant effect on the whole design; wind can be an assistant in hot, humid climates to provide natural ventilation. The architect can maximize/minimize exposure to wind through plan orientation, position of walls/roof openings, and vegetation according to its purpose (figure 1-8). Moreover, the wind direction will affect the building layout, location of entrances, windows, and doors.

- *Vegetation*

The architect could make use of it for enhancing privacy or to create "natural rooms," or, could be a primary source of shade as well.

- *Views*

The site location for a sustainable building should maximize the views of natural features.

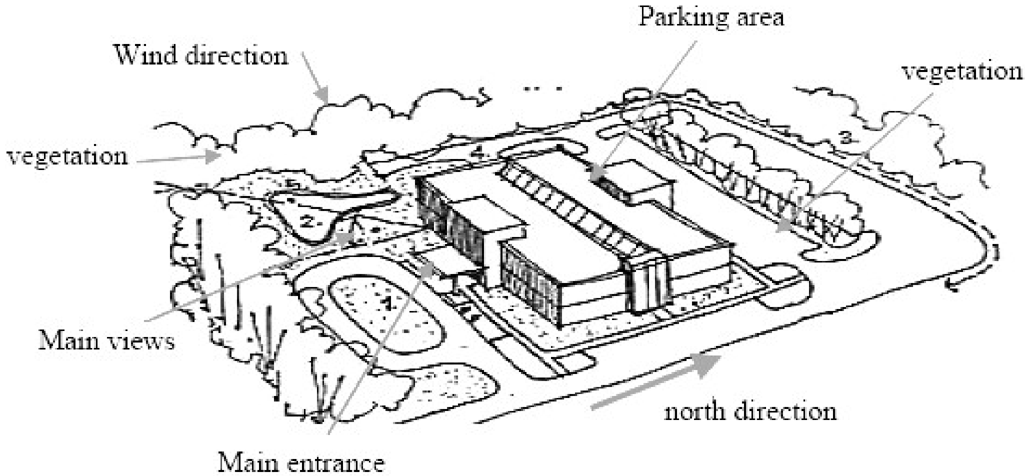

Figure 1- Site analysis and zoning for any building[24]

b) Site topography

Site slops and soil conditions should be known by the architect in order to select the suitable structural system. The site could be divided into zones, rock soil which needs special machines to dig it, other zones like sand soils will be treated in different way than the first one. Moreover, high slopes require special sitting of structures and costly construction practices. Slopes are not impossible to deign if innovative design solutions and construction techniques are applied. Topography can potentially provide vertical separation and more privacy for individual structures. Changes in topography could be used also to enhance and vary the way the visitor experiences[25].

1-5-2-2 Sustainable site: Reuse Existing Infrastructure

The architect should select sites where he could make use of existing infrastructure, or sites that require minimal extension to infrastructure in order to reduce the infrastructure construction costs. Where highways, streets, roads, bridges, airports and airways, water supply and water resources, wastewater management, electric power generation and transmission, and telecommunications should be presented in the site or required minimal extension.

[24] Public Technology inc, 1996, *Sustainable Building Technical Manual Green Building Design, Construction, and Operations, p38.*

[25] Leslie Starr Hart, 1994, *Guiding Principles of Sustainable Design,* Published by Gordon Press Publishers Denver, Colorado, p29.

1-5-2-3 Sustainable site: Cultural and historical context

Sustainable principles seek the balance between cultural and historical patterns which is existed on the site and the new technological development. The architect should take into consideration two issues before designing a sustainable building: *understanding the building occupant's culture and psychology, and knowing the vernacular architecture.*

a) Understanding the building occupants cultures and psychology

The sustainable design should take into consideration the cultures and habits of the people whom are going to use it. For example to design a building in Cairo is completely different from designing the same building in Aswan. Although the two cities are in the same country but there is a great different in people culture, habits, and way of thinking.

b) Knowing the vernacular architecture

Cultural history should be reinforced through design by investigating the vernacular design vocabulary. Local design elements and architectural character should be analyzed and employed to establish an architectural theme for new development. The architect should analyze usually the local historic building styles, systems, and materials for maintaining harmony with natural systems. Moreover, using local building material, craftsmen, and techniques to the greatest extent considered to be practicable in the development of new facilities. The designer could mix the site historical concept with the technological systems and this could be the building main concept. He could reuse historic buildings whenever possible to contribute to the quality of the place, and extend the payback of their materials.

1-5-2-4 Sustainable site: site planning

Careful site planning can minimize the heavy equipment attack and the ecosystem damage to the site. Sustainable site planning should consist of a whole system approach that contains some issues that architect should pay attention to it.

- Building foundations, it should not alter the flow of groundwater through the site.
- Finished structures, it should respect existing drainage.
- Trees and vegetation, it should only be removed when absolutely necessary for access[26].
- Reduce heat islands using landscaping and building design methods;

[26] Jong-Jin Kim, 1998, *Sustainable Architecture Module: Introduction to Sustainable Design,* College of Architecture and Urban Planning, The University of Michigan, Published by National Pollution Prevention Center for Higher Education, p27.

- Pay attention to agricultural resources and avoid disruption whenever possible.
- Site the building with public transportation access and limit on-site parking.
- Site transportation paths should be designed in a way that does not interfere with each other.
- Control erosion through improved landscaping practices;
- Consider site security concurrently with sustainable site issues. Location of access roads, parking, and perimeter lighting, among others are key issues that should be addressed.
- Balance site sustainability with site security/safety.
- Use native or climate tolerant trees to improve the quality of the site and minimum maintenance.

1-5-3 Indoor Environmental Quality (IEQ)

Indoor environmental quality has the major concern for interior space sustainability development, as it has impact on health, comfort, psychology, and productivity of building occupants. People spend more than half of their life in the indoor environment. The indoor environmental level can some times have pollutants level higher than the outdoor pollutants level. Thus, it could increase the risk of illness. there are some factors affects the indoor environmental quality which include; thermal comfort and indoor air quality (IAQ), lighting quality, acoustics and noise quality.

1-5-3-1 IEQ: Maintaining better indoor air quality

ASHRAE[27] defines acceptable indoor air quality as "air in which there are no known contaminants at harmful concentrations and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction"[28]. To protect the indoor environmental quality, the designers should understand the indoor air quality problems and seek to eliminate potential sources of contamination that originate from outdoors as well as indoors. Better ventilation quality and controlling oxygen and carbon dioxide levels are considered the main considerations that should be considered to maintain a better indoor air quality.

[27] The American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc.

[28] C.Y. Shaw, 1997, Construction Technology Updates, *Maintaining Acceptable Air Quality in Office Buildings through Ventilation*, National Research Council of Canada, No. 3, Jan.
From website: http://irc.nrc-cnrc.gc.ca/pubs/ctus/3_e.html

1-5-3-2 IEQ: Providing human thermal comfort in summer

The indoor climatic settings have a major impact on man's behavior and quality of the work done. People do not perform well in spaces that are too hot or too cold. Generally the range for thermal comfort is that the temperature is between 20°C and 27°C and relative humidity between 30 and 60 percent[29]. Temperature or humidity out of this average is not comfortable for the occupants. Air flow velocity is another variable for the indoor climate which affects the human comfort.

1-5-3-3 IEQ: Lighting quality

It is an important factor affecting the indoor environmental quality; some lights can cause irritation and health problems. Natural light is the most comfortable light source for the eye, but it could cause glare if it not well designed. Correctly designed reflectors and different shading devices, and appropriate arrangement of light sources can avoid this glare. Proper day lighting design can reduce energy usage for electric lighting by 50 % to 80%[30], moreover, it provides occupants connection between indoor spaces and outdoors, and thus, increases occupant productivity and reduces illness. The ideal healthy indoor light environment is one that allows natural light indoors while preventing direct radiations to enter to prevent glare and providing visual comfort.

1-5-3-4 IEQ: Acoustic and noise quality

The noise level is a major problem that should be controlled in the sustainable design. Noise could be caused from air handling systems, lights, transformers, ventilation systems, air ducts, elevators, machinery, and other sources. It results discomfort and even health problems for occupants. Designer can easily prevent most of these problems by the mean of perfect building design, for example designer should take care not to locate a conference room next to chiller plant. Moreover, if the building is totally naturally ventilated, the designer should well design the inlet and outlet openings to avoid noise discomfort. This could be avoided by installing sound absorbing materials on walls and ceiling to enhance the indoor acoustic quality.

1-6 Future Development of Sustainable Buildings

Buildings design is today a far more complex procedure than it used to be, and it will be more complicated in the near future. The expectations for the future sustainable building improvement are in: materials, construction methods,

[29] ASHRAE Handbook, 2005,Thermal Comfort chapter, Fundamentals volume of the *ASHRAE Handbook*, ASHRAE, Inc., Atlanta, GA, 2005.

[30] Brian Edwards, 2003, *Green Buildings Pay*, second edition, Published *Taylor & Francis*, p12.

advanced computer applications in lighting and ventilation. In the future, the designers will be directed to the designing of green buildings. Some more expectations for the future development of sustainable design discussed as follows:

- The future sustainable buildings design will aim to generate energy and consumes no fossil fuels by the year 2030. Building structures will produce it own needs of energy and no need for any outer energy[31].
- Passive design strategies will have a significant effect on energy performance, passive cooling, ventilation, and lighting which will be the main characteristics for the future sustainable buildings.
- Future sustainable buildings will have no impacts on the environment, but it will positively impact on it.
- During the building design, computer aids will be needed to know the quantities and qualities of buildings components and its impact on the surrounding environment. While, after construction, Multiple building systems will be coordinated together with central computer programs, particularly in communication, air conditioning, and lighting systems.
- Robotic manufacturing of building components and materials will be widely used, beside the use of sophisticated three-dimensional computer programs to design buildings.

1-7 Conclusions

This chapter has studied the main principals for the building sustainability development, and the strategies for their application in any building. Studying the sustainability development of building deign leads to decrease the negative impacts on the environment, increase the health and comfort of building occupants, thus, improving building performance and productivity. Moreover, this chapter has studied the main objectives of sustainable building which are to reduce consumption of non-renewable resources, minimize waste, and create healthy, productive environments. It has discussed the energy efficiency, site selection, and indoor environmental quality as it has a great effect on designing a passive cooling building which is the main study of this research. The following table summarizes the main indicator to design a sustainable building.

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[31] Kibert, Charles J., 2005, *Sustainable Construction: Green Building Design and Delivery*, published by John Wiley and sons, Hoboken, New Jersey.

Building sustainability development indicators h	Energy efficiency	Building passive design
		Energy efficient electric systems
		Alternative sources of energy
	Sustainable site selection and planning	Site analysis
		Reuse existing infrastructure
		Respect the culture and historical context
	Materials conservation	Local sourcing and materials
		Durability of building components
	Water conservation	Water recycling
		Water saving plumbing fixtures
	Indoor environmental quality	Interior air free from Pollutant
		Providing human thermal comfort in summer
		Better lighting quality

Table 1- Sustainability indicators for buildings[32]

[32] Ibid

2-1 Introduction

Cooling is the transfer of heat from the space, or air supplied to the space in order to achieve a lower temperature and/or lower humidity level than those of the natural surroundings[1]. Recently, the usage of mechanical air- conditioners have increased significantly in buildings, this results in increasing the building energy consumption and bills. Passive design can reduce the building cooling loads and improve the indoor comfort conditions. Furthermore, using alternative passive cooling techniques could provide comfortable indoor conditions while minimizing the energy consumption through the use of natural energy resources. This chapter explains the factors affect the Enhancement of the internal space cooling. 1st factor concerns the ***architectural design considerations for passive cooling*** which refers to efficient architectural design features for decreasing the transmittance of external high temperature and decreasing the internal sources emitting heat energy as well 2nd factor is the presence of ***passive cooling techniques*** which based on the cooling procedures (radiation, evaporation, ventilation, shading, and insulation processes).

2-2 Architectural Considerations for Passive Cooling

To design a passive cooling building, the flow of heat energy into the internal space should be controlled using building architectural design and building structure to prevent the internal heat gain. This could be achieved by taking into account the following two issues:

- Decreasing the transmittance of external high temperatures, and
- Decreasing the internal sources emitting heat energy.

2-2-1 Decreasing the Transmittance of External High Temperatures

Any surface on the earth gains heat from solar radiations and loses heat by outgoing radiations. The incoming solar radiation is ultimately subdivided into two fractions: the radiations which are absorbed by the surface and converted into heat, and the radiations which are reflected away towards the sky without any effect on the temperature and humidity conditions of the environment.[2]

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[1]**M. Santamouris, D. Asimakopoulos**, *Passive Cooling of Buildings*, P1, published by Earth sc an. 1996.

[2] **Baruch Givoni**, 1998, *Climate Considerations in Building and Urban Design*, publisher John Wiley and Sons", P266.

The solar heat enters the building through its walls, windows, and roof with different percent (figure 2-1). When solar radiation falls on a vertical wall, it is partially reflected and partially absorbed by the building walls. The amount of solar radiations absorbed by the walls can penetrate to the interior of the building which leads to increasing the internal temperature. The percentage of solar radiation absorbed or reflected can vary from 20- 80 % according to some factors in the exterior walls: color, the exterior finishing, the thermal resistance, and the envelope construction materials.

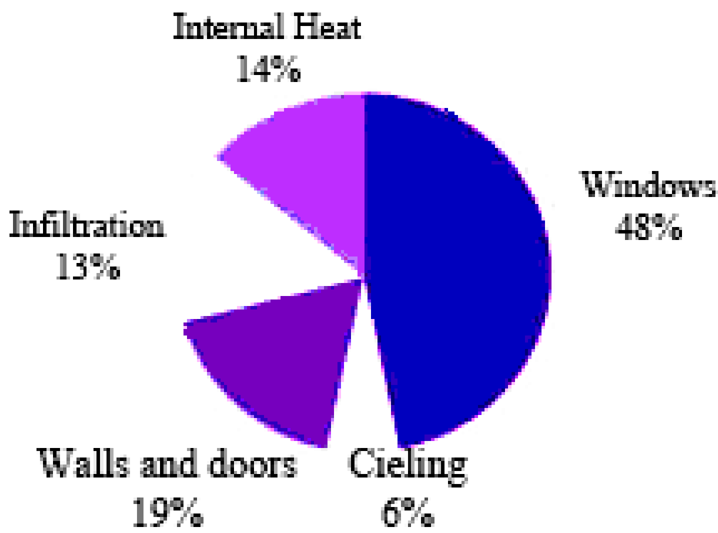

Figure 2- Percentage of solar heat gain from different sources in the building[3]

The best way to deal with solar radiation reduction is to prevent it from reaching building surfaces in the first place. Appropriate building design and structure elements can minimize heat gain and consequently its cooling needs. The general building architectural features that prevent solar radiations from entering the space are:

- Appropriate site layout, building location, and orientation
- Efficient plan zoning
- Building envelope materials
- Airtight Construction
- Minimum fenestration

[3] Window Shading for Cooling, accessed 2007, http://www.builditsolar.com/Projects/Cooling/Shading/Shading.htm

2-2-1-1 Appropriate site layout, building location, and orientation

The architect should consider the sun directions in the site over the year before designing any building to avoid direct solar load. The building could be protected from direct sunlight by placing it on a location within the site that utilizes existing features such as trees, vegetation, topography, etc. that could prevents the direct solar radiation from reaching the building external envelope.

2-2-1-2 Efficient plan zoning

Careful planning and space zoning could have great effect on separating high-gain spaces from low gain, so that ventilation and other strategies can be applied to a different degree to remove heat generated by internal gains. Moreover, In case of open offices, the interior walls, partitions and other obstructions should be minimized to permit an efficient airflow rates to the whole space.

2-2-1-3 Building envelope materials

Envelope materials are of great importance for protecting the interior space against direct solar radiations. Materials should be carefully selected for walls and roof as their thermal properties and thickness affect their absorbance or reflectance to the solar radiation. Moreover, the envelope materials determine the relationship between the outdoor temperature and the indoor temperature, so good specifications of materials and details could reduce heat transfer to the interior space. Building materials conduct heat from outside to the inside at different rates depending on its basic properties: thermal conductivity, thermal resistance, and reflectivity.

)a *Thermal Conductivity*

It is the heat transfer to the interior through the material molecules. Thermal conductivity is an important issue for building insulation and related fields. The heat flows to the interior space depends on the conductivity of the envelope materials and its thickness, a greater thickness means less heat flow and will be of lower conductivity. Heat radiations enter the building through:

- External envelope: when the external surfaces is heated and exposed to the wind, the wind speed greatly increases the conduction coefficient and leads to internal heat gains.
- Roof: when the roof exposed to the sun, its external side will be warmer than the internal side, this causes the heat to flow downward through the roof material and will heat the internal air by convection.

)b Thermal Resistance

In hot regions, choosing high thermal resistance materials for the envelope will minimize the heat flow into the building during the daytime hours. The thermal resistance is proportional to the thickness of construction layer of the construction and inversely proportional to its conductivity[4]. The exterior walls should have the appropriate thickness, so that the interior of the building remains cool during the day, and the stored heat is transferred into the interior during the night. While, if the wall is too thin, the heat will penetrate into the interior space during the day when it is not needed, and there will not be enough stored heat left over to keep the interior space warm through the evening. Thus, the thickness and heavy structure of the walls and the roof stabilize the indoor temperature. Materials commonly used for efficient thermal mass design are: Adobe brick or mud brick, Natural rocks and stones, and Concrete and other forms of masonry.

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)c Reflectivity of exterior walls and roof finishing materials

For efficient passive cooling, the building exterior finishes and roof materials should characterized by its high reflectivity to reduce the solar gain. Reflective roofing products could helps in reducing cooling loads, as the roof is exposed to the sun for the whole day. Thus, rate of heat flow transmitted through exterior wall from outside hot air to inside air is proportional to: air temperature difference, area of the wall, and reflectivity of the exterior finishing material.

Selecting a maximum reflectivity material to the roof surface is the cheapest and most effective way to avoid transmission of solar radiation. The following graph (figure 2-2) shows the solar reflectivity of roofs according to material and color.

[4] Comfortable Low Energy Architecture, Thermal Resistance, accessed October 2008, http://www.learn.londonmet.ac.uk/packages/clear/thermal/buildings/building_fabric/properties/resistance.html

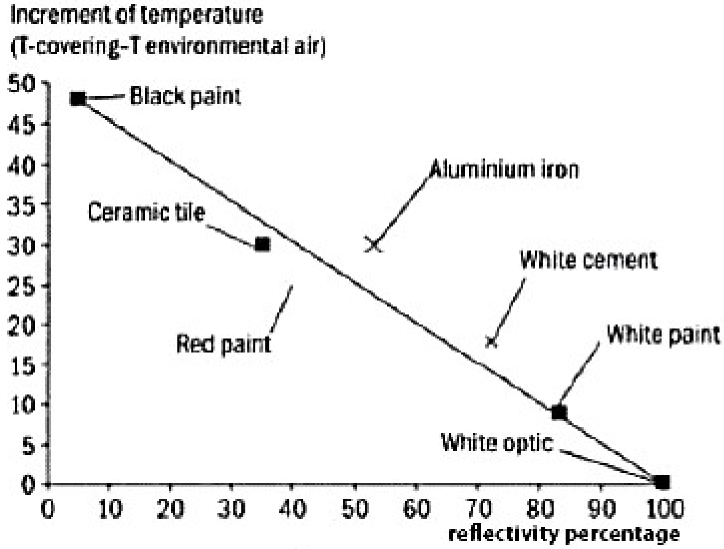

Figure 2- solar reflectivity percentage on roofs according to material and color [5]

From the previous graph, the white painted roofs have the maximum reflectivity percent and thus, have the minimum increase in surface temperature, while black painted roofs has the minimum reflectivity, thus, have the maximum increase in surface temperature[6].

d) Non-porous materials

The second pathway for external high temperature to enter a building is by conduction through the building envelope materials due to the temperature difference between the inside and outside. Using less porous materials in the building fabric can minimize the heat flow[7].

2-2-1-4 Airtight Construction

Buildings are a composition of various materials and components, and have multiple edges, overlaps, and joints which are not always carefully closed. Typical weak spots are: connections between outside & inside walls, roofs & floors; outside woodwork, rolling shutters, and their connections with outside

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[5] **Energy and Resources Institute**, 2004, *Sustainable Building Design Manual*, Published by TERI Press, p 99.

[6] **Baruch Givoni**, 1994, *Passive and Low Energy Cooling of Buildings*, publisher: by John Wiley and Sons", P33.

[7] Ibid

masonry. It's only possible to realize an airtight construction by careful detailing together with special products using windows and doors with good quality airtight seals and filling gaps around them to decrease the infiltration[8]. In summer time, hot air can enter the building via the windward side, causes increasing in the internal temperature which leads to increase the cooling costs. In commercial buildings the lack of air tightness can have more side effects, such as reduction of acoustic performance and fire protection.

2-2-1-5 Minimum fenestration

Glass is a very good thermal conductor, the more glass in a facade, the more heat will flow in from the outside regardless of shading[9]. Furthermore, large areas of hot glass can generate convective heating the air inside the space. This can be prevented by minimizing the fenestration areas.

2-2-2 Decreasing Internal Sources Emitting Heat Energy

Interior elements and furniture also affect the interior cooling efficiency and the amount of heat gained or lost. Internal heat can be gained from artificial lighting, equipments, and people. Selecting suitable internal architectural design elements and materials can keep the indoor maximum temperature less than the outdoor temperature, this could be done by:

- Maximizing daylighting,, and
- Using energy efficient lighting installations.

2-2-2-1 Maximizing daylighting

Daylight is the most efficient way of lighting an interior space as the artificial lighting increases the internal heat gain. Careful design of fenestration that maximizes daylight (whilst excluding direct sunlight) could not only save electrical energy but also reduce internal gains.

2-2-2-2 Using energy efficient lighting installations

Lighting installations could be a significant cooling load in many buildings, especially open-plan offices where a uniform light level has been designed for over the entire floor area. The use of more efficient lamps and luminaries, occupancy sensors, daylight dimming and task lighting can significantly reduce the overall lighting load[10].

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[8] Leonardo Energy, Passive house, How to construction an airtight building? How to avoid the most common leaks?, accessed 2008,
http://www.leonardo-energy.org/drupal/taxonomy/term/254

[9] Ibid

[10] Ibid

2-3 Passive Cooling Strategies

Once all the unwanted internal heat gains have been dealt with (in the previous section), then it should be sufficient to keep internal space temperatures comfortable in mild summer regions. While in many other regions of particularly very hot summer it is often necessary to provide additional cooling potentials. The most cost and environmental efficient way of cooling is by using passive cooling systems. Passive cooling systems are the use of the available technologies to cool buildings in a naturally way without the need of power energy. They are based on five natural processes: ***radiation, Evaporation, Ventilation, shading, and insulation.*** Selecting a passive cooling technique depends on climatic characteristics, type of building, and desired indoor climate.

- ***Radiative cooling:*** is the process by which a body loses heat by radiation. In the case of the earth-atmosphere system it refers to the process by which long-wave (infra red) radiation is emitted to balance the absorption of short-wave (visible) energy from the sun.
- ***Evaporative cooling:*** is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it. Latent heat describes the amount of heat that is needed to evaporate the liquid; this heat comes from the object itself to the surrounding. When considering water evaporating into air, the wet-bulb temperature, as compared to the air's dry-bulb temperature, is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater the evaporative cooling effect. When the temperatures are the same, no net evaporation of water in air occurs, thus there is no cooling effect[11].
- ***Natural Ventilation:*** it is a form of convective cooling that has the potential to cool the human body directly through convection and evaporation or indirectly by cooling the structure of the building surrounding the occupants[12].
- ***Shading:*** it is a process of blocking totally or partially sun light radiations from entering the building

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[11] Evaporative cooler, Wikipedia, accessed 2009
http://en.wikipedia.org/wiki/Evaporative_cooler

[12] **Francis Allard, Matheos Santamouris, Servando Alvarez**, 1999, *Natural Ventilation in Buildings: A Design Handbook*, published by Earthscan, p3.

- ***Insulation:*** acts as a barrier to heat flow and is essential to keep any space warm in winter and cool in summer. A well insulated space will provide a year-round comfort and cut cooling and heating bills by up to half. This is true in both hot and cold climates. This, in turn, reduces greenhouse emissions. Presence of roof and ceiling insulation can save up to 45 percent of heating and cooling energy, while it can save up to15 percent of heating and cooling energy with wall insulation[13].

The next diagram presents the selected passive cooling techniques for every cooling strategy that will be explained in the next sections.

[13] Ibid

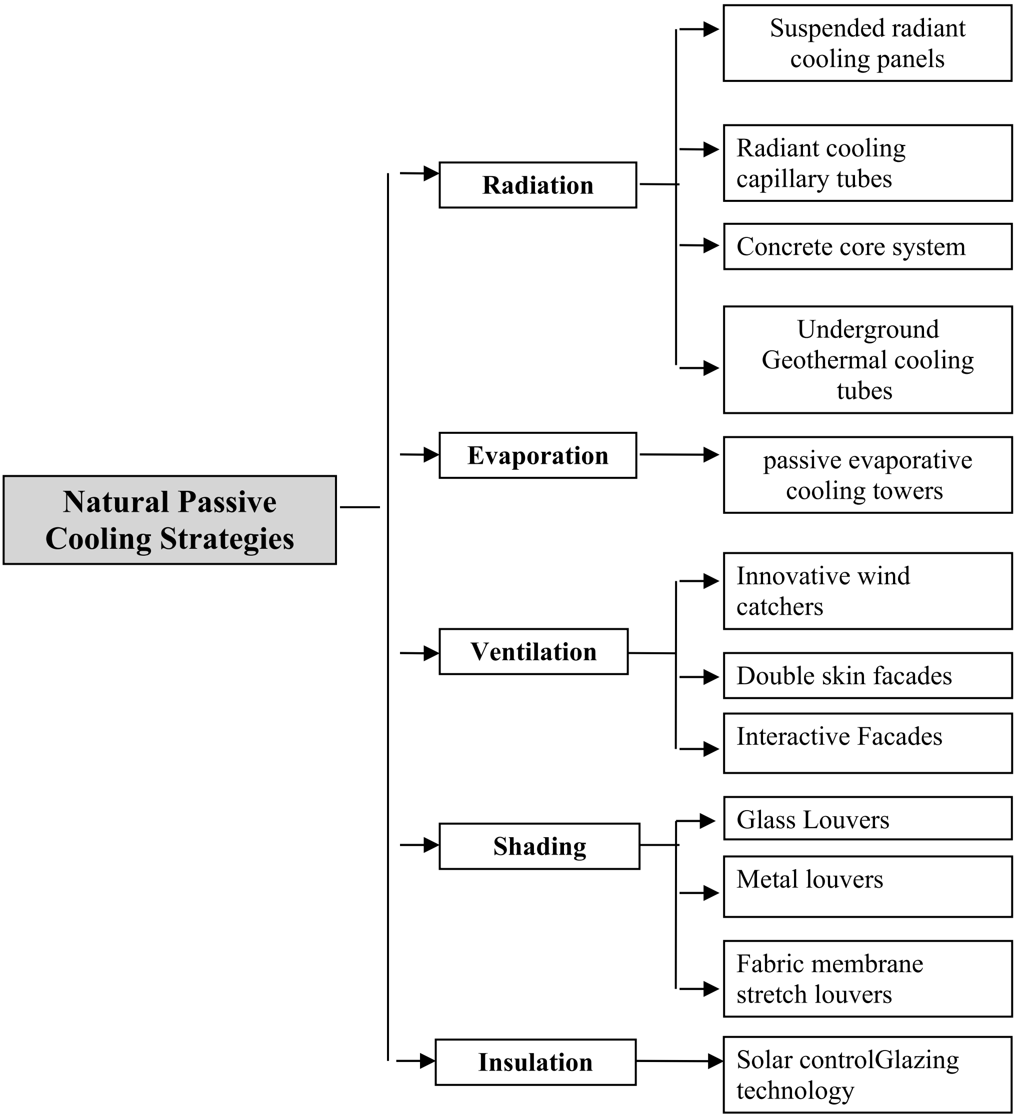


Figure 2- Diagram presents the selected passive cooling techniques for every cooling strategy to be studied in this research

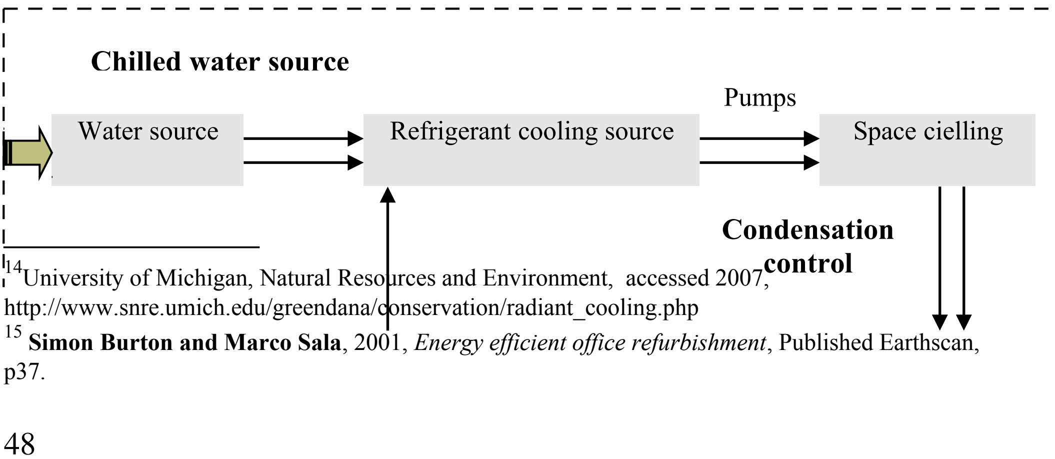
2-3-1 Radiation: Radiant Cooling Pipes

Any ordinary surface loses heat by the emission of long wave radiations towards the around environment. This fact guides the architects to cool the interior space by radiant cooling system. The idea of radiant cooling is not new, cool stream water was channeled through heavy masonry building walls in hot climates to provide radiant space cooling in the Middle East. Today, the researches are rediscovering these systems and their appliance on energy-efficient buildings for providing better human comfort.

2-3-1-1 Concept and components

Radiant cooling systems rely on chilled pipes that distribute cooling throughout a space by absorbing the emitted long wave heat radiations. Convection cooling is occurred in parallel, when warm air gets contact to the cool surface to be cooled. Radiant cooling uses chilled water as a transport medium due to its physical properties. Cold water runs through pipes at the ceiling level, it acts as a heat sink for the warm air inside the room. Therefore, the air will be replaced by the traditional forced air system (warm air rises and cold air falls) (figure 2-4). This translates into substantial energy savings in the building, as water is about three times more efficient than air as a heat transfer medium[14].

Radiant cooling can be retrofitted to existing offices, moreover, it may be of particularly useful if there are low floor ceiling heights. To ensure better indoor air quality and avoid condensation, radiant cooling systems need to be used in conjunction with a low-volume, low-velocity ventilation systems. Since radiant cooling systems do not use forced airflow to facilitate interior air cooling, a uniform temperature gradient can be created, providing a very comfortable internal environment for the occupants[15].



[14] University of Michigan, Natural Resources and Environment, accessed 2007, http://www.snre.umich.edu/greendana/conservation/radiant_cooling.php

[15] **Simon Burton and Marco Sala**, 2001, *Energy efficient office refurbishment*, Published Earthscan, p37.

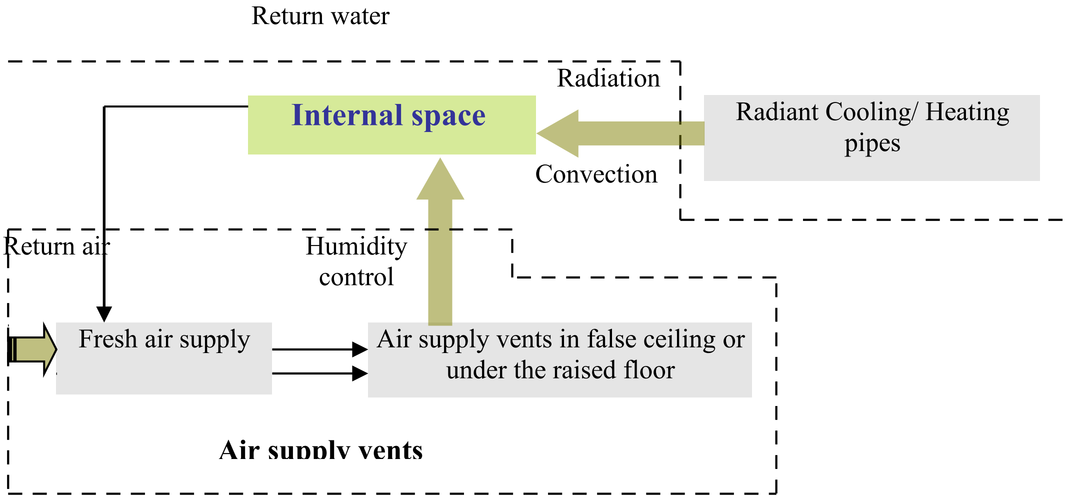


Figure 2- Diagram for radiant cooling pipes system concept and components

a) *Chilled water source*

- *Non-Refrigerant cooling sources*

This sources can supply moderate water temperature to the radiant tubes, it can reduce the room temperature by about 1-2 °C. It can be used in residential and small commercial projects in mild climates. In some cases, water can be cooled directly by a loop of tubing buried deep into the ground as the average ground temperature may be sufficient for the simple cooling capacity. Cooling towers and related fluid-air heat exchangers or coolers can also be used to cool the water.

- *Refrigerant cooling sources*

To add cooling to the radiant cooling distribution, the system requires a source of chilled water. Water is cooled in chillers, and then pumped through tubes to the radiant ceiling of the space to decrease the air temperature, then the warm water returns back to the chiller be re-cooled (figure 2-5).

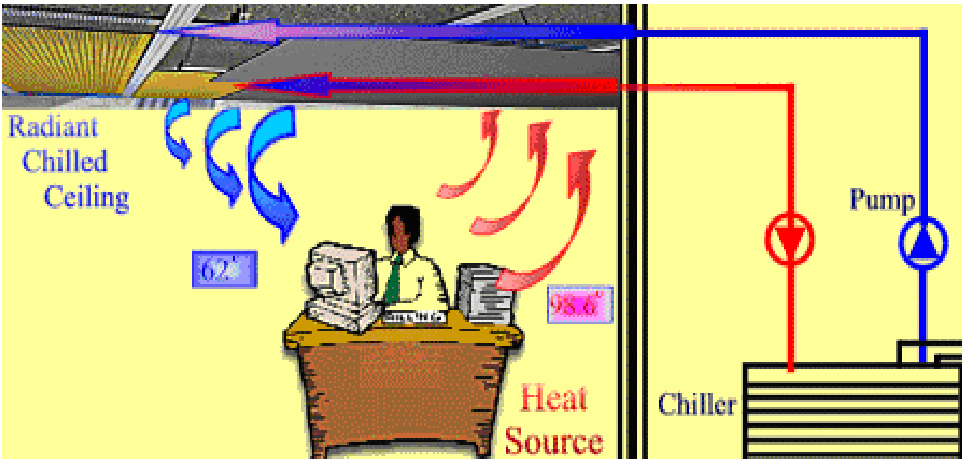


Figure 2- radiant cooling system concept[16]

b) Air supply vents

In radiant cooling system, the temperature control function is separated from the ventilation function. Once the radiant ceiling cools the air inside the space, there will be no need of additional air for the cooling process. The air system needs only to be a fresh air by using a delivery system with humidity control. The delivery system could be as fixation of fans connected to the outside fresh air in the false ceiling or under the raised floor. These air supply vents is smaller and less famous than the conventional systems. Windows could be also a source of fresh air supply to the system, but it is not recommended because in this case will be no control of the fresh air or humidity entering the space, which will results insufficient cooling.

The next figure (figure 2-6) is a clear example of the combination of radiant cooling with the controlled fresh air entering the space from the supply source under the floor. Also the figure shows the combination of the radiant cooling- ventilation system with the surrounding issues

[16] Rudek, Construction Services Inc. Radiant Heating & Radiant Cooling, A New Concept of Air Conditioning, accessed 2008
http://www.rudekinc.com/radiant-cooling.htm

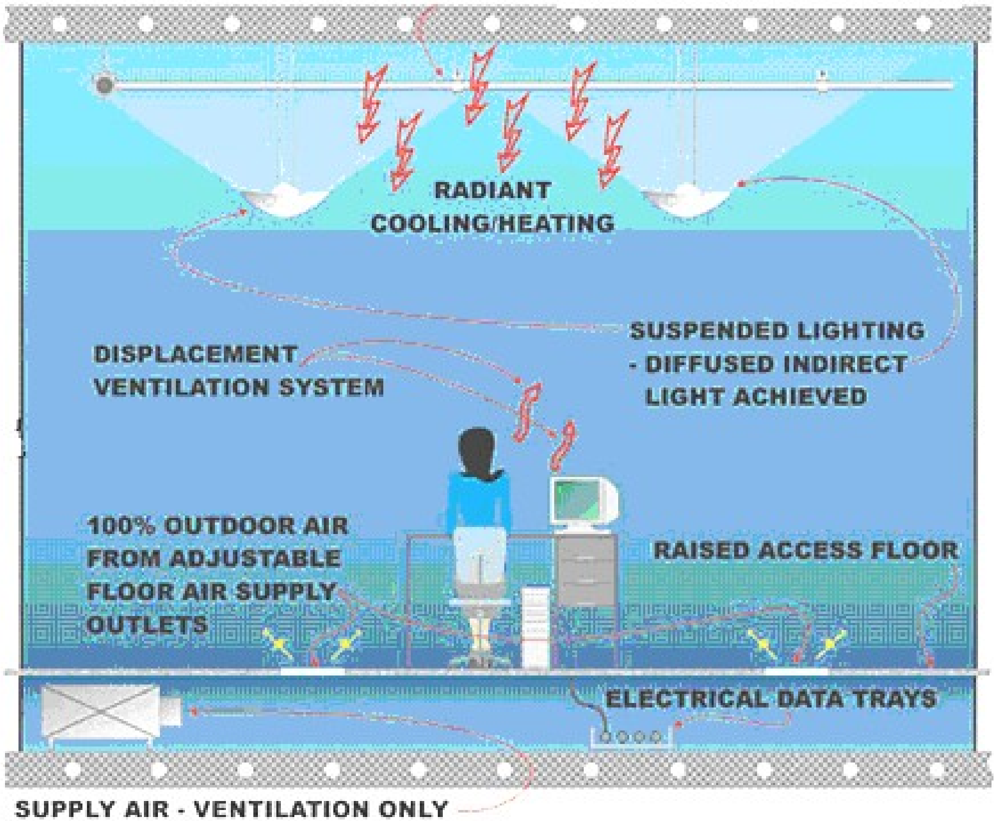


*Figure 2- **Air supply vents presented under the raised floor***[17]

c) Condensation control

In dry climates radiant cooling capacity may be more efficient by using lower water temperatures. While in humid climates, condensation is an important factor should be considered before taking the decision whether or not to use this system within the design, and has been the greatest reason for its lack of usage in these types of environments.

Condensation occurs when temperature reaches the dew point[18]. For example, for an indoor air temperature of 26 °C with 50 % relative air humidity, the dew point is around 15 °C[19]. Thus, with proper control systems, reaching this point could be controlled to avoid condensation. When sensors read that the temperature is reaching this limit, sensors

[17] Geoff McDonell, Selecting radiant ceiling cooling and heating systems (part 1),accessed 2007, http://www.csemag.com/article/CA6492841.html

[18] The dew point is the temperature to which a given parcel of air must be cooled, at constant barometric pressure, for water vapor to condense into water. The condensed water is called dew.

[19] En0B, Concrete core temperature control, accessed November 2008 http://www.enob.info/en/analysis/analysis/?sb_projects[uid]=83&cHash=40afd3ba01

modulate the water accordingly. The amount of chilled water in the system is controlled by closing the control valves to control the dew point to the desired temperature or by raising the water temperature. The sensor's limiting factor depends on the temperature of the water and the space's dew point. Moreover, proper ventilation is also an important factor for preventing condensation.

2-3-1-2 Types of radiant cooling pipes

Suspended radiant cooling panels, radiant cooling capillary tubes, and concrete core system are various systems for the radiant cooling depending on the method of delivering the chilled water.

a) Suspended radiant cooling panels

The usage of suspended radiant cooling panels is well known in common applications, as it considered being an effective, easy, and inexpensive passive cooling solution.

i) System description

It is generally consists of copper or plastic tubing attached to the back of aluminum or steel panels and is suspended as part of a ceiling system over the occupied space. The exposed face of the panel is downward to cool the space. This combination of panel widths and lengths will cover all possible applications. These radiant panels have a relatively light thermal mass and therefore respond quite quickly when a control valve is opened or closed to modulate the cool water flow through them. The difference between the temperatures in the panels and the room causes the heat energy transfer from the air to the panel, so the panel looses its coolness (figure 2-7). Thus, radiant cooling is occurred as the cold radiant ceiling panel absorbs radiant heat from the hotter surfaces. This constitutes approximately 60 % of the cooling effect.

The remaining 40 % is achieved by convection[20]: The warm room air, which is less dense, rises and flows along the ceiling. It then transfers its heat energy by convection to the cooler radiant ceiling panel. The cooled air which is now denser falls back into the room.

[20] Zehnder ZBN, Ceiling Heating and Cooling System, Technical catalogue, accessed 2007 http://www.zehnder.co.uk/pdf/zip_technical_brochure.pdf

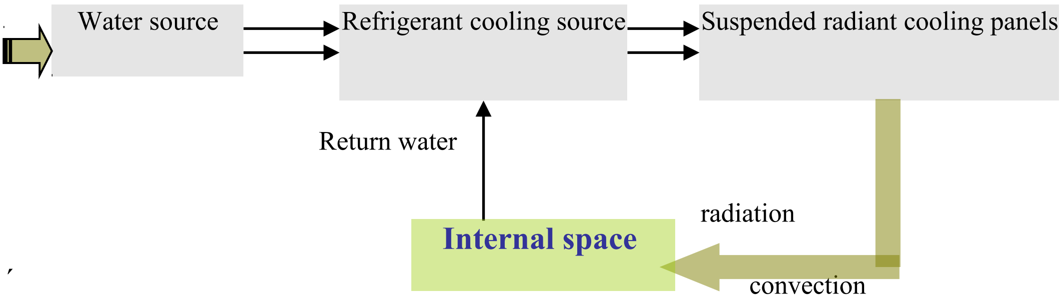


Figure 2- Diagram for the Radiant cooling panels working idea

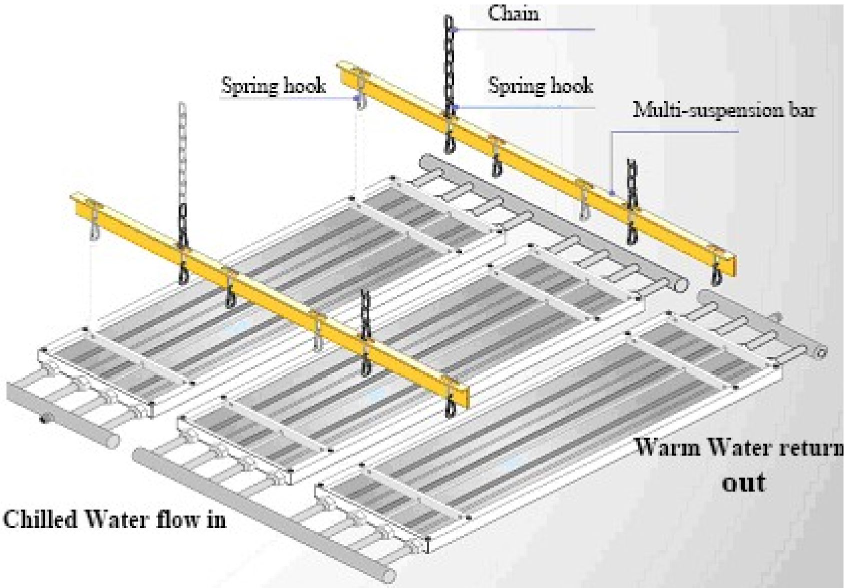


Figure 2- Radiant cooling panels system components[21]

ii) System components

Radiant cooling ceiling panels stands for quality, functionality and design. The system is composed of: Precision Steel Tubes, The tubes Headers, Radiant Panels Fixed suspension bar, Insulation boards, Assembly chain for fixation on the ceiling (figure 2-9).

- Precision Steel Tubes: They are four steel tubes of diameter 28mm; they are welded with the radiant plate. Cold water flows through it for radiant cooling.

[21] Ibid

- Headers: They are round tubing with a diameter of 32 mm[22], connected at the end of the steel tubes. The headers and collectors are fitted externally or it may locate in the inside of the plate. The various header configurations permit customized plates connections.

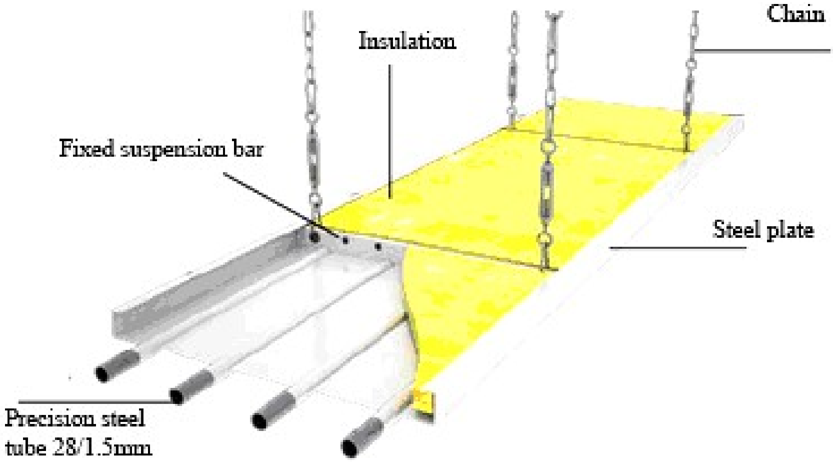


Figure 2- Radiant cooling ceiling panels' structure details[23]

- Radiant Panels: the Standard widths of the radiant panels are 300, 450, 600, 750, 900, 1050 and 1200 mm. The individual panels can be manufactured up to a length of 7.5 m. The individual panels are combined by means of welded joints or crimp fittings into the desired designs and the joints are hidden by cover plates[24].
- Fixed suspension bars: they are fixed bars onto the plate for fixation the panel with the chain.
- Insulation: Insulation boards are located on the topside of the radiant panel to provide a heat barrier and can also absorb sound. It is used to drive the radiant energy downwards.
- Assembly Chain: The panels are suspended with chain hanging sets fixed directly to the integral suspension bars for installing the radiant ceiling panels on the ceiling

b) Radiant cooling capillary tubes system

This system is very popular and common in Europe due to its efficiency and economic, it is widely used in residential and commercial buildings. Its

[22] Ibid

[23] Ibid

[24] Ibid

concept is to maximize the radiant cooling surface area of the space ceiling. This results cooling the space in a very energy-efficient system, it can be used as any radiant system for heating and cooling the space.

i) System description

Radiant capillary tube system consists of very small capillary tubing imbedded into walls or ceilings, usually in a layer of plaster finish. The cool water flows through mats of capillary so that the cold capillary mats above drywall/plaster ceiling then absorbs the thermal energy radiating from people and their surroundings (sensible load), results lowering the mean radiant temperature of the room. After the liquid absorbs the heat it is transported back to a chiller with the help of a small pump where the temperature of water is lowered once again. The system cooling idea is shown in the next figure (figure 2-10).

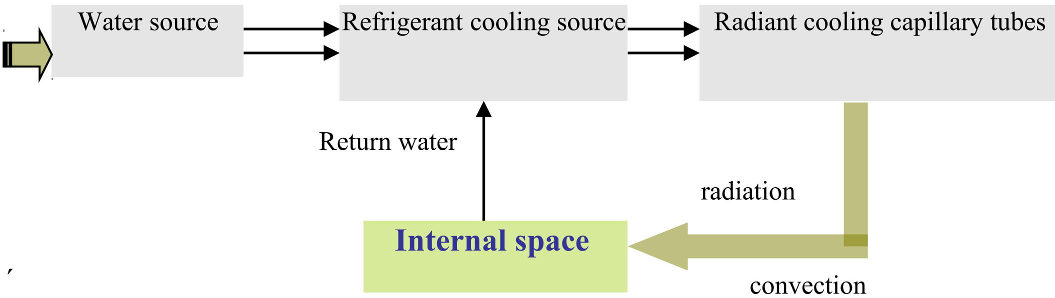


Figure 2- Radiant cooling capillary tubes working idea

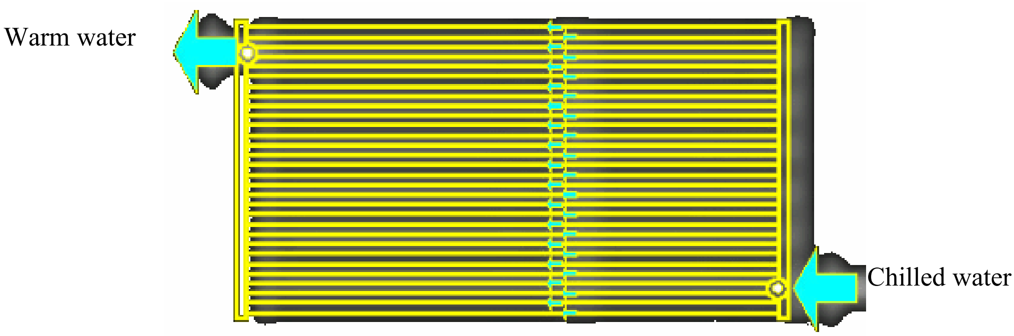


Figure 2- Recycling of water in the capillary tubes[25]

ii) Technical details

[25]KaRo, Radiant Cooling Corporation, Capillary Tubes, accessed October 2008 http://www.radiantcooling.org/capillary.htm

The system is composed of capillary tubes which are extremely thin (diameter 3-4 mm), made of plastic, rubber, or copper and they are connected close together (approximately 3/8" inches apart) into mates. Because the capillary tubes are so close together the heat emission of the mats remains more time than any radiant system. Besides, these mats experience very little loss of pressure, which performs a high cooling capacity. These mates are made completely of polypropylene materials; it can be imbedded in walls/ ceiling plaster, gypsum board, or mounted on ceiling panels (figure 2-12).

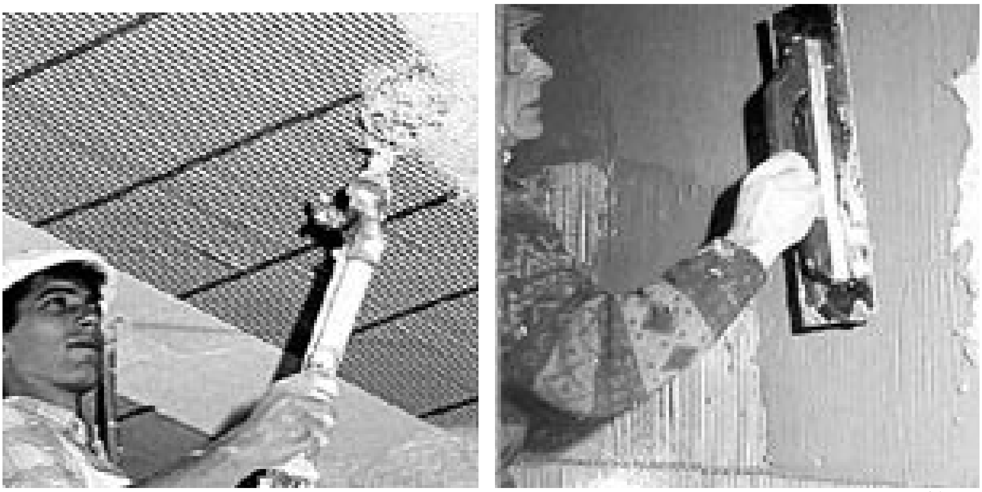


Figure 2- Embedding the capillary tube cooling mates into the ceiling or the walls[26]

iii) Response Time

Typically a response time of 30 to 60 minutes[27] or more are common, depending on the thickness of plaster and proximity to building structural mass. It is common to use slow acting pulse width modulation controls to operate these systems. Due to the relatively rapid heat gain and response time of these systems, a water chiller is required to provide sufficient cooling water during the daytime occupied periods. (Figure 2-13) is considered a simulation process presents the respond time of the capillary tubes radiant cooling system. In this case the temperature of the chilled water going into the capillary tubes is about 9°C and the temperature of the internal space is about 29°C. it is observed from the simulation response time is that the radiant

[26]Finally a system that gives you both, Indoor Air Quality, Through Radiant Heating & Radiant Cooling, No Draft, No Noise, accessed 2008, http://oikos.com/products/mechanical/karo/

[27] **Geoff McDonell**, Selecting radiant ceiling cooling and heating systems (part 2), accessed 2008, http://www.csemag.com/article/CA6499931.html

temperature of the surface of the ceiling is decreased about 17°C, and the radiant interior space temperature will decease from 5 to 10 °C depending on the internal ventilation, humidity, electrical equipments, and consumers.

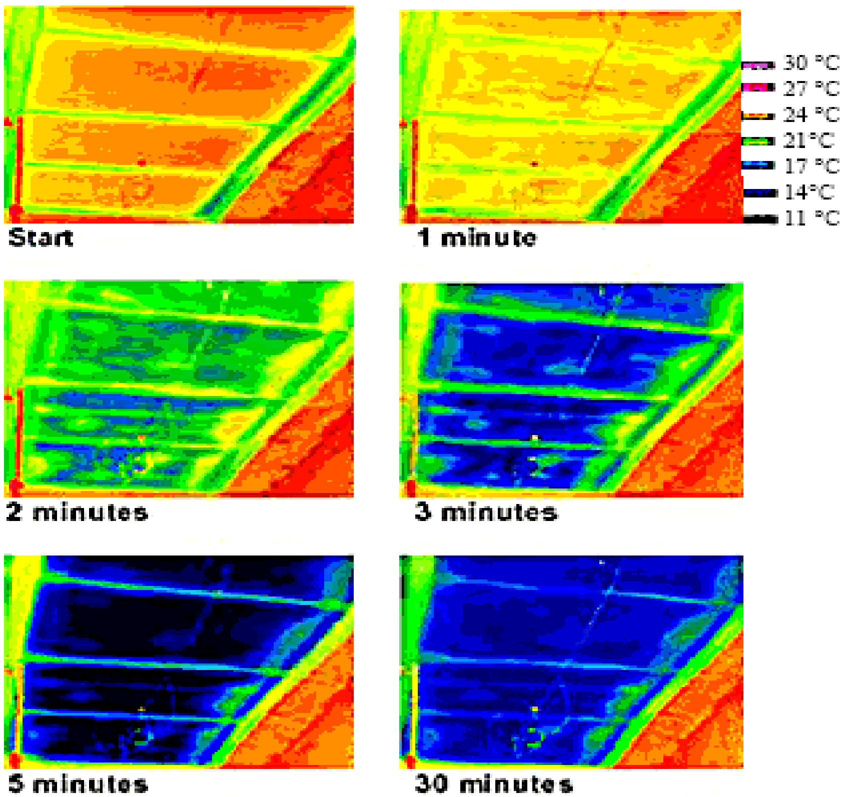


Figure 2- The response time for the capillary tube system to cool the whole ceiling[28]

It is considered to be more energy-efficient compared to the suspended ceiling panels, as the capillary tubes mates are in contact with the structural ceiling or walls. This allows a more building mass thermal storage, which provides a more stable indoor climate. This results a relatively increase in the time of the system response to cool the space due to the time it takes to cool down the thermal mass of the plaster layer besides the building thermal mass. Moreover, in this system the water runs through many parallel capillary tubes, rather than running through just one tube, as in a system with thicker tubes.

[28] KaRo, Radiant Cooling Corporation, Capillary Tubes, accessed October 2008 http://www.radiantcooling.org/capillary.htm

c) Concrete core-cooled ceiling (Radiant slab)

In concrete core cooled slab tubing system, tubes are embedded into the concrete slab before it is being cored on the building site. This system allows the building mass to work as an energy storage reservoir (heating/cooling storage).

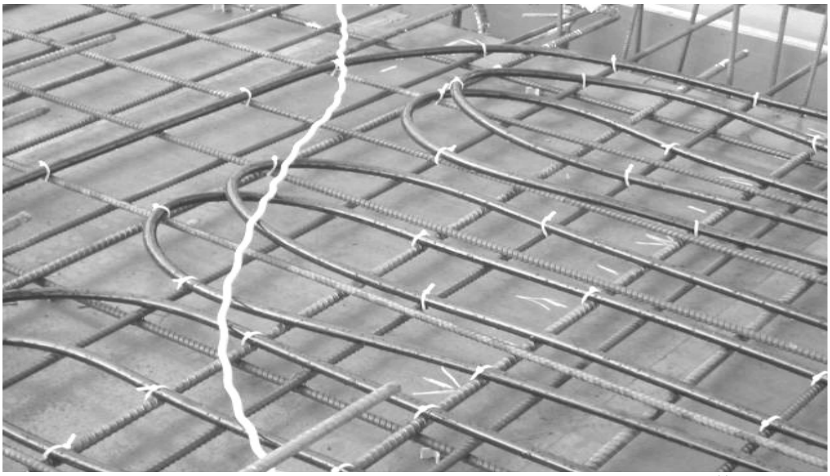
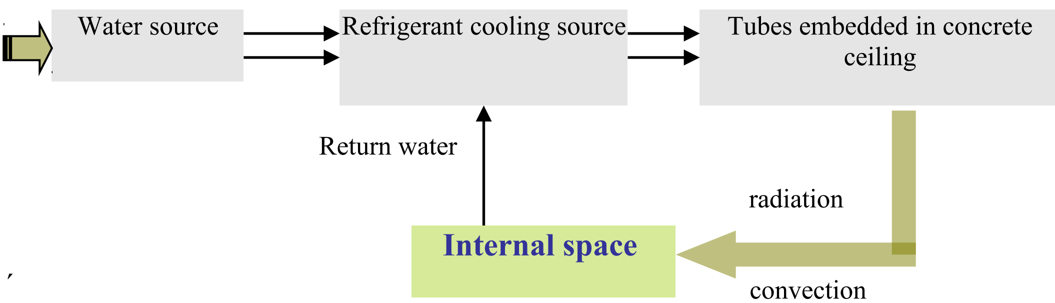


Figure 2- Chilled water pipes embedded in concrete slab[29]

i) System description

The system consists of a concrete slab (about 250mm thick) with plastic pipes embedded in it (figure 2-15). Cooled water is pumped to these plastic tubes and circulated through it. The thermal storage of the concrete slab will easily handle the internal local heat loads, as the cooler concrete slab creates a radiant cooling effect with the internal space. It can provide superior indoor comfort, compared to conventional all-air systems[30].



[29] http://www.csemag.com/article/CA6513022.html?nid=3507

[30] **Geoff McDonell**, Selecting radiant ceiling cooling and heating systems (part 2), OMICRON, Vancouver, British Columbia. --Consulting-Specifying Engineer, 2007

Figure 2- Radiant concrete core-cooled cieling working idea

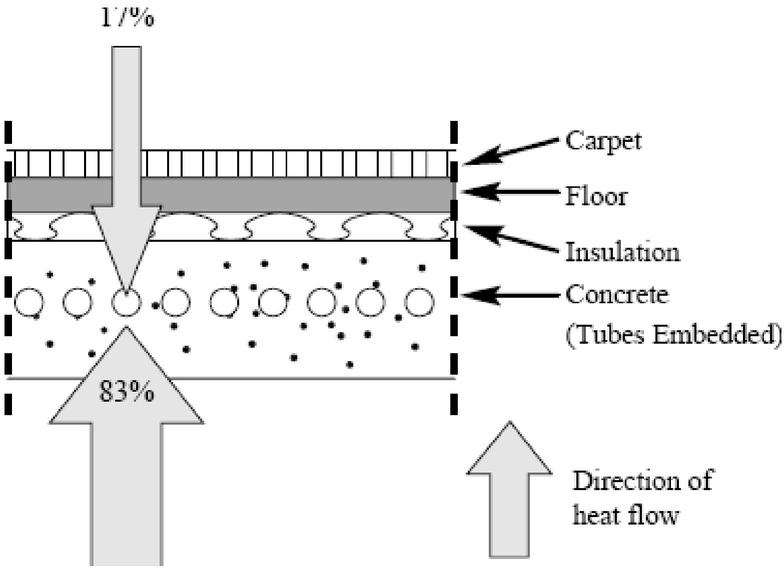
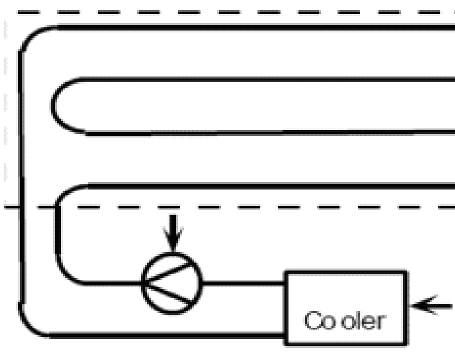


Figure 2- Heat transfer for concrete core cooling system [31]

Radiant concrete slab system is normally operated by using a constant water flow by a pump with a variable temperature reset schedule according to the seasons and the outdoor ambient temperature (figure 2-17). Typically, the minimum summer peak cooling temperature is around 63.5 F (17.5°C)[32], which can provide comfortable space temperatures.



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[31] CBS Newsletter, Hydronic Radiant Cooling Systems, , pg 4, http://eetdnews.lbl.gov/cbs_nl/nl4/RadiantCooling.html

[32] **Geoff McDonell**, Selecting radiant ceiling cooling and heating systems (part3), accessed 2007 http://www.csemag.com/article/CA6499931.html

Figure 2- functional sketch of a Concrete Core Cooling System[33]

ii) Technical details

- The concrete tubing is generally from 15 to 20 mm diameter[34] depending on the slab areas and water flow rates required for the cooling loads in the space.
- Spacing of the tubes can be anywhere in intervals from 10 to 30 cm[35], depending on the desired average surface temperature of the ceiling. The tubes lie at the central height of the concrete slab as it is the mostly statically zone.
- This system can be used in steel structure buildings, by using concrete floor

iii) Response Time

Concrete slabs have high thermal mass which in turns are generally too slow to react to rapid changes in cooling loads. When the radiant cooling tubes are opened and chilled water flows inside, the rate of heat exchange (to decrease its temperature and then decrease the air radiant temperature) tends to be quite slow. It requires from one to two hours per inch (25 mm) [36]. This thermal lag has created the need for nighttime precooling for reaching the change in temperature needs in the midday time.

2-3-1-3 System considerations

- *Supplementary cooling systems:* in very hot days, if the heat in individual rooms cannot be prevented, then there is a need of adding supplementary radiant cooling panels.
- *Free slab surfaces:* for providing more efficiency for this system, suspended ceilings should not be combined with this system as the suspended ceiling significantly reduces the heat transfer to the radiant ceiling to be cooled by convection, as well as reduce the direct radiation exchange. Therefore, the radiant slab surfaces are to be kept as free as possible. However, attention must be paid to the acoustic issue; sound-absorbent constructions are usually necessary.

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[33] **Tim Weber**, Civ., Dietrich Schmidt, Gudni Jóhannesson, *Concrete Core Cooling and Heating -a Case Study about Energy Analysis on Building Components*, p4

[34] **BINE Themeninfo1**, A compact guide to energy research, Thermo-active building systems, 2007, p8

[35] ibid

[36] **Timothy Moore, Fred Bauman, and Charlie Huizenga**, REPORT APRIL 2006, *RADIANT COOLING RESEARCH SCOPING STUDY*, INTERNAL Center for the Built Environment (CBE), University of California, Berkeley, p5.

- *Glazing:* The architect should carefully select the high thermal resistance glazing materials as the interior surface temperature of the glass must not exceed 80˚F (27°C)[37] otherwise, they become radiant heating panels, which will create increase in the radiant temperature irregularly.
- Architects should consider the building design so that to reduce the internal cooling loads in order to minimize the building climate control requirements.
- Radiant ceiling system is the most efficient passive cooling system; it can separate the space-sensible temperature control function from the ventilation function to arrive at an energy efficient system. It needs only fresh air (100% outdoor air) delivery system to control humidity.
- Maximize the radiant surface to maximize the radiant cooling fluid temperature, so that to provide the necessary heat exchange for comfort control.
- Design and select a control system appropriate for the thermal mass and response time of the radiant system used.
- In humid climates, the indoor relative humidity should be controlled.

2-3-1-4 System properties

a) *Energy efficiency*

A radiant cooling system is considered an efficient cooling system, the amount of energy consumed is much less than that consumed in any other system. It uses mechanical pumps to pump water to the tubes and it is much easier than the task to pump air and thus, use less energy. Radiant ceilings can reduce cooling energy by 15% to 20%[38].

- The actual amount of energy saved is depending on many factors beside the water flowing temperature and the panel temperature, including how well the building is insulated, the building size, and the ventilation rates into the space. it is suitable for all energy sources including alternative energy sources.
- Spaces may be zoned by the use of a control valve for each zone.

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[37] **Geoff McDonell**, PEng, Selecting radiant ceiling cooling and heating systems (part3), accessed 2007 http://www.csemag.com/article/CA6499931.html

[38] **John Dieckmann**, , **Kurt W. Roth, Ph.D., and James Brodrick, Ph.D**., *Radiant Ceiling Cooling, ASHRAE* journal, June 2004, p 42.

- It has short response time, as the response time[39] could be controlled by standard HVAC controls for relatively fast-acting temperature control functions.
- With the addition of a control device and one or two valves, the same tubing can cool a space as well as heat it, the fact that results in reduction on energy consumption for one process rather than two processes.
- Thermal storage can also be used over a longer period of time and can be charged at night to be more effective in the daytime. In addition, it has a relatively lower sensible cooling capacity about 77 W/m2[40] not including associated ventilation supplies.

b) Construction and running costs

This system needs less construction costs than the mechanical air-condition system, its costs is associated with supplying of chilled water, pumps and insulation. However, the radiant panel construction costs depend on several conditions like: the required cooling level, type of distribution, structural conditions and architectural requirements. next graph (figure 2-18) shows that the running costs of conventional air cooling systems is much higher than radiant ceiling panel system with minimum air exchange in the same required cooling load.

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[39] **Geoff McDonell**, Selecting radiant ceiling cooling and heating systems (part 2), accessed November 2008.
http://www.csemag.com/article/CA6499931.html

[40] **Timothy Moore, Fred Bauman,** and **Charlie Huizenga**, *Radiant cooling research scoping study* report, April 2006, internal Center for the Built Environment (CBE), University of California, Berkeley, p 17.

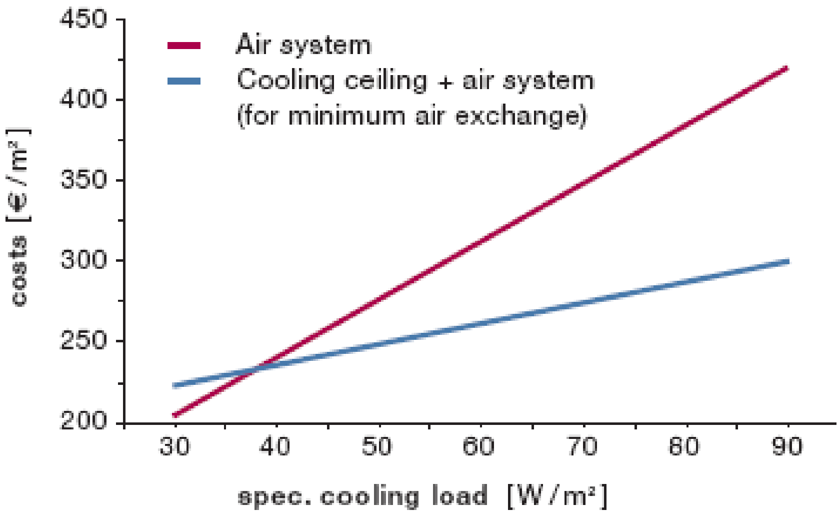

Figure 2- Running costs of air system vs. radiant cooling ceiling panel system[41]

The radiant cooling system require little or no further maintenance, the maintenance involved for the water pumps, control valves, point sensors, and chillers. But, it requires much less maintenance compared to the mechanical air-conditioning.

c) Compact design

Space saving is considered most saving issue in the radiant cooling system, as the need for large amounts of ducts above the ceiling has been greatly reduced. This reduction on ceiling height can be translated into a reduction in overall building height, so this system is perfect to be applied in office buildings. For instance, if this technique were to be applied in the construction of a ten-story office tower, the total height of the building could be reduced by ten feet. This would translate into significant savings in materials and labor in the construction of the building's structure[42]. Therefore, the owner can save money in construction by decreasing the overall height of the building or adding about one floor for every five floors when compared to conventional construction.

d) Electrical consumption

The power demand calculation for the radiant cooling system is about 22 W(electric) for the supply fan, 11W(electric) for the return fan, and 20 W for the water pump. While in the conventional air cooling system, the

[41] **Zehnder ZBN**, *Ceiling Heating and Cooling System, Technical catalogue*, 2007 , p17. http://www.zehnder.co.uk/pdf/zip_technical_brochure.pdf

[42] TWA Panel Systems Inc, Radiant Cooling, accessed 2007 http://www.twapanels.ca/cooling.html

cooling coil requires 21 W for air sensible cooling, 641 W for water sensible cooling, and 216 W for air dehumidification. Table 2-4, below summarizes the components of the electrical power demand of the all-air system and the radiant cooling system. The values in the table show that the electrical power demand of The Capillary Tube System is only 71.5% of the electrical power demand of the all-air system[43].
Next table summarizes the components of the electrical power demand of the all-air system and the RC system. The values in the table show that the electrical power demand of the RC system is only 71.5% of the electrical power demand of the all-air system.

	All-Air cooling system	**Radiant cooling system**
Supply Fan (w)	222	21
Air Sensible cooling (w)	721	---
Air Dehumidification (w)	216	216
Exhaust Fan (w)	111	11
Water Pump (w)	---	20
Water Sensible cooling (w)	---	641
Total	1270W **100%**	909W **71.5%**

Table 2- Electric power demand of air cooling systems vs. capillary tube system[44]

The previous table is for an estimated electrical power demand for the removal of internal loads from a two-person office with a floor area of 25 m2.

2-3-1-5 System disadvantage

Radiant panel cooling system is considered an efficient passive cooling system, however, there are some disadvantages, but comparing with its efficiency it can be easily avoided. Some of these disadvantages are as follows:

- It requires very clean water to fill the system to avoid plugging the small capillary tubes
- Severe fire event will damage the system and require extensive repairs.
- Lag time in controlling the system especially when used in slabs or materials of high density.

[43] KaRo, Radiant Cooling Corporation, Capillary Tubes, accessed October 2008, http://www.radiantcooling.org/capillary.htm

[44] **Feustel, H.E.,** *Peak-Power Reduction Potential for Radiant Cooling Systems*, In Proceedings of ACEEE 1992 Summer Study on Energy Efficiency in Buildings, Vol. 1, Berkeley, CA:ACEEE, 1992, p 1.57-1.66.

- Higher initial costs, but at it saves the running costs.
- Operating temperatures and humidity levels should be carefully designed to avoid condensation on the panels under extreme conditions.
- Radiant metallic panels reflect sound waves, therefore, in order to maintain the acoustics in the rooms the false ceiling should be combined with sound absorption materials.
- Requires detailed coordination between architect, mechanical engineer, and structural engineer.

2-3-1-6 System applications

It is suitable for a wide variety of commercial applications including, Factories, storage facilities, schools, malls, showrooms, hospitals and educational facilities. They are compact in design and available in a range of styles which can be integrated into installation to any design with providing excellent comfort conditions. Moreover, radiant cooling panel system can be used in sport halls as it could cross up to 120m (figure 2-19), (figure 2-20).

Figure 2- radiant panel cooling system in an open sport hall[45]

[45] ibid

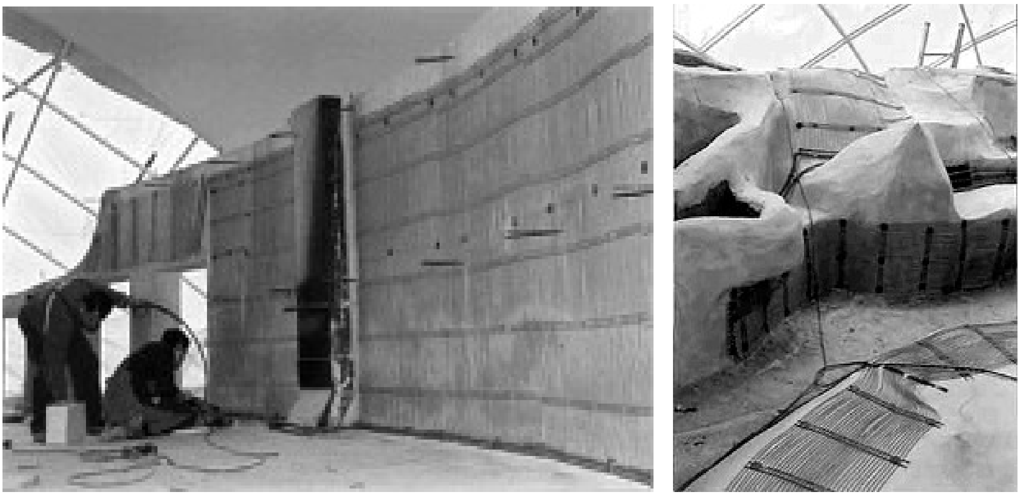

Figure 2- Embedding the radiant capillary tube mates into the walls of the Aquarium, Penguin House- Zoologischer Garten- Berlin - Germany - 2002 [46]

2-3-1-7 Radiant cooling system versus conventional forced air systems

	Radiant Cooling Systems	Conventional Forced Air Systems
Main idea	**Its main idea is to decrease the radiant temperature inside the space. It uses a combination of radiation (60%) and convection processes (40%).**	**The main idea of forced air conditioning system is to cool the air and force it to inside the space. it uses convection only using air distribution through ductwork**
Cooling Transport	**Exchanges heat with water rather than air. Water is a better heating and cooling transport agent than air.**	**Air requires a much larger volume to transport the same amount of heating and cooling capacity.**
Energy consumption	**The energy needed to transport this volume of water is 30% less than an equal forced air model, so the motor capacity will be reduced by 75%.**	**More electrical energy is required for cooling the air, pumps for force the cooled air to ducts, and controls.**
Required space	**Low floor height requirements due to small ductwork, air conditioning units and fans. Radiant panel**	**It requires additional ceiling spaces for ductwork. Moreover, space required for air handling units, and rooms for the whole mechanical**

[46]KaRo, the system of air-conditioning with capillary tube technology, accessed 2008 http://www.radiantcooling.org/climate.htm

	cooling system can be added to an exiting structure. just to fix the panels onto the ceiling. It can be also fixed on the floor or walls.	**machines.**
Noise	**Radiant cooling systems has no noise side effect compared to the conventional cooling systems, as while radiant cooling notices an additional benefit of noise reduction as the capillary tubes are silent when water runs through it.**	**This system uses huge chillers, motors, and duct systems. All these components have noise effect.**
Human comfort	**This system has better air quality as it uses 100% outside air. The application of radiant cooling significantly improving indoor air quality and reduce airborne transmitted contaminants. Improved air quality results in a better indoor environment, increasing productivity and health.**	**The conventional cooling systems do not change the air in the same rate of the radiant cooling. It re-circulates the air inside the space which will leads to increase in the air contamination.**
Construction costs	**Construction costs depend on the selected radiant system and the ceiling design. Moreover, costs of tubes, valves, and pumps fixation, but it still less costs than mechanical air cooling.**	**Mechanical air-conditioning system construction costs are in supplying air pumps, air chillers and mechanical machines system.**
zoning	**Zoning flexibility as space can be easily controlled by the opening and closing of the valves depending upon the room thermostat.**	**Cool zoning here is flexible**
Maintenance	**Low maintenance as there are few electrical devices compared to a forced air system. Also sub-stations consist of control valves, dew point sensors, pumps; heat exchangers will require some maintenance.**	**It requires much maintenance for the air handling units, pumps, air diffusers, and controls.**

Table 2- The Radiant Cooling system Vs Conventional Forced Air systems

2-3-2 Radiation: Underground Geothermal Cooling

Ground temperature remains almost constant during the day at depths about three meters, even during the hot summer days. So it is possible to get advantage of this by exchanging heat with the earth through a ground heat exchanger. The indoor warm air is circulated through underground tubes to be cooled. This approach would be the most suitable in hot-dry regions with mild winter. In such places this direct conductive cooling would be very effective. Earth cooling tubes present an alternative passive cooling system for controlling interior temperature within residential and commercial spaces. Geothermal cooling can be achieved through: circulating air through underground air tubes or presence of heat exchanger fluid for increasing efficiency[47]. This system could be used as dual function (for heating and cooling).

2-3-2-1 Concept and components

Cooling tubes are long, underground metal or plastic pipes through which air is drawn. The idea is that as the air travels through the pipes, it gives up some of its heat to the surrounding soil due to its attachment to the underground cool tubes sides, and then it enters the space as cooler air (figure 2-21). This will occur only if the earth is at least several degrees cooler than air in the space[48].

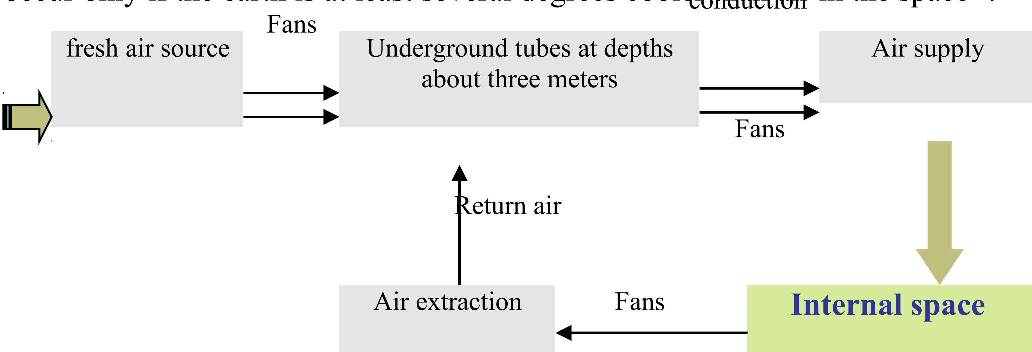

Figure 2- Diagram for Underground Geothermal Cooling system concept and components

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[47] Earth cooling tubes, accessed 2008
http://wapedia.mobi/en/Earth_cooling_tubes

[48] US Department of Energy, Energy Efficiency and Renewable Energy, Earth Cooling Tubes, accessed 2007.
http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12460

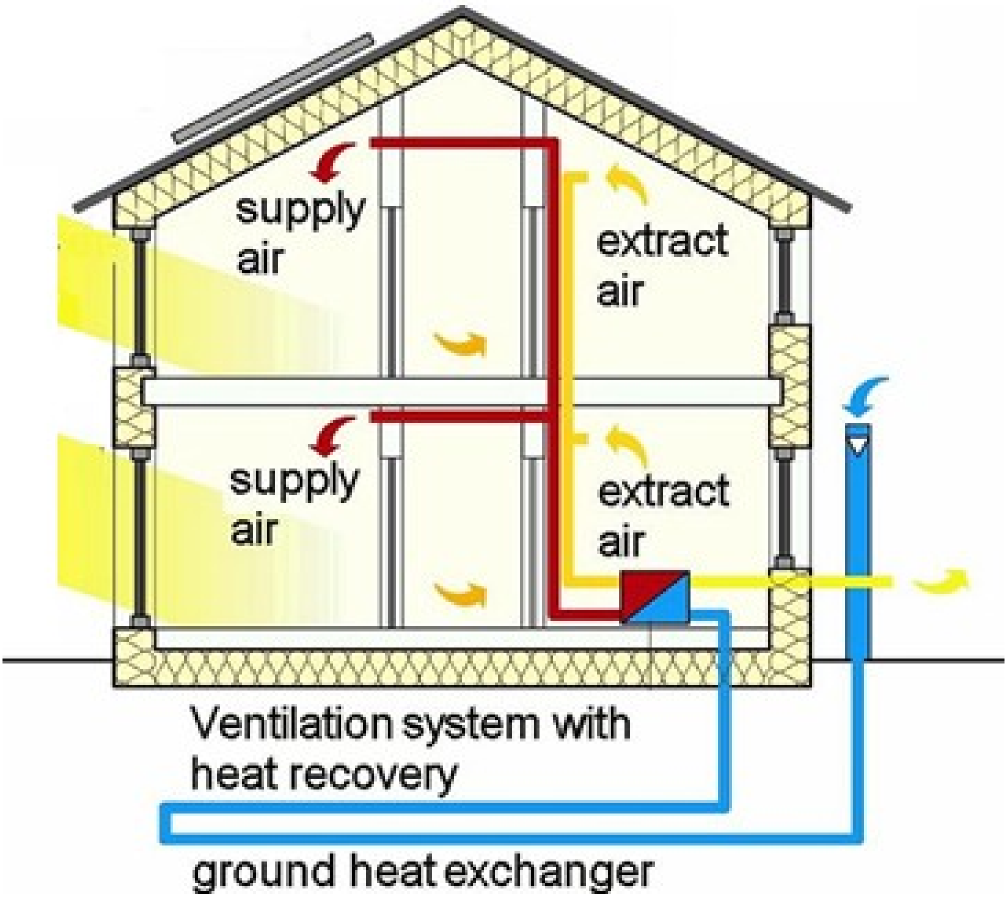

Figure 2- Geothermal cooling/ heating working process[49]

2-3-2-2 Types of earth cooling

There are basically three configurations for this system either Open-loop system or Closed-loop system or combination system.

a) *Open loop system*

Outdoor air is pumped through into the under ground tubes and delivered directly as fresh cool air into the space.

b) *Closed loop system*

In a closed-loop system, the interior air is re-circulated through the earth cooling tubes. The air inside the room is pumped through the earth tubes to the under ground so that it loses some heat and returns back to the same

[49] The Encyclopaedia of Alternative Energy and Sustainable Living, Earth cooling tube, accessed 2007. http://www.daviddarling.info/encyclopedia/E/AE_earth_cooling_tube.html

room. This closed loop system provides no ventilation, as no fresh air from out side comes into the space so it is not preferable.

a) *Combination system*

This system can be constructed with dampers that allow either closed or open operation, depending on fresh air ventilation requirements. Such a design, even in closed loop mode, could draw a quantity of fresh air.

2-3-2-3 System technical details

a) *Tube Material:* Choosing a tube material for under ground cooling is an important aspect, in which the material strength, corrosion resistance, durability, and cost will affect on the efficiency of the air cooling. PVC or polypropylene tubes which is coated with inner by antimicrobial layers could be used for tubes, besides they are easier to install, and are more corrosion resistant. Aluminum tubes are widely used as well but it is more expensive.

b) *Tube Diameter:* The optimum tube diameter differs widely with tube length, flow velocity, and flow volumes. Diameters between 6 and 18 inches (15.2 and 45.7 centimeters) [50] appear to be the most appropriate for this system.

a) *Tube Location:* Cooling tube performance varies significantly from sunny to shady locations. In case of open loop system the inlets and the cooling tubes themselves should be placed in shady areas.

b) *Tube Depth:* Tubes should be buried at least 1.8 meters below the ground level. The ambient Earth temperature is typically 10 to 23 °C[51] all year round in the temperate latitudes.

c) *Tube Length:* There is no simple formula for determining the proper tube length in relation to the amount of cooling desired. There is a diminishing returns effect as the tube gets longer and longer. As the tubes get longer, the installation cost will increases, and the energy required for the fan to drive air through them also will increases. Local soil conditions, soil moisture, tube depth, and other site-specific factors should be considered to determine the proper length[52].

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[50] The Encyclopaedia of Alternative Energy and Sustainable Living, Earth cooling tube, accessed 2007. http://www.daviddarling.info/encyclopedia/E/AE_earth_cooling_tube.html

[51] Ibid

[52] Earth Cooling Tubes, accessed 2008,

d) *Soil Properties*: Cooling tube performance varies from soil to another depending on the moisture content amount in the soil. As the moisture percentage has the more effectiveness on the air coolness inside the tube.

e) *Geothermal heat exchanger pump:* Like an air conditioner, these systems use a heat pump to force the transfer of heat. Heat exchanger pumps can capture heat from a cool area and transfer it to a warm area, against the natural direction of flow, or they can enhance the natural flow of heat from a warm area to a cool one.

2-3-2-4 System considerations

- The Earth tubes should be installed at a 2-3 degree grade[53] to ensure the constant removal of condensed water from the tubes. The condensation drain is to be located at the lowest point of the tube.
- Tubes joints should be smooth from the interior surface to permit easier flow, moreover, Joints connecting the tubes together must be tight enough to prevent water or gas infiltration.
- Porous materials like uncoated concrete tubes cannot be used.
- Earth Tubes with antimicrobial inner layers should be used in installations to inhibit the potential growth of molds and bacteria within the tubes.
- An external condensation tower could be installed at a depth lower than the point of tubes entry to spaces. The condensation tower installation requires the added use of a condensate pump in which to remove the water from the tower. However, in either installation, the tube must continually slope towards either the condensation tower or the condensation drain.

2-3-2-5 Geothermal heat exchanger through presence of intermediate fluid

Closed loop geothermal heat pumps circulate a carrier fluid (usually a water/antifreeze mix) through pipes buried in the ground. As the fluid circulates underground, it extracts its heat to the ground and, on its return, the now cool fluid passes through the heat pump which uses electricity to extract the coolness from the fluid. The warm fluid is sent back through the ground thus continuing the cycle (figure 2-23). The heat lost and that gained by the heat pump appliance as a byproduct is used to heat the building.

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http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12460

[53] Wikipedia, Ground-coupled heat exchanger, accessed 2007, http://en.wikipedia.org/wiki/Ground-coupled_heat_exchanger

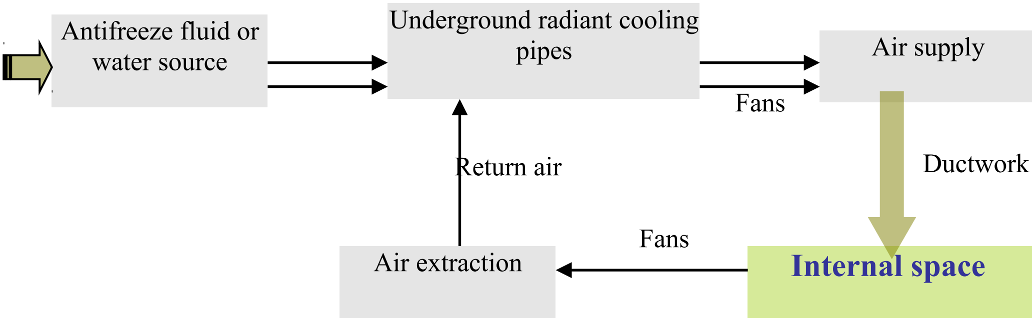

Figure 2- Diagram for Underground Geothermal Cooling system through presence of intermediate fluid concept and components

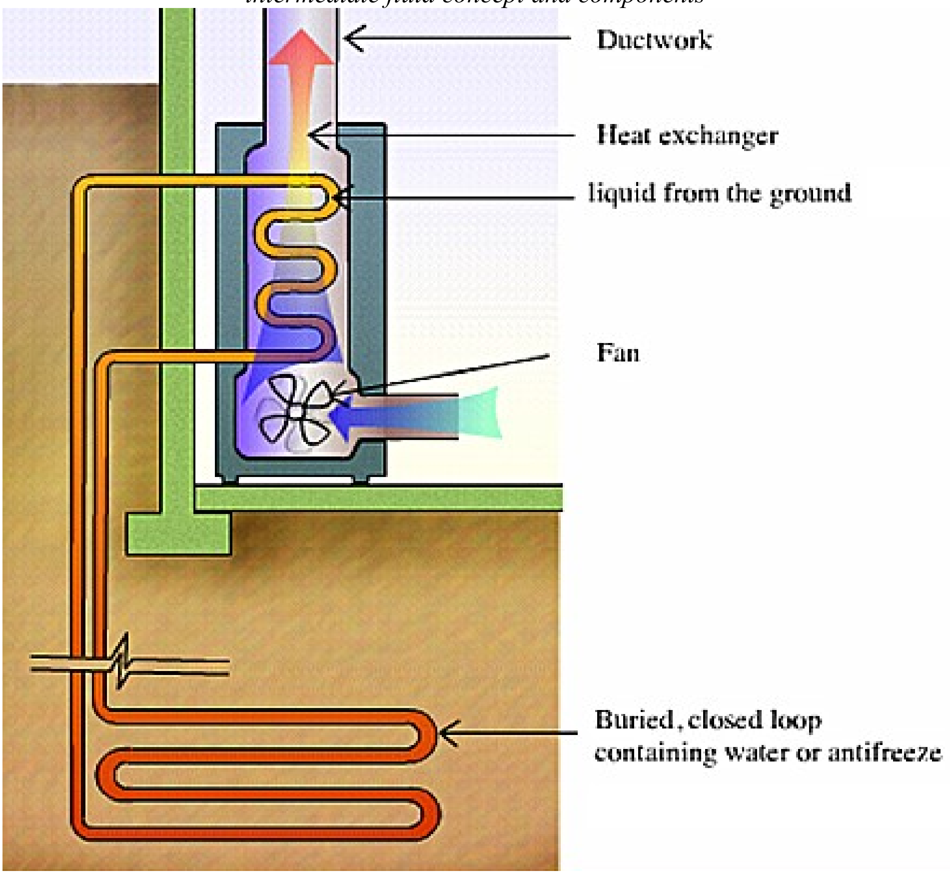

Figure 2- Geothermal heat exchanger through presence of intermediate fluid working idea[54]

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[54] Geothermal or Ground source heat pumps, accessed 2009, http://www.consumerenergycenter.org/home/heating_cooling/geothermal.html

Length of the loop depends upon a number of factors, including the type of loop configuration used; building's heating and air conditioning load; local soil conditions and landscaping; and the severity of climate. Larger buildings requiring more heating or air conditioning generally need larger loops than smaller buildings. Moreover, buildings in climates where temperatures are extreme also generally require larger loops. Here are the typical loop configurations:

a) *Horizontal Ground Closed Loops*: in this type fluid runs through the pipe in a closed system. A typical horizontal loop will be 400 to 600 feet long for each ton of heating and cooling[55].

b) *Vertical Ground Closed Loops:* This type of loop is used where there is little yard space, when surface rocks make digging impractical, or when a little landscape is wanted. Vertical holes 150 to 450 feet deep are buried in the ground, and a single loop of pipe with a U-bend at the bottom is inserted before the hole is backfilled. Each vertical pipe is then connected to a horizontal underground pipe that carries fluid in a closed system to and from the indoor exchange unit. Vertical loops are generally more expensive to install, but require less piping than horizontal loops because the Earth's temperature is more stable farther below the surface.

c) *Pond Closed Loops:* This type of loop design may be the most economical when a home is near a body of water such as a shallow pond or lake. Fluid circulates underwater through polyethylene piping in a closed system, just as it does through ground loops. Since it is a closed system, it results in no adverse impacts on the aquatic system.

d) *Open loops*: include an Open Loop System in which ground water is pumped into and out of a building, transferring its heat in the process; and Standing Column Well Systems, which can be up to 1,500 feet deep and can also furnish clean water.

2-3-2-6 System properties

a) Efficiency and effectiveness

The efficiency of Earth cooling tubes vary widely depending on the location, altitude, ambient Earth temperature, climatic temperature-and-relative-humidity extremes, direct solar radiation, tube diameter / length /

[55] Ibid

depth, soil type, soil moisture content and the efficiency of the building's exterior envelope design. Following some cases for maintaining more or less cooling efficiency:

- *Minimum efficiency:* dry, low density soils, and with no ground shading will yield the minimum effectiveness for cooling.
- *Maximum efficiency:* Damp, moist, high densities soils, and with considerable shading perform well, as the dens soil in contact with the cooling tubes can conduct heat more efficiently than less dens soil.
- Larger tubes permit a slower airflow, which also yields more efficient energy transfer, permits much higher volumes to be transferred, and permits more air exchanges in a shorter time period.
- Earth cooling tubes are much less effective in hot humid climates where the ambient temperature of the Earth is more than human comfort temperature.
- Protecting the soil surface of tubing from direct solar radiation will increase its efficiency. As, Once the soil surface temperature is lowered, the temperatures of layers below the surface will also lowered.

b) Construction and running costs

Earth cooling tubes are often available and economical alternative to conventional cooling systems since there are no compressors, chemicals or burners and only blowers are required to move the air. However, Earth cooling tube systems can be very expensive in hard soils, as the machines used for digging the soil and installation can be more expensive than using other passive cooling systems. While they may be more costly to install initially than regular heat pumps, they can produce markedly lower energy bills up to - 30 % to 40 % lower.

c) Health Considerations

Formal research indicates that Earth cooling tubes reduce building ventilation air pollution. it is found not to support the growth of bacteria and fungi; rather it is found to reduce the quantity of bacteria and fungi thus making the air safer for humans to inhale. It is therefore clear that the use of earth air tunnel not only helps save the energy but also helps reduce the air pollution by reducing bacteria and fungi. It is acceptable as long as regular controls are undertaken and if appropriate cleaning facilities are available[56].

d) Durability
Geothermal heat exchanger pumps are durable and require little maintenance. They have fewer mechanical components than other systems, and most of those components are underground, sheltered from the weather. The underground piping used in the system is often guaranteed to last 25 to 50 years and is virtually worry-free. The components inside the building are small and easily accessible for maintenance. Cool air is distributed through ductwork, just as in a regular forced-air system.

2-3-2-7 System disadvantages
This system has many advantages, however it has some problems should be taken into account before the designing process. These problems are summarized as follows:

- Earth cooling tubes perform poorly in hot, humid areas, as the ground does not remain sufficiently cool at a reasonable depth during the summer months.
- Condensation is an important aspect should be resist for effective cooling so mechanical equipments could be necessary for dehumidification.
- The dark and humid atmosphere of the cooling tubes may be a suitable atmosphere for odor-producing molds, bacteria, and fungi. Good construction and drainage could eliminate these problems.
- Insects and rodents may enter the tubes of an open-loop system. The system should install have a grille and insect screen at the tube inlet to prevent the insects' entry.

2-3-2-8 System application
Sherman hospital, Elgin, Illinois
New Sherman hospital in Elgin, Illinois offers a powerful example of the economic environmental innovative design with a gross man- made geothermal lake. The geothermal lake for heating and cooling will make Sherman hospital one of the most energy efficient health care facilities reducing the load on conventional cooling and heating systems and lowering space conditioning costs by 30 to 40 %. Because water at the lake bottom is cooler than outside air in summer and warmer in winter, the system could be used to lower and riser

[56] Ibid

air temperature accordingly (figure 2-25). Warm air is extracted from the hospital and circulated through the pip loop to the lake, upon return the cooled liquid offsets the indoor air temperature and then redistributed through the facility.

Figure 2- section in the geothermal heat exchange tubes, application, Sherman hospital, Elgin, Illinois, 2009[57]

2-3-3 Evaporation: Passive Evaporative Cooling Towers

When water evaporates it absorbs a large amount of heat from its surroundings. This idea can be used to enhance the cooling rates in passive cooling systems. It is done by bringing the outdoor air into the interior space after humidifying it by spraying of water drops. This strategy is the main idea in Evaporative Passive Cooling Tower. Its utilization originated in the Middle-East, Iran, north of India, North Africa (figure 2-26), as all these regions are suffering from a hot and dry climate[58].

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[57] **John Guzzon**, *HVAC revolution Gains (geothermal) Heat*, Medical Construction & Design, *January/February 2008*.

[58] Evaporative Cooling, accessed 2007, http://www.arch.mcgill.ca/prof/bourke/arch672/fall2002/evapor.htm

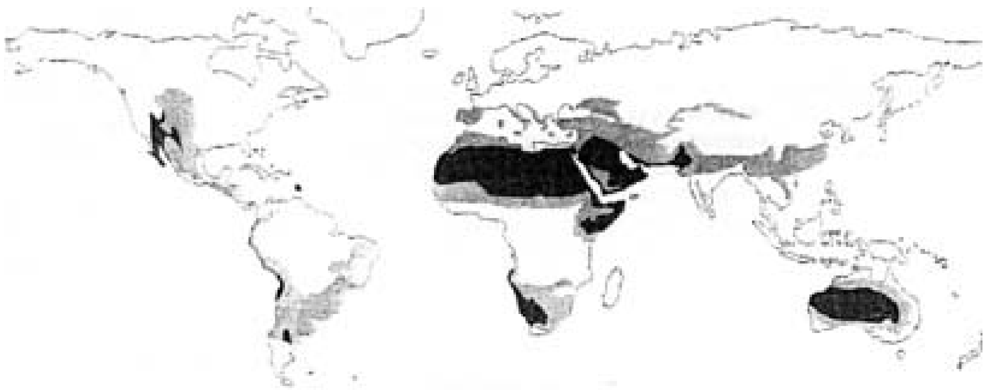

Figure 2- the spread of evaporative cooling system in hot- dry regions[59]

As the evaporative cooling process allows the cooling of air by using the natural effect of evaporation to remove heat from the air, then, the amount of sensible heat absorbed depends on the amount of water that can be evaporated in the system.

2-3-3-1 Concept and components

The general principal of evaporative cooling tower is to allow air to pass through appropriately wet pads placed at the top of the tower to evaporate the water from pads. Large amounts of heat from air are consumed by water as it evaporates. Evaporation cools the incoming air, causing a downdraft of cool air thereby raising the relative humidity of the air and reducing its temperature. Cool moist air is heavier than hot dry air and drops down the tower into the interior space.

This system is only efficient when the relative humidity is low, thus it has an effective use in dry climates. In dry climates, the installation and operating costs of an evaporative cooler can be much lower than refrigerate air conditioning often by 80%[60].Vents should have a larger opening to permits the cool air to go through it to the internal space. The pads can be made of wood shavings or other materials that absorb and hold moisture while resisting fungus. Small distribution lines supply water to the top of the pads. Water soaks the pads and trickles through them to collect in a sump at the bottom of the cooler. A small re-circulating water pump sends the collected water back to the top of the pads. Since water is continually lost through evaporation, a float valve adds water to the sump when the level gets low (figure 2-27). Under

[59] Ibid

[60] Evaporative cooler, accessed 2007, http://en.wikipedia.org/wiki/Evaporative_cooling#Evaporative_cooling

normal conditions, a swamp cooler can use between 11to 56 liters of water a day[61].

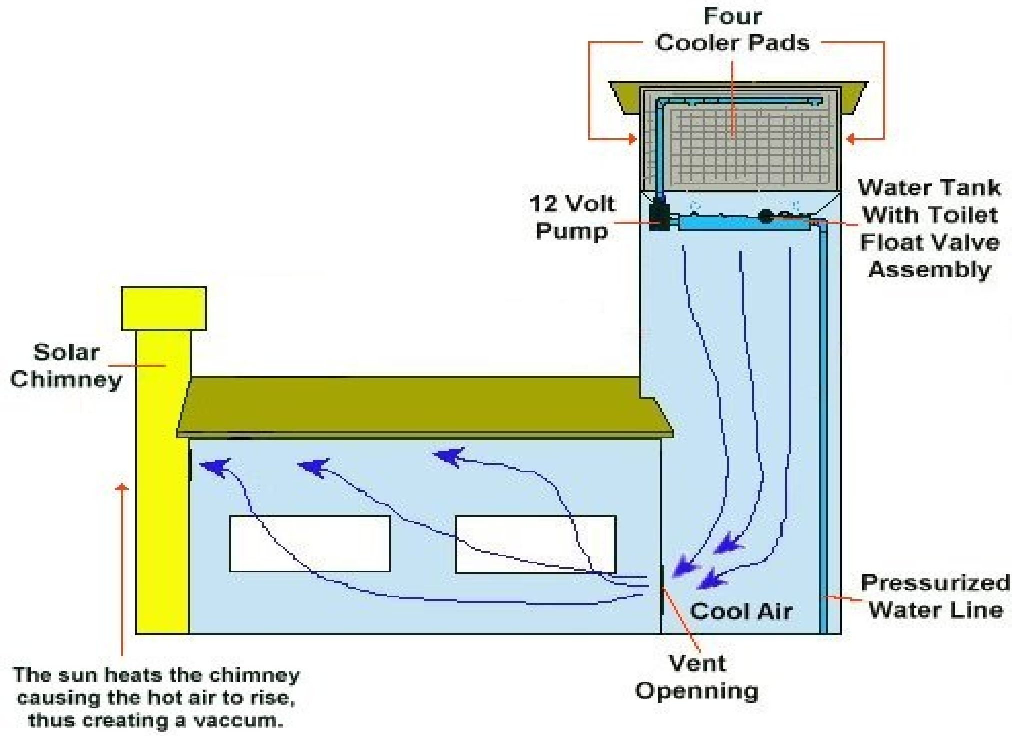

Figure 2- the most common evaporative downdraft cooling tower[62]

Evaporative coolers could use photovoltaic panels to generate the electricity used to run the blower and the water pump. For hot, desert areas, the combination of evaporative cooling and solar power are a perfect match. PV cells can provide enough electricity to run the system effectively[63].

[61] consumer energy center, evaporative cooling, accessed 2008, http://www.consumerenergycenter.org/home/heating_cooling/evaporative.html

[62] Passive Air Conditioning, accessed 2007, http://www.thefarm.org/charities/i4at/lib2/aircool.htm

[63] Evaporative Cooling, accessed 2008, http://www.consumerenergycenter.org/home/heating_cooling/evaporative.html

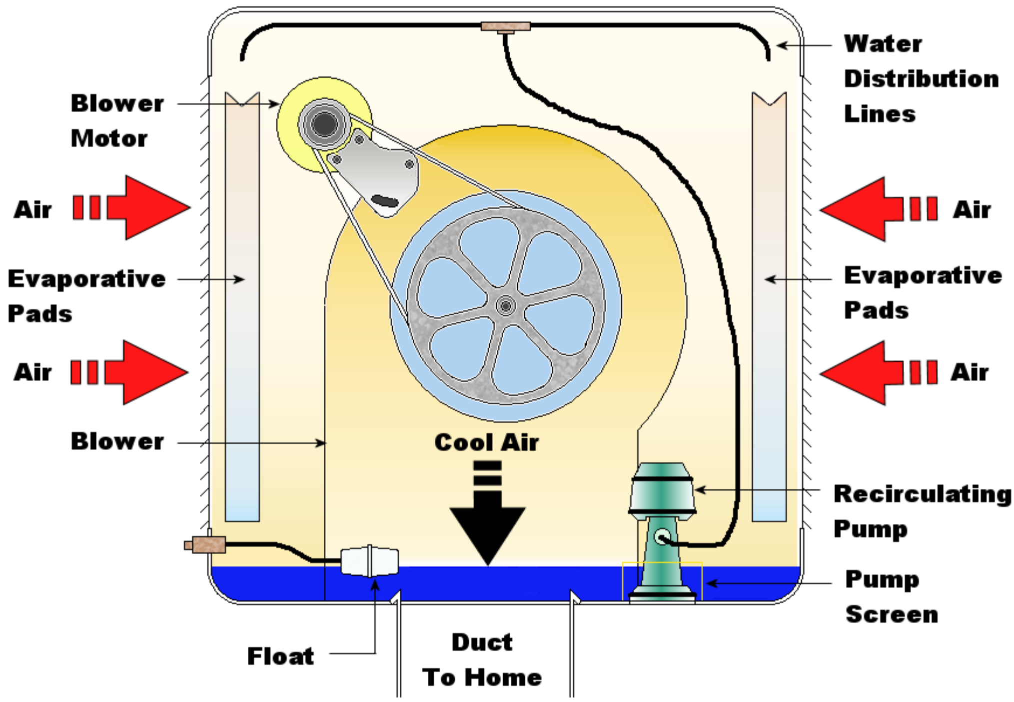

Figure 2- Evaporative cooling working idea[64]

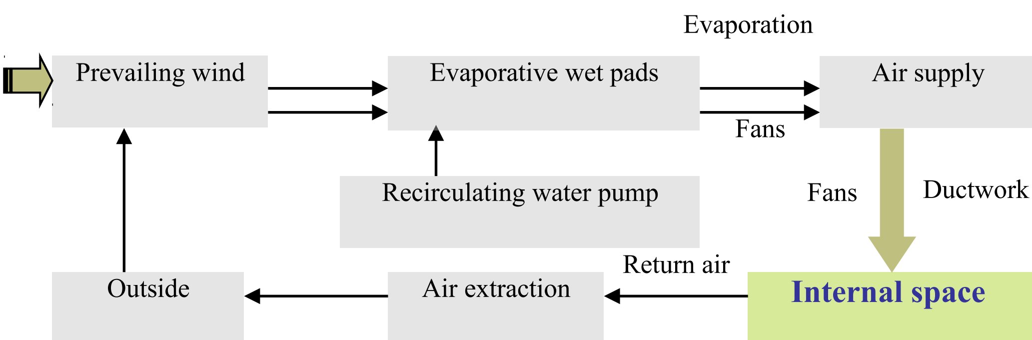

Figure 2- Diagram for Passive Evaporative Cooling Towers system concept and components

2-3-3-2 System technical details

Generally, the evaporative tower dimensions, height, and the distance from the bottom of the pads to the air outlet, will determine the velocity or pressure of the air. The greater this distance the more air pressure created. Here are some technical descriptions for more efficient cooling effect.

[64] Ibid

a) *Cool tower dimensions:* Generally cool towers without fans are from 20 to 30 feet tall and between 6 and 10 feet square (6'x 6', to 10' x 10'). Thus, the common efficient cooling tower is about 6 x 6 x 30 feet. Typically cool towers of this size will require from 10 to 150 watts, and will cool 1,000 to 2,500 square feet. Airflow for these cool towers will range from 2,500 to 8,000 CFM (cubic ft. per minute)[65].
b) *Cooling Tank:* it contains 15-30 gallons of water with a float valve assembly to keep the tank full.
c) *Electric pump:* It is a small 12 Volt pump to circulate water over the cooler pads, it is located outside the tank.
d) *Cooler pads:* they are sited at the top of a tower with pump re-circulating water over them (figure 2-29). There is some issues should be considered for more efficient cooling pads performance[66]. These considerations are as follows:
   - The wetted surface area of the pad to airflow ratio should be as large as possible.
   - The cooling pad should not act as a filter, as this will cause a drop in evaporative efficiency and supply airflow.
   - Pads should be able to handle with high water flow rates in order to trap dust and other solids.
   - Water flow down the pad should be uniform.
   - Water should adhere to the pads and not drop off and be carried into the machine.
   - Cooling pads should remain rigid, and should not sag or loose shape.
   - Pads should be treated against UV degradation and should not rot as this leads to bacterial growth and odors.

2-3-3-3 Advanced cooling tower

To create a larger air flow down the cool tower, the cooling system could be advanced. This system is the same as the previous one, but there is one large upwind swivel scoop installed above the pads in the tower to direct maximum air from the wind to the cooler pads (figure 2-30). Air scoops should have a tail system to keep the scoop oriented into the wind direction. The intake air scoop should be made out of light aluminum[67].

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[65] Passive Air Conditioning, accessed 2007, http://www.thefarm.org/charities/i4at/lib2/aircool.htm

[66] cool Breeze Air conditioning, Cooling Pads, accessed 2008, http://www.coolbreeze.co.za/pads.htm

[67] Passive Air Conditioning, accessed 2007, http://www.thefarm.org/charities/i4at/lib2/aircool.htm

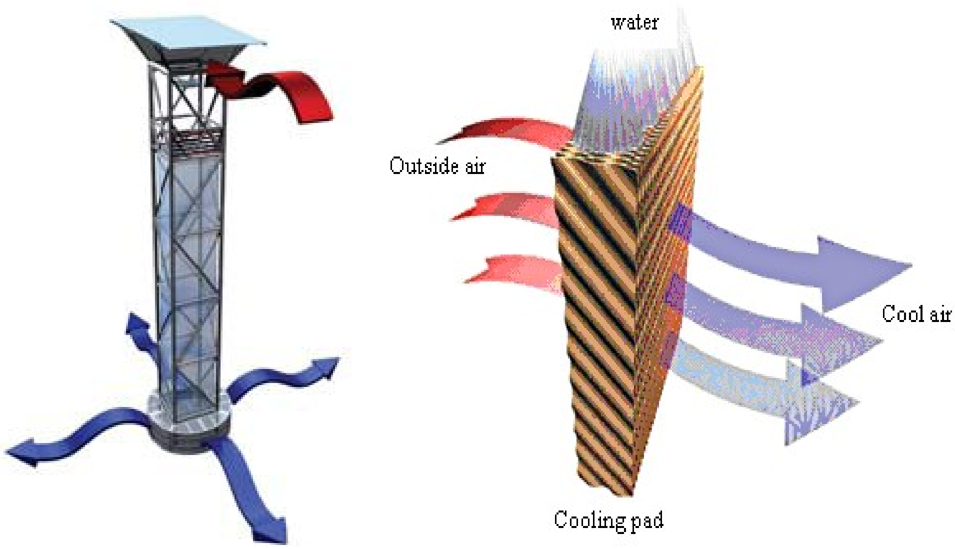

Figure 2- sketch for the air cooling idea in the evaporative cooling pads[68]

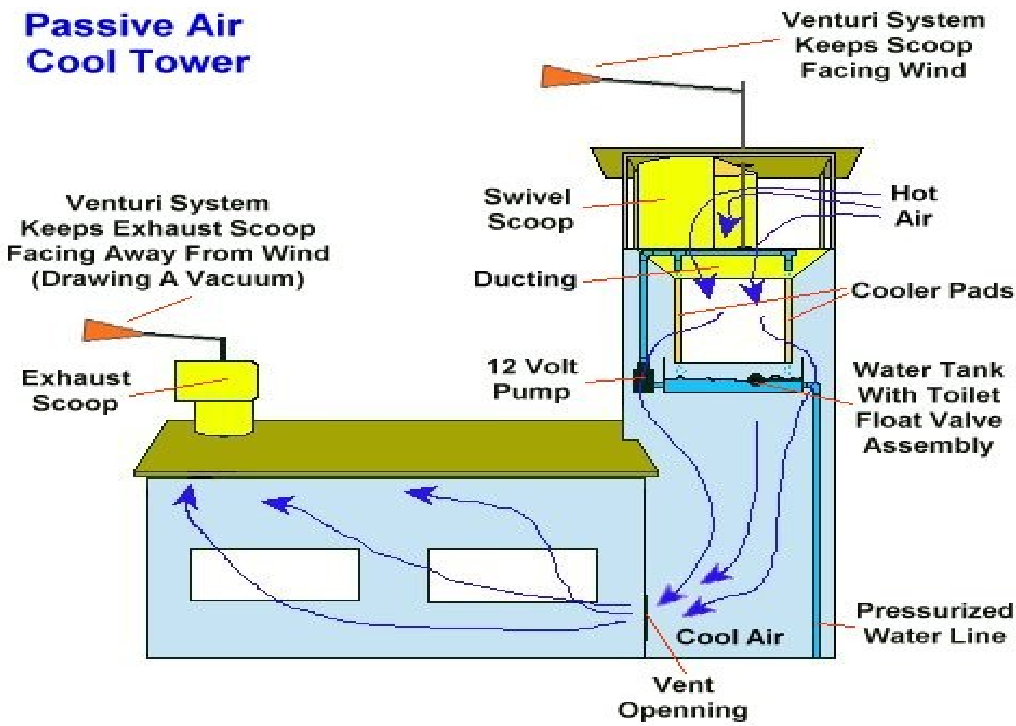

Figure 2- Advanced cooling tower [69]

[68] Ibid

[69] Ibid

2-3-3-4 System advantages and disadvantages

a) *System advantages*

- It uses less electricity, thus it saves energy and natural resources, as much as 80% on running costs compared with refrigerated air conditioning.
- Evaporative coolers cost less to buy, less to install and less to operate than refrigeration air conditioners.
- Evaporative cooling provides a complete fresh air change every few minutes, so it's much healthier and more comfortable to the building occupants
- Evaporative cooling is an efficient technique for hot-dry regions such as Egypt, as the humidifying properties of evaporative coolers have a major advantage.
- It is possible to cool different areas of the building at different time.
- It considered being a quieter system.
- This system is easy in usage; it can be controlled with single keypad with no technical terms.
- It can be designed as stand alone systems or as backup systems in conventional air-conditioning-systems.

b) *System disadvantages*

- Evaporative coolers require a constant supply of water to operate, and when there is a water shortage, it will not be as a practical system.
- it could be used for several stores building but it will be less effective in the lower levels
- An evaporative system needs 3-4 times air exchange rate more than conventional air-conditioning systems.
- Evaporative cooling is most appropriate in buildings with relatively small cooling loads, such as commercial and residential buildings – or buildings that do not require tight humidity and temperature control.

2-3-3-5 System application

Dubbo Campus, Charles Sturt University

The Interactive Learning Centre targets to design an innovative approach to passive cooling using four passive evaporative cooling towers. The evaporative cooling towers overhang into the sky to catch the dry hot outside air and focus it to the evaporated water in order to cool it (figure 2-32).

Figure 2- Passive Downdraught Evaporative Cooling, Dubbo Campus, Charles Sturt University[70]

The cooled air projected to the central atrium providing cooling to all perimeter rooms as well as the core.

Figure 2- Interior view: pen Plan Resource Centre, Charles Sturt University[71]

[70] **The official journal of Airah**, February 2003, *Cooling Rural Australia Passive Downdraught Evaporative Cooling*, Dubbo Campus, Charles Sturt University, p22.

[71] Ibid

2-4 Conclusions

This chapter has introduced the main idea of passive cooling; moreover it has presented the main factors affecting the internal passive cooling. It gives some solutions to efficient passive design building envelope in order to decrease the cooling loads. Moreover, this chapter has shown the efficiency of appliance of various passive cooling techniques (radiant cooling, underground cooling, and passive evaporative cooling tower) on interior spaces cooling, as it has high potential to reducing building energy consumption and peak power demand. It has proved that passive cooling techniques can be used to reduce mechanical air conditioning requirements in hot dry climates. The following Diagram summarizes the passive cooling main principals for enhancing the building sustainability.

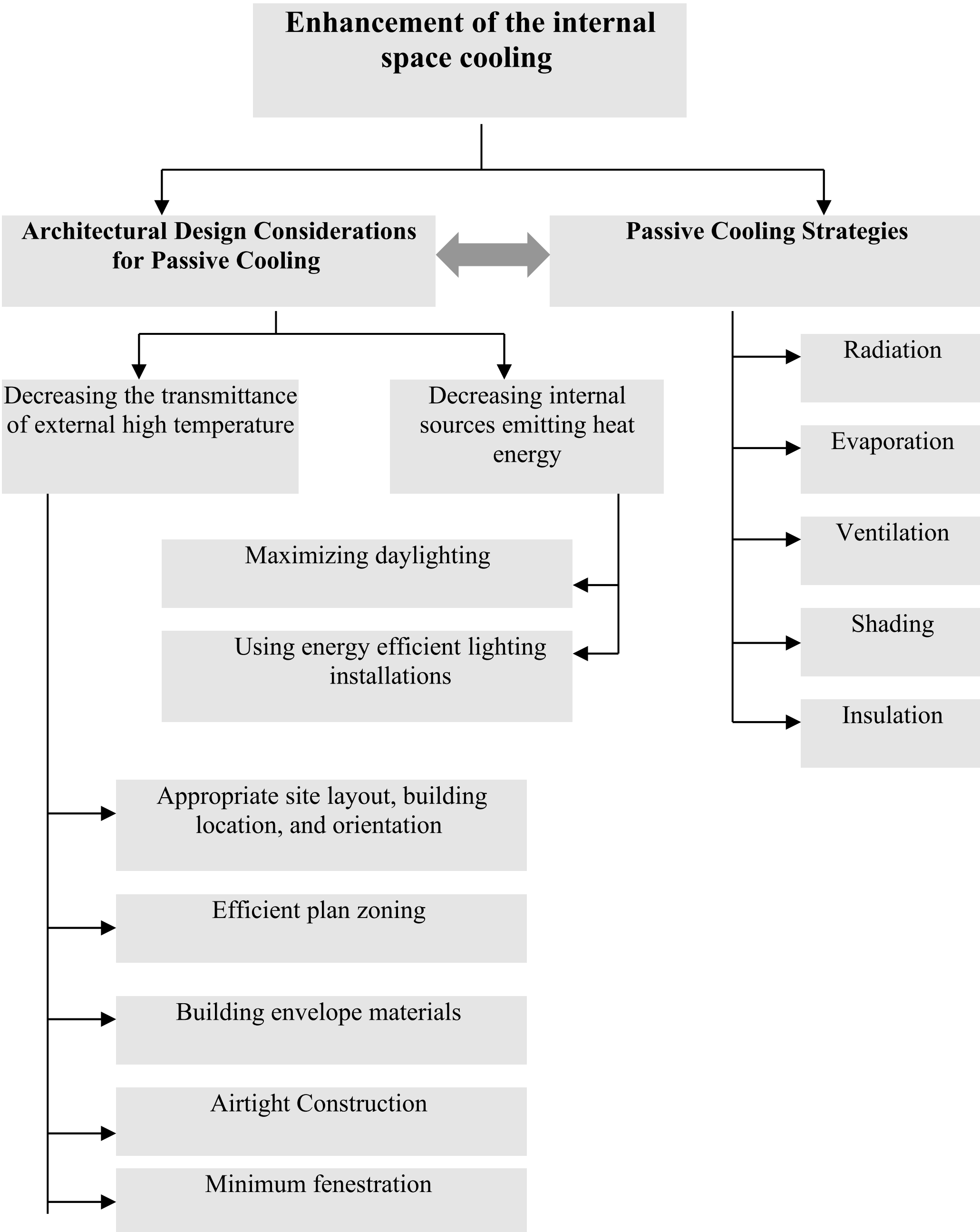

Figure 2- Diagram summarizes the passive cooling main principals for enhancing the building sustainability

3-1 Introduction

Natural Ventilation has been a major passive cooling technique for so long all over the world. It is usually a better choice than conventional air conditioning. It has the potential to reduce first costs and operating costs for some commercial buildings while maintaining ventilation rates consistent with acceptable indoor air quality and the required level of oxygen. Beside, ventilation is also necessary for indoor spaces for providing a suitable level of fresh air and controlling odors and indoor air pollutants. Recently, there is a wide consideration from researchers about advanced natural ventilation technologies for obtaining the maximum efficiency. This chapter reviews the main concepts, considerations, and strategies for natural ventilation process. Moreover, it introduces the main three innovative natural ventilation systems (double skin facades, innovative wind catchers, and interactive facades) and explains their efficiency in appliance.

3-2 Natural Ventilation Main Idea and Considerations

Natural Ventilation is a form of convective cooling that has the potential to cool the human body directly through convection and evaporation, or indirectly by cooling the structure of the building surrounding the occupants[1]. The following section presents the main idea and architecture considerations for natural ventilation process.

3-2-1 Main Idea

Natural ventilationis based on fundamental heat transfer mode by supplying and removing air through an indoor space by natural techniques. As the air flowing next to a surface carries away heat, and lowers its temperature. Natural ventilation is one of the primary means of reducing the cooling loads in buildings by removing the heat from the indoor. Air movement through a building results from the pressure difference between indoor and outdoor. This pressure difference can be achieved by wind forces coming from the outside or by temperature difference between inside and outside. This pressure difference is driven by two primary natural forces that affect greatly on the building design, these two pressure difference are:

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[1] **Francis Allard, Matheos Santamouris, Servando Alvarez**, 1999, *Natural Ventilation in Buildings: A Design Handbook*, published by Earthscan, p3.

- Wind pressure: its idea is based on air movement from high to low pressure zones; it considered the main principle of cross ventilation systems.
- Buoyancy effect: its idea based on the hot air rises and the cool air comes instead of it, this effect is the main principal of stack ventilation systems.

3-2-2 Architecture Considerations for Efficient Natural Ventilation

In hot summer, to take advantages of the natural ventilation in buildings in order to cool the occupants directly. Architects should dissipate any internal heat gains and protect the building from direct sun radiations. To achieve these goals the architect should consider the following items before designing a passive design building:

- *Evaluation of ventilation rates for different spaces:* by a manual process to determin ventilation rates for interior space by using equations depending on the area of the opening, wind speed, air density, and pressure difference (Appendix A).
- *Building type and space usage:* Building type should be considered as it will affect the ventilation rates needed; high ventilation rates could be suitable for some interior spaces and not suitable for other[2]. For example, High ventilation rates may not be suitable for offices or for spaces requiring high security (such as computer and other sensitive instrument rooms, toxic producing processes, hospitals, clinics).
- *Orientation of building openings:* For better ventilation, the building openings should be oriented to take maximum benefits of the local gradient wind. The edge of the building should be sitting perpendicular to the summer prevailing winds.
- *Total area of inlet and outlet openings:* average indoor velocity and number of air changes is highest when inlet area is equal to or slightly less than outlet area as in the equation: Outlet area / Inlet area = 1.25 [3].
- *Location of the openings on the facades:* for body cooling, the best location for windows is at or below body level[4]. Moreover, the vertical level of inlets varies with the space usage, for example: inlet level in

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[2] **Baruch Givoni**, , 1998,*Climate considerations in building and urban design*, Published by John Wiley and Sons, P93.

[3] **Donald L. Basham, James W. Wright, Kathleen I. Ferguson**, **Get W. Moy**, 16 January , 2004, Unified Facilities Criteria (UFC), *Cooling Buildings By Natural Ventilation, Department of defense,* United States of America.

bedrooms is at bed height, while, in offices is at sitting height. Vertical placement is also affected by window type since different window types produce different airflow patterns.

- *Presence of interior obstructions between inlet and outlet openings:* like Partitions and interior walls have a great effect on lowering the interior air flow rate path direction from inlet to outlet openings as it changes the airflow pattern and more of the air's velocity is wasted[5].
- *Presence of louvers and overhangs*: they are used to minimize the solar gain and to maximize the benefits of natural ventilation.
- Windows glazing materials should be considered to minimize the solar radiation into the space.
- *Careful choosing the site characteristics and topography* will help maximizing the air flow and cross ventilation.
- *Width-to-height ratio of openings: it* should be more than 1, as far as possible (orient the openings horizontally to be more efficient).
- *Climate analyses:* There is wide variety of computational designing tools that could help analyzing the exterior climate including temperatures, humidity, wind velocity, and solar radiation in both 2-D and 3-D graphics for every hour of the year before designing process.
- *Integration with HVAC in hot climates:* In moderate climates cooling by natural ventilation may be the only passive cooling strategy in the building and can replace conventional air conditioning systems. But, for very hot summer regions, buildings could require air conditioning some times, the best solution is to divide the building into separate zones for natural ventilation and mechanical ventilation. Automatic controls can be used for changeover the two systems, when it becomes so hot, controls automatically shut the windows to open the air conditioning system, and the opposite could be also happened when the climate changed.

3-3 Natural Ventilation Techniques

The development of natural ventilation systems in the last decades allows for more comfort and improvement the building sustainability. Innovative wind catchers, Double skin facades, and interactive facades are considered natural ventilation techniques that are widely spread recently in commercial buildings.

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[4] **Baruch Givoni**, 1998, *Climate considerations in building and urban design*, Published by John Wiley and Sons, P95.

[5] Ibid.

The next section will present the concept of each of these systems, their technical description, and ventilation performance of each.

3-3-1 Wind Catchers

Wind catcher is an effective natural ventilation system that could be applied in hot climates, where there is a daily variation in temperatures. This climate has high temperatures during day time and low temperatures during night time.

3-3-1-1 Historical overview

Wind catchers are found since thousands of years in the Middle East where "Wind Towers" were often a common sight. The basic idea of the wind towers is to encapsulate any prevailing wind. The intake openings in the wind tower collect the prevailing wind and turned it 90° to bring it down into the rooms below[6]. During night time, the cooler air comes in contact with the bottom of the tower through the rooms; it gets heated up by the warm surface of wind tower and thus an air flow is maintained in the reverse direction.

Figure 3- Historical wind catchers in the Middle East[7]

Traditional wind towers have been usually constructed from local natural materials for example it could be made of wood- reinforced masonry with openings at height above the building level ranging from 2m to 20m[8] (figure 3-1).

As traditional wind catcher has proved its efficiency as a natural ventilation system in the past, wind catchers have been developed to increase the ventilation efficiency where conventional air conditioning systems do not provide efficient airflow rate. They have the same idea of traditional ones but they are modified and have more complicated manufacture and controlling to achieve better air rates quality.

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6 Ibid

7 **Monodrought wind catcher natural ventilation system**, technical catalogue .PDF, September 2006. P2.

8 **Hazim B. Awbi**, 2003, *Ventilation of Buildings*, Published by Taylor & Francis, p334.

Innovative wind catcher has proved to be an effective method for providing natural ventilation to any commercial building as it provides natural cooling without any moving parts. The wind catchers available are shaped circular or square sectioned that divided into four quadrants acting as air supply/ extract ducts (figure 3-2).

Figure 3- Innovative wind catcher ventilation system in York University[9]

3-3-1-2 Concept and components

a) *Ventilating louvers*

They are metal louvers on the surface of the whole wind catcher. They considered as inlets and outlets that collect winds from any direction and turn it 90° to the room below.

a) *Control dampers*

The system is composed of a series of modulating dampers at the base of the system with a combined ceiling diffuser.

b) *Ceiling diffusers*

It is connected to the dampers at the ceiling level to control the volume of fresh air flow into the building.

3-3-1-3 Ventilation idea

Ventilation in wind catchers is achieved through difference in wind pressure. The vertical vents encapsulate the prevailing wind from any direction and captured by the louvers serving the quadrants and internal turning vanes on the windward side turn the air through 90° and carried down through compartmented ducts down into the room below, through a controlled damper

[9]Monodraught Ltd, wind catcher features, accessed 2008, http://www.monodraught.com/windcatcher/features.php

arrangement[10]. As the wind changes direction at rooftop level, the system quadrants also change their function to continually provide incoming air to the interior. The force of the wind is driven down into the space below have a greater density than the internal air, this cooler incoming air flows down to floor level whilst the less dense warmer internal air rises and extracted through the quadrants. This change in air pressure produces enough airflow to make the room comfortably fresh (figure 3-4).

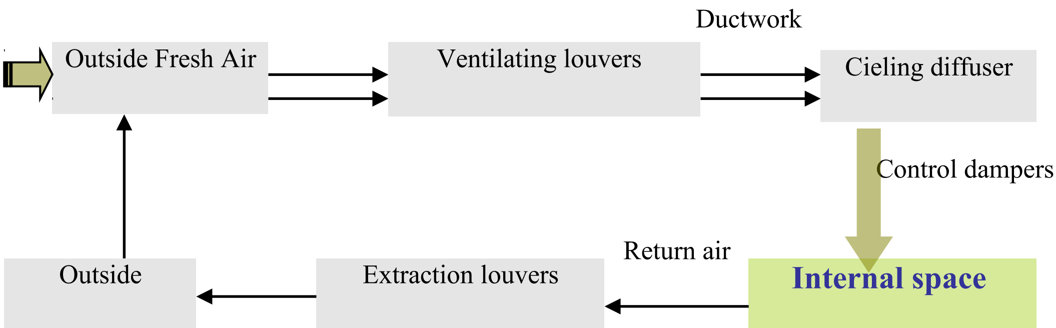
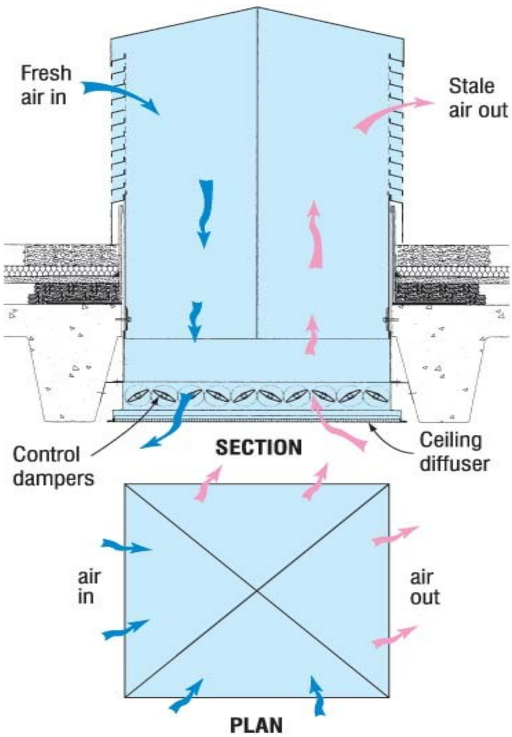


Figure 3- Diagram for innovative wind catchers ventilation idea



[10] Ibid

Figure 3- Innovated wind catcher working idea[11]

3-3-1-4 System performance

a) Night-time ventilation

Night ventilation in the wind catcher system is placed by the presence of control dampers which could be programmed to open fully at the midnight to encapsulate the night air and carries it down into the building below. This cool air used to cool the building structure that had absorbed heat through out the whole day (figure 3-5). Moreover this cold air leaves the building interior feeling fresh and clean for the benefit of the occupants arriving in the morning. The dampers could be programmed to be closed automatically again when the interior temperature achieves a certain temperature.

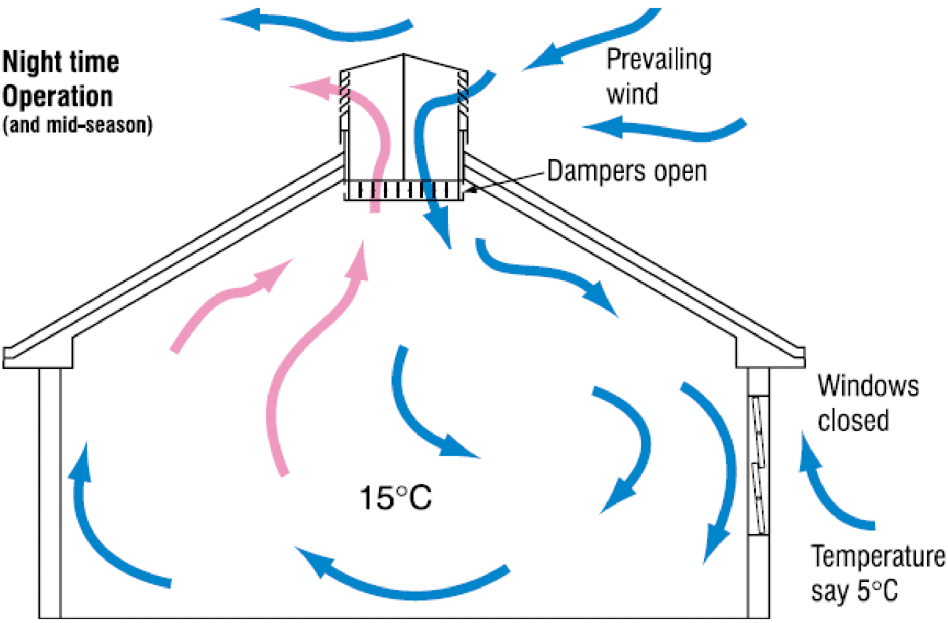


Figure 3- Night time cooling in wind catcher system[12]

b) Summer daytime ventilation

The wind catcher system doesn't need opening windows or vents in the building side. But, for obtaining maximum interior ventilation benefits, in hot summer months, doors and windows are more likely to be opened and this will aid stack effect ventilation, with fresh air coming in through

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[11] Ibid

[12] **Monodraught Ltd, natural ventilation systems,** September 2006, company profile catalogue. PDF, p6.

windows on the windward side of the building and be exhausted through the passive stack element of the wind catcher system (figure 3-6).

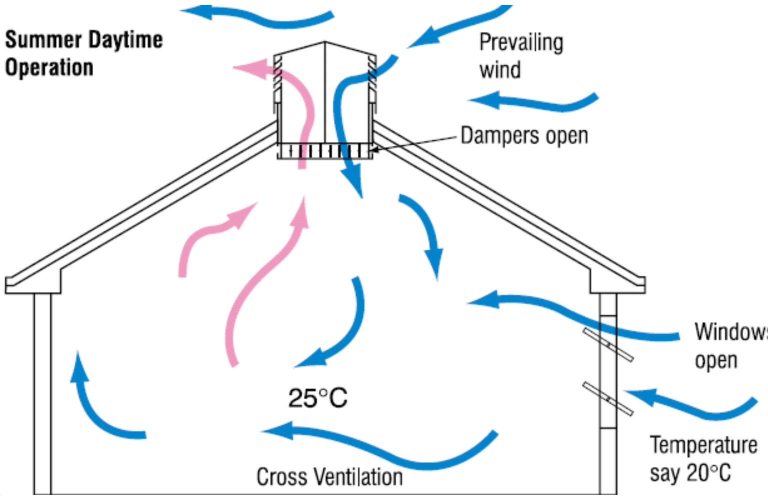

Figure 3- Summer daytime operation with cross ventilation in wind catcher system[13]

c) Multi zoned operation (remote air dispersal ducted) system

Innovative wind catcher system is suitable for all building types with intermediate ceilings. One wind catcher can serve more than one zone through ducts. The system utilizes the same wind catcher design as mentioned before but the inlets/ outlets are connected via ductwork to four diffusers in the ceiling of the ventilated spaces. This ensures effective air distribution within the space and enables the ceiling diffusers to be sited for maximum benefit in relation to space utilization[14] (figure 3-7).

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[13] Ibid.

[14] **Passivent,** July 2005AIRSCOOP VENTILATORS technical catalogue. PDF, p 5.

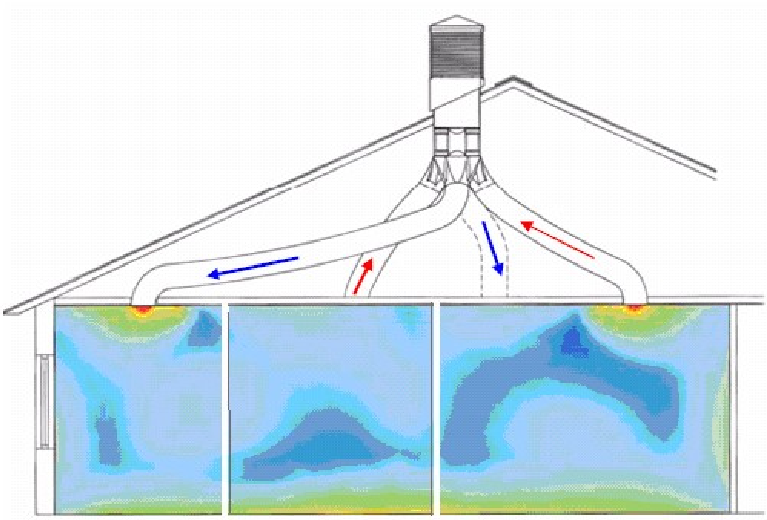

Figure 3- Multi zoned operation (Remote Air Dispersal ducted) system [15]

d) Multi floor operation system

This system is an effective solution for a low rise building, for providing ventilation in multi floor building each room should be ventilated with separate duct to avoid acoustic problems and to eliminate the ingress of external traffic noise as well. Automatic dampers and ceiling grilles can either be located at ceiling level to each duct or the duct can be turned through 90° at ceiling level[16], (figure3-8). Rectangular duct shaped systems are generally provided to lower floors as they can reduce the impact on floor space as the duct passes through an intermediate floor.

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[15] Ibid.

[16] **Monodraught Ltd, natural ventilation systems**, September 2006, company profile catalogue. PDF, p9.

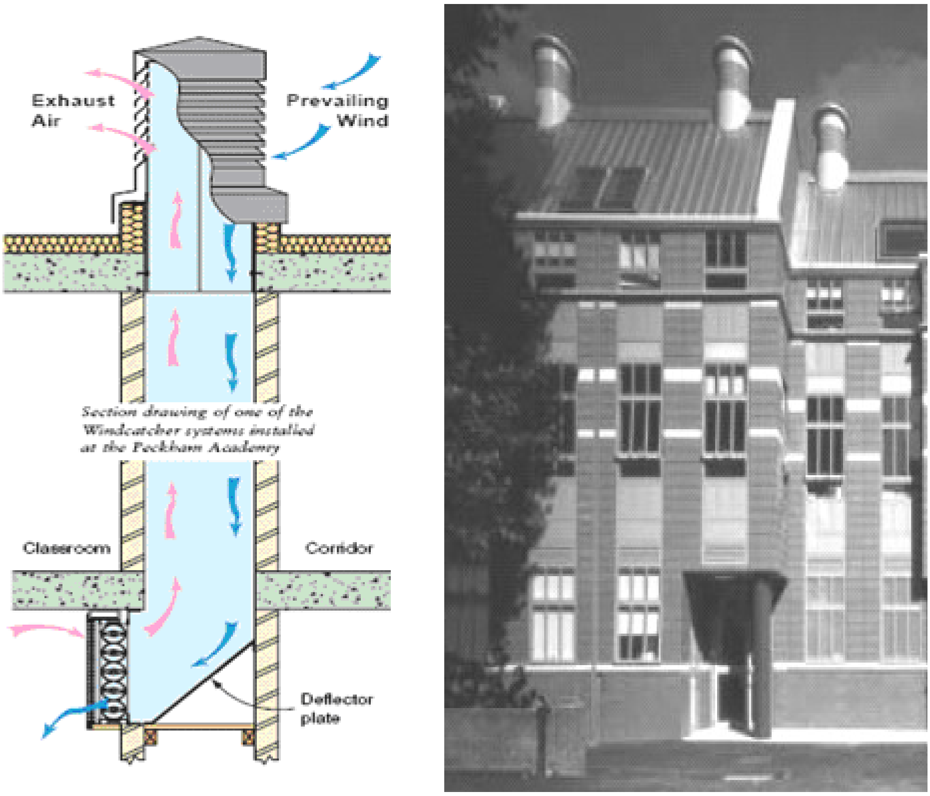

Figure 3- Multi floor operation system design, Adeyy and Stanhope school in Deptford [17]

3-3-1-5 Properties of innovative wind catchers

a) *Low maintenance*

Conventional ventilation system components need regular maintenance and filters constantly need cleaning or replacement. While, innovative wind catcher systems require no maintenance externally and need low maintenance for the internal dampers as they are manufactured from recycled plastic.

b) *Presence of fire dampers*

Fire dampers could be incorporated into the design of the wind catcher ventilation stacks without having any effectiveness on the ventilation efficiency. Moreover, it considered the most secure natural ventilation system; it is not possible to break into or out of the building through the wind catchers. Stainless security grilles can be incorporated into the base of the system.

[17] Ibid

c) Acoustic matter and noise transmission

Since the wind catchers openings is located above the building, then the air is drawing from the above roof level. This air supply system avoids transmission of traffic noise compared to low level openings. In addition, acoustic insulation pods could be suspended on the internal side of wind catcher terminals to achieve maximum sound insulation (figure 3-9).

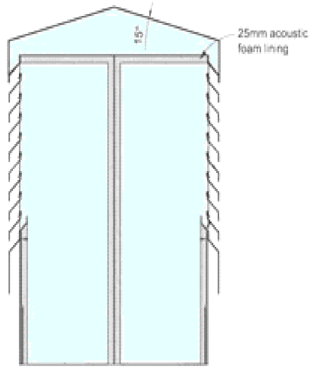

Figure 3- Side view: placement of acoustic insulation pods on the internal side of terminals[18]

Moreover, the BRE Acoustics Centre[19] has made some tests (in January 2002 and 2005) on the noise transmission of the innovative wind catcher. It was established that in its standard format, the wind catcher systems has the effect of reducing noise transmission by 26dB as compared to an open window[20]. So, this ventilation system is considered very good solution for providing natural ventilation to office spaces.

d) Summer and winter operation

The dampers are totally opened for night time cooling during summer months. In winter months, the dampers could be minimum opened for example 3% to 5% which will allow ventilation with avoiding the cooling problems.

3-3-1-6 Controlling devices

The ventilation process in innovated wind catchers could be easily controlled either individually or by central system. The central system could be fitted with a spring/summer/autumn/winter switch, so openings of the dampers are totally opened or partially depending on the season switch. There are three main methods of controlling in the wind catcher natural ventilation system; manual controller, semi-Automatic controller, and fully automatic controller.

a) Manual Control Damper

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[18] Monodraught Ltd, acoustic matters, accessed 2008, http://www.monodraught.com/windcatcher/features.php

[19] BRE are world leading research, consultancy, training, testing and certification organizations delivering sustainability and innovation across the built environment and beyond.

[20] Monodraught Ltd, wind catcher features, accessed 2008, http://www.monodraught.com/windcatcher/features.php

The manual damper is the easiest and the most basic method of controlling the air flow rate through the wind catcher dampers; Instead of motorized dampers, manual dampers are fitted and are operated by a switch at ceiling diffuser level. The most general cases are that the dampers are left fully open during summer months and only partially open during winter months with respect to the controllability of the user.

b) *Semi-Automatic Controller*

It is a stand alone control system which allows the user to control the opening or closing the dampers by pushing on a button or by twisting the dial to the desired position to suit the conditions. In other choice it can be automatically controlled system as the dampers are automatically opened or closed depending on the internal temperature. The dampers are automatically opened when the temperature is more than 24 ºC (for example) and are automatically closed when the temperature is less than 17 ºC. However, at anytime the user can override the damper position using the push buttons.

c) Fully Automatic Controller

In this controller system a fully programmable control panel is presented within the wind catcher, the system is connected to temperature, air quality and CO_2 sensors depending upon the particular application. As the sensors signalize the temperature level or CO_2 level in the room, it sends signal to the automatic control panel so that to open or close the dampers[21]. The control panel can be located in a plant control room; it does not need to be located in the room which was served. This control system can serve multiple rooms

d) Controller sensors

- The temperature sensor: For large room areas, two or more temperature sensors should be positioned in the room to correctly know the internal temperature by taking their average. The temperature sensors are updating its programming with different seasons to prevent heat loss during this period. The temperature sensor is incorporates to manual or automatic facilities to open or close the dampers for more efficient ventilation rate.
- CO2 sensor: The CO_2 concentration level in the interior air is very important issue for good indoor quality and comfort, The CO_2 concentration level between 300 and 2,000 ppm is used as

[21] Ibid p7.

an indicator of indoor air quality (ASHRAE recommends they should not exceed 1,000 inside a space) it can be adjusted at 1500ppm[22].Once this level is reached, the dampers will open automatically for a period of 20 minutes before returning to the closed down position. CO_2 sensors are recommended for Classrooms, Sports Halls, Gymnasiums and Offices[23].

- Air Quality sensor: In case of highly densely populated rooms, such as conference rooms or social areas, air quality sensors are recommended in conjunction with temperature sensors to detect odors or heavy particulate contaminants.

3-3-1-7 Solar powered wind catcher

Innovative wind catcher has been used over 15 years ago and it has proved its efficiency, but in some cases in very hot summer there are some potential problems of internal over heating. Designers have made some improvements on the existing wind catchers in order to add ventilation on hot sunny days while maintaining zero running costs.

Figure 3- Wind catcher with polycrystalline solar panels for generating power, Hazeley School[24]

The improvement is by supplying the wind catcher with polycrystalline solar panels which are embed into the internal fan that brings in additional fresh air up to 260l/s[25] (figure 3-10). The fan operation can be set to extract fresh air without any energy cost. Thus, it considered to be a ventilation system of a zero energy consumption which allows the efficient natural ventilation rates to the interior.

a) *System working idea*

The system works by using the solar radiation as a basic power system for the fans, so, the brighter the sun the greater the fan speed and thus the more

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[22] American National Standards Institute, American Society of Heating ASHRAE, *Ventilation for Acceptable Indoor Air Quality*, *The ASHRAE Standard 62.1*, Published by American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.,USA, 2001.

[23] Ibid.

[24] Ibid, p3.

[25] **Monodraught Ltd,** September 2006, natural ventilation systems, company profile catalogue. PDF, p17.

ventilation rates. The idea is that the sun's power produces 3V[26] through the solar panel; the power is increased by the solar panel by 250% then transmitted to the a 200mm internal fan, which in turns gets free working power to the fan and thus the fan works. The fan carries the air stream through the central duct in the wind catcher unit and from it to the space below it (figure3-11).

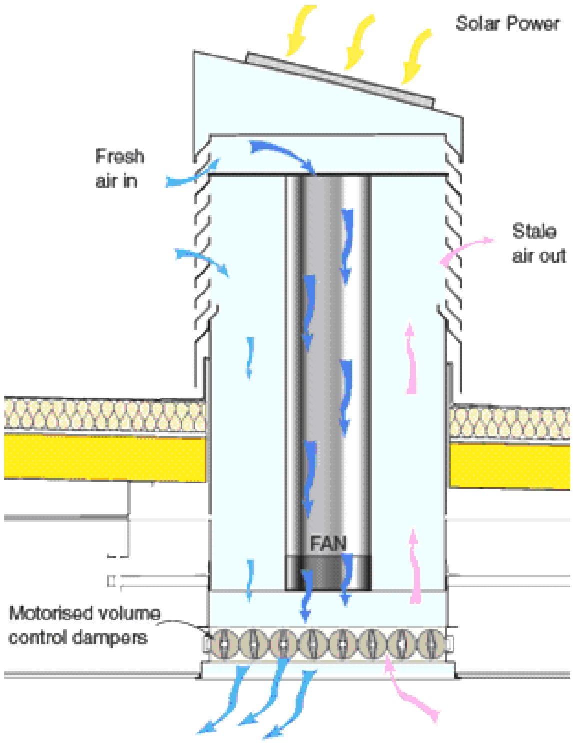

Figure 3- Working idea of solar powered wind catchers' ventilation system[27]

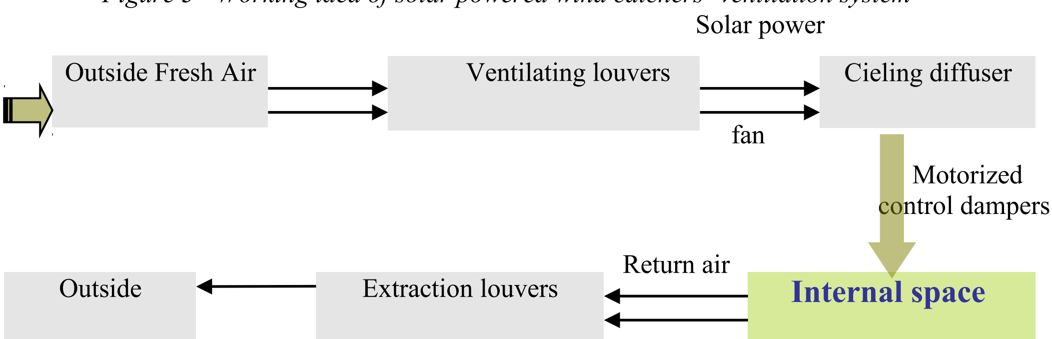

Figure 3- Diagram for innovative wind catchers' ventilation idea

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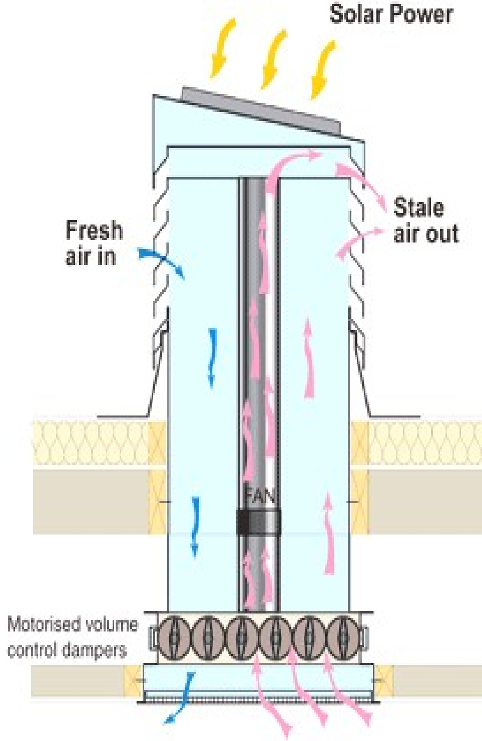
[26] Ibid.

[27]Ibid, p17.

b) Fan performance



- For Normal Conditions: Under normal conditions, the prevailing wind is collected by the air inlet openings and turned 90° to the below room. The system will ventilate the room no matter about the quality of sun radiation, as it is not necessary to open the fan for normal conditions.
- For Sunny Conditions: The high-efficiency polycrystalline solar panel is optimized for sunny weather, so more power is generated on sunny days. In hot sunny days, extra ventilation may be required. The solar radiation powers the fan to provide additional ventilation to overcome the heat gained internally. It will provide constant supply of ventilation rates by the fan guidance even when there is no wind.
- Fully Automatic Controller: The controller includes three settings for the solar powered fan, full speed controller: which allows the system to automatically select the maximum available power of the fan for very hot conditions. The half fan speed: it controls the speed of the fan to its half speed for normal conditions, and off: which shuts the volume control damper in cool weather. The system monitors the output power from the solar panel every 5 milliseconds and changes its configuration to maximize the power available. With the normal solar panel connection, a power generation of 12V from the solar panel will provide approximately 100 l/s of extra ventilation. Under low sunlight conditions, the system shuts down the output to the fan to prevent low power from damaging the fan[28].

c) Extract version

The operation of the solar power wind catcher system can also be used in the extract mode using the same power supply and power transmission but system is used mainly as extract but still allows the fresh air to enter one

[28] Ibid

side of the system to provide the make-up air to replace the air removed by this form of powered extract.

Figure 3- Solar powered wind catcher extract version[29]

3-3-1-8 Natural ventilation and lighting wind catcher

The recent development to the innovative wind catchers is providing natural light in addition to natural ventilation; this is done by adding sun catcher dome to the top of the wind catcher system. This system introduces natural daylight to the interior through sun pipe from the roof into the building below it (figure 3-14).

Figure 3- Application of natural light and ventilation wind catcher in school[30]

Sun pipe system maximizes the concept of natural lighting by reflecting sunlight down through an aluminum tube. This innovative natural lighting and ventilation system applied at larger scale in commercial and industrial scale. It can be applied in Houses, schools, Shops, and Offices and also it is an ideal solution also for toilets and kitchens.

a) *System components*

The system is composed of some elements combined together to permits natural daylight and ventilation. Sun catcher systems are manufactured from 400mm to 1500mm sizes in both circular and square formats. Each system is carefully sized to meet both the ventilation and day lighting requirements of the room[31] (figure 3-15). It is composed of:

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[29] abs-sola-boost, extract version, accessed 2008, http://www.monodraught.com/other-products/abs-sola-boost/extract-version.php

[30] **Monodraught Ltd**, September 2006, natural ventilation systems, company profile catalogue. PDF, p25.

[31] Monodraught Ltd, SunCatcher, accessed 2008, http://www.sunpipe.co.uk/suncatcher/index.php

- A polycarbonate top dome: This dome is preserves the light pipe against dust and its prismatic polycarbonate ceiling diffuses light into the tube then to the space below.
- A sun pipe: It consists of a 230mm diameter mirror finished, highly reflective aluminum tube to reflect the sunlight and even normal daylight, down to the room.

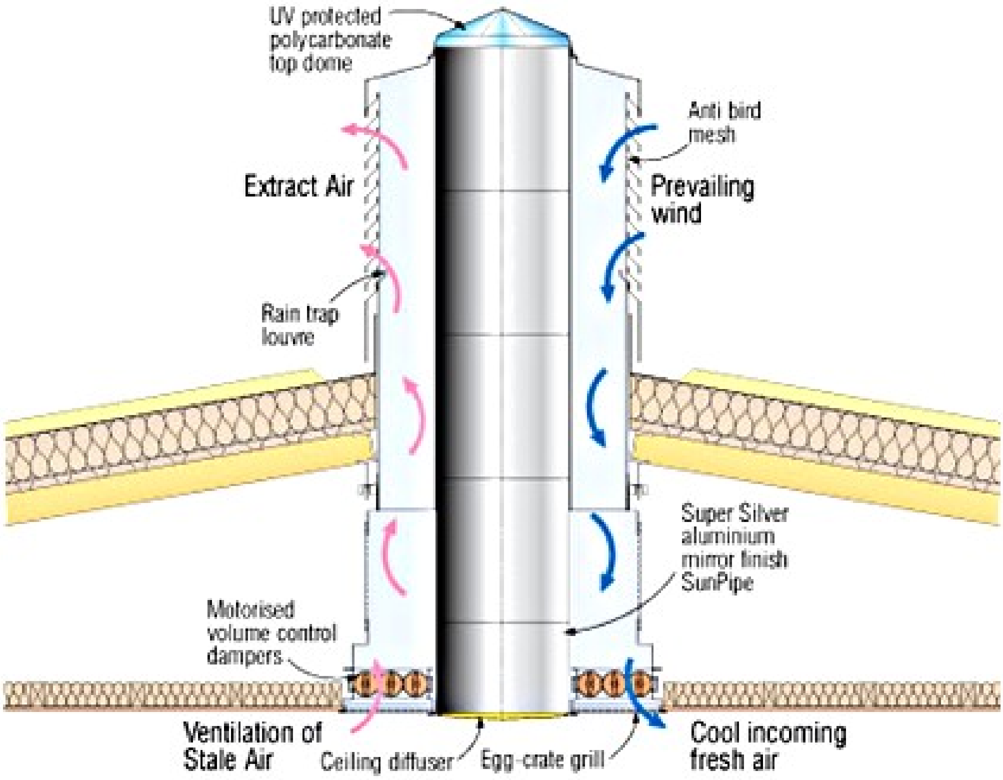

Figure 3- The sun catcher system components[32]

b) System properties

The sun capture system is an alternative natural ventilation system to roof lights and skylights. It considered an ideal method for providing natural ventilation to the internal commercial spaces (figure3-14), it has the following properties:

[32] **Monodraught Ltd**, September 2006, natural ventilation systems, company profile catalogue. PDF, p24.

- Energy free process: The sun catcher system provides energy free natural lighting and natural ventilation to internal spaces especially in summer months.
- Provide night-Time Cooling: The dampers could be programmed to fully open at night- time during summer months to allow the prevailing wind movement to force fresh air down into the room below. This can achieve the cleaning effect by removing pollutants and odors from the room.
- Low operation system costs: It has a low operation costs and with no running costs for internal natural ventilation and day lighting.

3-3-1-9 System application

Imperial College library, London

The library is on the top floor with a full height glazing and suffered for many years from overheating in summer months and mechanical ventilation system could not cope. In summer 2004, Windcatchers natural ventilation systems were the chosen strategy to overcome the overheating problem due to their energy saving features in addition to improvement of health and comfort aspects.


Figure 3- The solar-wind catcher system in BMW head offices[33]

[33] Ibid, p25.

Figure 3- ***View of the Windcatchers from outside on the*** *Imperial College library roof*[34]

Figure 3- Interior view ***of the Windcatchers diffusers on the ceiling of the library***[35]

3-3-2 Double Skin Façades

Double skin façade is considered one of very promising energy efficient façade concepts that have been developed over the last few years. It has gained a lot of popularity throughout the world, due to its characteristics such as transparency,

[34] **Monodraught Ltd** , August 2007, natural ventilation systems, company profile catalogue. PDF, p12.
[35] Ibid

durability, sound insulation, and heat insulation. The most important feature for the double skin facades that will be introduced is providing natural ventilation, sun protection, and passive cooling efficiency.
Double skin facade general concept is similar to exterior shading systems as solar radiation loads are blocked before entering the building and the heat within the intermediate space between the double skins drawn off through the exterior skin by natural or mechanical ventilate means. The following section explains the concept of double Skin Facades, main components, and its historical development. The double skin façade can offer up to 9 degree Celsius[36] lower room temperatures than the standard façade with outward openings. It could be defined as: “a façade covering one or several stores constructed with multiple glazed skins. The skins can be air tighten or not. In this kind of façade, the air cavity situated between the skins is naturally or mechanically ventilated”[37].

3-3-2-1 Historical overview

Double skin facades are not a new approach, it passed historically through four different stages from the beginning of the 20th century where the double skin façade was considered engineering solutions. Passing over the Second World War during the 40's, the modern glass architecture was developed after the Second World War; the US is the main direction of this development, the complete envelope construction idea has been suggested by the American engineer Buckminster Fuller. The idea was based on putting various buildings under one translucent dome - a kind of "air bubble" - that would assure protection from the environment[38].
Then during the energy crisis in the 70th the designers’ main direction of thinking was how to reduce the energy consumption of the buildings. This fact creates the ability for developing the exhaust ventilated façade. The development of the facade has additional single glazing on the interior side of a conventional curtain wall. So, these double glazing walls will work against energy loss and sun reflection to prevent over heating. Beside, a solar shading system is positioned in the cavity between them. Until now In the 90’s the idea of double skin façade was widely used all over the world in commercial buildings with increasing the environmental concerns.
These different in stages will be explained according to the surrounding circumstances and according to different purposes in the following table.

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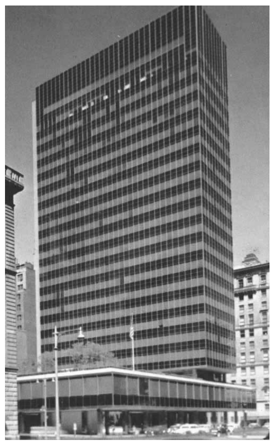
[36] **Lars H. Ringvold**, 2004, *Innovative Façade Concepts*, ALUMINUM 2004, World Trade Fair and Conference for the Aluminum Industry. PDF, Essen, p17.

[37] the Source book of the Belgian Building Research Institute [BBRI], 2002

[38] Ibid

	Overview	Case studies
Beginning of 20^{th} century	It is considered just as engineering solutions rather than architectural works. Some of the first examples are the production building for the Steiff Company in Giengen on the Brenz, designed by R. Steiff in 1903, and the Hallidie Building in San Francisco, designed by W. Polk in 1915-17. In 1928 Le Corbusier designed the Centrosoyus in Moscow with double skin facade[39]. A year later he started the design for the Cite de Refuge (1929) and the Immeuble Clarte (1930) in Paris.	 ***Hallidie Building, San Francisco*** designed by W. Polk ***(1917)***
Second World War	Introduction to double glass facades, but these examples still have some problems in energy loss in winter and over heating in summer[40]. The idea was clear in the main examples including the skyscrapers 'Lever Building (1951-52) by the architectural office SOM, the 'Seagram Building' (1954-58) by Mies van der Rohe, both in New York.	 'Lever Building, New York by the architectural office SOM (1951-52)

[39] **Wolfgang Streicher**, 2005, *BESTFAÇADE, Best Practice for Double Skin Façades*, report. PDF, p12.

[40] Ibid

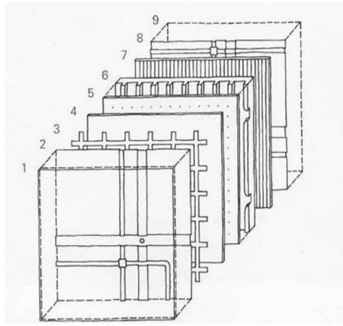
Eenergy crisis (70's, early 80's)	After the energy crisis in 1970 In 1981 the English architect Mike Davies proposed the development of a 'polyvalent wall', as a new method to control the energy flows between interior and exterior spaces by means of a multi-layered compound element changeable function layers, as a new approach to finding a solution. This innovative idea is still leading today many research programs[41]. During the 80's this type of facades gain popularity due to its environmental concerns.	
The end of the 20th century(90th)	Renzo Piano Building Workshop and Christoph Kohl Becker developed the environmental concerns in the Debis headquarters in Berlin, 1999. The external skin is associated with rotating glass louvers. They create a thermal buffer in winter when they are closed, but in summer, in an open position, external air can flow freely in the cavity.	 ***Debis headquarters in Berlin*** *Figure 3- Historical development of double skin facades*[42]

Table 3- Historical overview on the stages of double skin facades

3-3-2-2 Main components

Double skin façade construction consists of: *outer glazed façade* to provide weather protection and sound insulation, *intermediate space (air cavity)* which is used to protect thermal impacts on the interior façade by presence of shading louvers and *interior façade*[43]. These compositions with each other can have a

[41] Ibid

[42] Building performance references, Double-skin façades and natural ventilation performance, accessed 2008,
http://gaia.lbl.gov/hpbf/perfor_c.htm#3

[43] Belgian Building Research Institute. 2002. Source book for a better understanding of conceptual and operational aspects of active facades. Dept of Building Physics, Indoor Climate and Building Services, Belgian Building Research Institute. Version no. 1. Available from Internet: <http://www.bbri.be/activefacades/index2.htm>.

significant performance in the natural ventilation concept (figure 3-20). They are described as follows:

1. *Exterior façade*

   It can be made of single or laminated glass with exterior air inlet and outlet openings controlled manually or automatically and can be fully glazed.

2. *Air cavity*

   It can be totally natural or mechanically ventilated. The width of the cavity can vary depending on its function between 20 cm to more than 2m[44]. This width influence the way that the façade air flow rates is maintained. The cavity can be closed or opened by motor-operated vents at the top and bottom, which are controlled by thermostats.

3. *Automatically controlled shading louvers*

   Blinds or roller shades are integrated inside the air cavity for enhancing the solar insulation. It used to extract the solar gain before it reaches the interior space. It could be manually or automatically controlled if sensors are presented to improve the shading coefficient.

4. *Interior façade*

   It considered as the insulating double glazing unit, always this layer is not completely glazed. It consists of fixed or operable, double or single-pane windows to allow natural ventilation to the interior space.

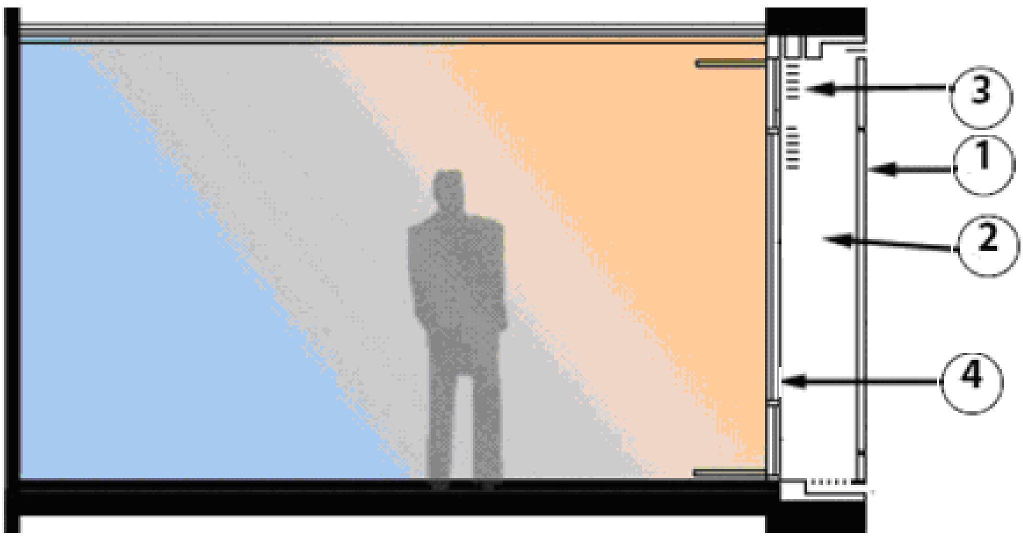


Figure 3- Main components of double skin façade[45]

[44] **Harris Poirazis**, 2004, *Double Skin Façades for Office Buildings,* A literature review, report. PDF, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology ,Lund University,

[45] LBNL, High- Performance Commercial Building Facades, Technological Solutions, Double skin Facades and Natural Ventilation, accessed 2007,

3-3-2-3 Classification of double skin facades

There are various approaches for classification of double skin facades, it could classify according to:

- Geometry of the cavity,
- ventilation in the cavity (Natural, Fan supported, Mechanical), or
- The air flow in the cavity.

a) *Classification according to geometry of the cavity* [46]

i) Multi storey double skin façade

In this case no horizontal or vertical partitioning exists between the two skins. The air cavity ventilation depends on openings near the floor and the roof of the building as inlet and outlet openings (figure 3-21). In this case the air cavity can extends a large height in the façade; it is extended around the whole building without intermediate partitions. For winter conditions, the façade openings at the top and bottom can be closed creating solar gain. While in summer the cavity is kept opened to cool down the air inside it and so the interior.

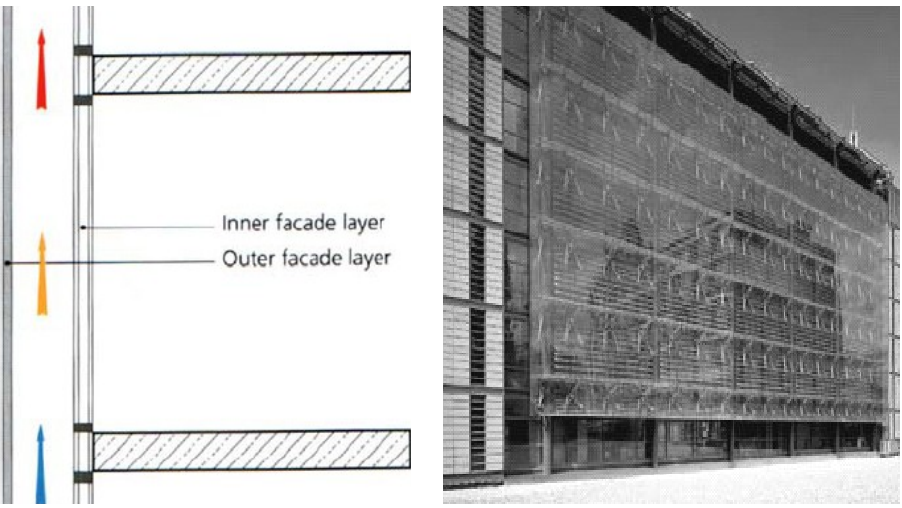


Figure 3- main idea of air movement of air in corridor Double Skin Façade[47]

ii) Corridor double skin façade:

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http://gaia.lbl.gov/hpbf/techno_c1.htm

[46] **Harris Poirazis**, 2004*Double Skin Façades for Office Buildings,* A literature review, report. PDF, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology ,Lund University, P31.

[47] Ibid

In this type, there is a horizontal intermediate partition between the two skins in each floor. Horizontal partitioning is created necessary for acoustical, fire security and ventilation reasons. The cavity inlet and outlet openings are placed near the ground and ceiling respectively, and the openings are placed in a diagonal form on every level to prevent mix of polluted air removed from the lower floor with the fresh air supplied to the next floor (figure 3-22).

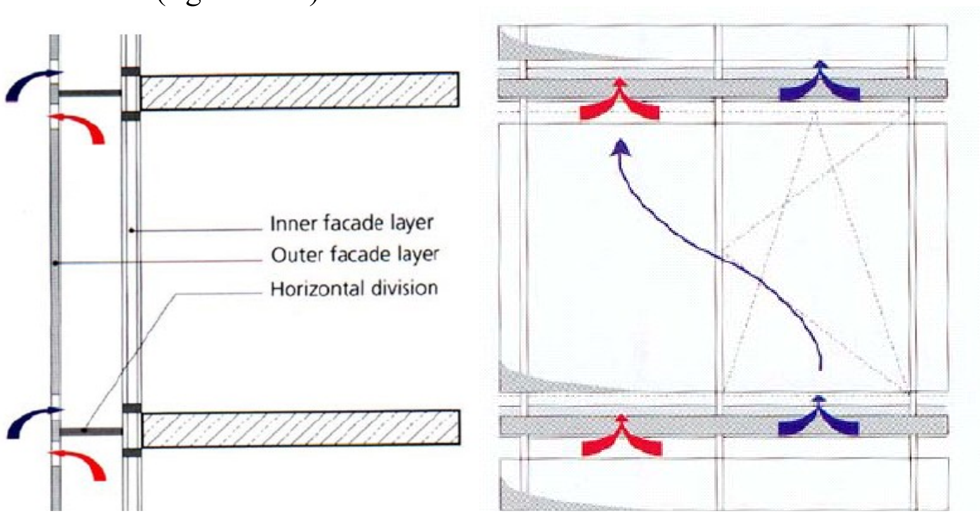

Figure 3- main idea of air movement of air in corridor Double Skin Façade[48]

iii) Box window type

In this case horizontal and vertical partitions divide the façade into small and independent boxes. The air cavity is divided horizontally and vertically at a module for each façade (figure 3-23). The inlet and outlet openings are on the same module of the façade. It is mostly applied in high external noise regions, as it considered the most efficient sound insulation type; this type is also suited for buildings need high degree of privacy.

[48] Ibid

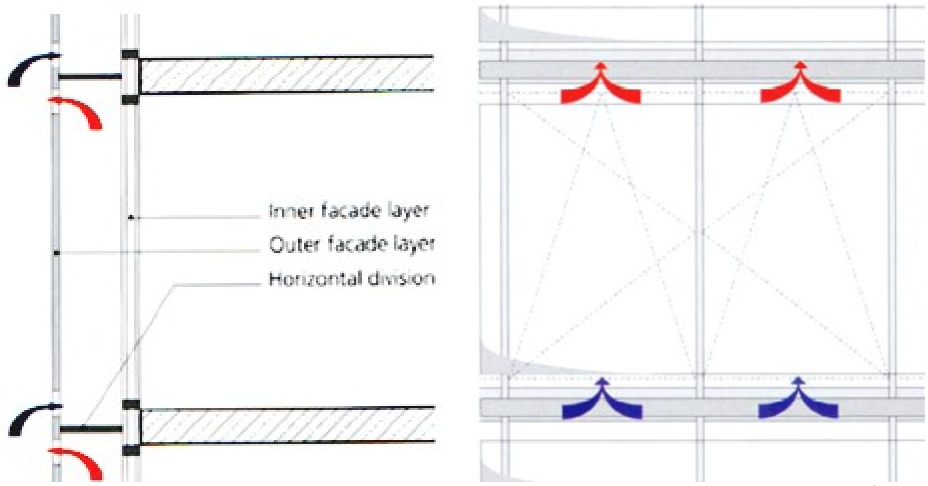

Figure 3- main idea of movement of air in Box-window Double Skin Facade[49]

iv) Shaft box type

This type consists of a series of box windows placed in the façade; these boxes are connecting with continuous vertical shafts situated in the façade extended to a number of stories to enhance the stack effect. The façade layout consists of an alternation of box windows and vertical shafts linked by means of bypass openings. The stack effect draws the air from the box windows into the vertical shafts and from there up to the top (figure 3-24). This system is also suited for buildings need high level of sound insulation. Due to the limitations in the height of stacks, this system is recommended for low-rise buildings.

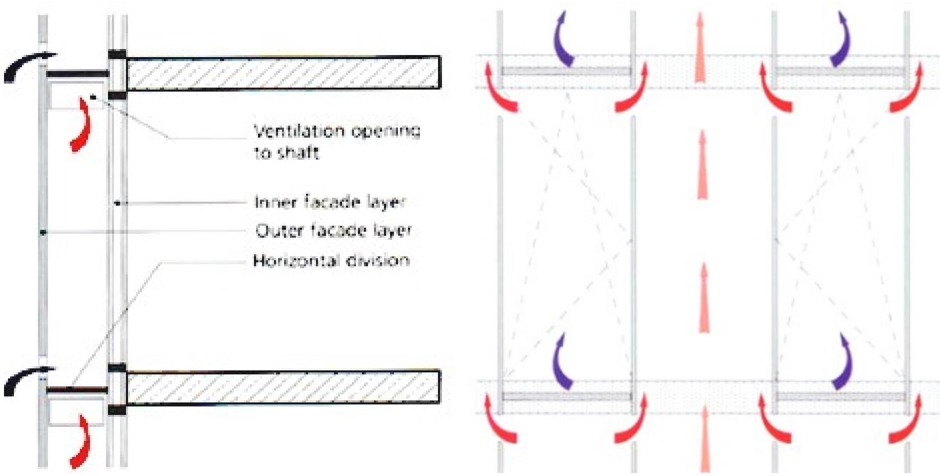

Figure 3- main idea of air movement in shaft box double skin façade[50]

[49] Ibid.

[50] Ibid.

b) Classification according to the air flow in the cavity

This classification of Double Skin Facades depends on the nature of the air flow into the intermediate space. It is classified into[51] :

i) Air supply façade

In this type the openings in the outer façade supply air into the cavity, then air is supplied into the interior space.

ii) Air exhaust façade

In this case the air flows from the interior space through the cavity to outside.

iii) Air curtain façade

The air flows in this case in the same side, as there is no exchange of the air between the inside and the outside spaces, it could be exterior or interior air curtain (figure 3-25).

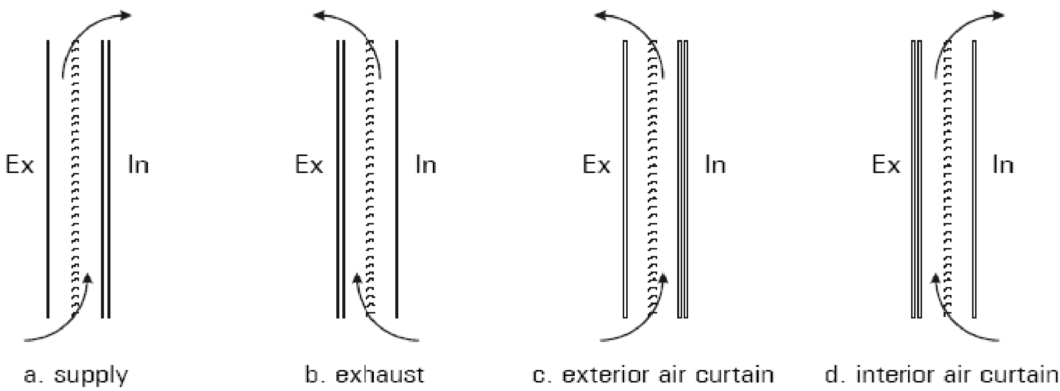

Figure 3- Types of double skin facades according to the airflow in the cavity[52]

c) Classification according to the ventilation system

This classification is according to the driving force of the air flow of the façade:

i) Mechanically ventilated systems

In these systems air flow is generated by fans adjusted into the air cavity, it considered to be much more controllable.

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[51] **Vijaya Yellamraju**, 2004, E*valuation and Design of Double Skin Facades for Office Buildings in Hot Climate*s, Master thesis. PDF, p20.

[52] Ibid, p21.

ii) Naturally ventilated systems

The driving forces in this system are thermal bouncy and wind pressure difference, so the airflow rate in this system should be controlled according to the outside climatic conditions. It may not be very suitable for extremely hot climates and also places where the temperature difference between the outside and inside space is not great enough to allow the stack effect to take place.

3-3-2-4 Heat extraction idea

The concept of solar heat gain control is achieved through shading devices and intermediate blinds that reflect back some of heat radiation which is entered to the cavity through the outer façade. Some of the heat released inside the cavity is then extracted out of the cavity through natural or mechanical ventilation. The remaining solar radiations are absorbed by the blinds (figure 3-26). Thus, there is no heat will be transferred into the interior space. This will lead to decreasing the interior cooling loads.

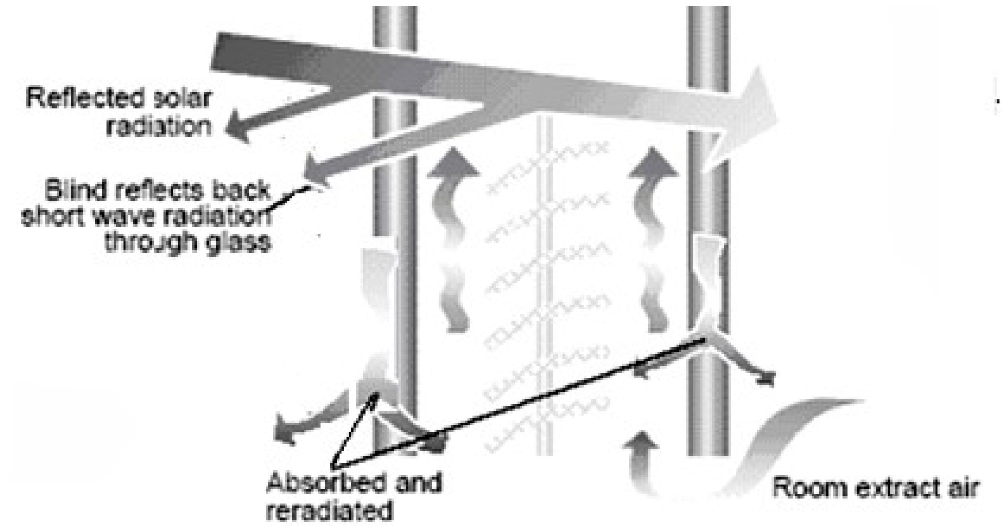

Figure 3- Heat transfer idea through double-skin facade [53]

These issues have a great effect on the heat extraction performance in the double skin facades:

- Glazing materials of internal and external facades
- Type and position of shading devices
- The cavity geometry
- Size and position of the inlet and outlet openings of the cavity

[53] ibid, p35.

a) Glazing materials of internal and external facades

Materials used in the double skin facades have a significant influence in the cavity heat extraction, ventilation and interior cooling process efficiency. Virtually any type of glass can be applied in double skin facades, depending on the environmental conditions (figure 3-27). Nevertheless, it is now possible to make custom glass for each and every climatic condition. The selection of pane types depends on the double skin façade type (depth and height of the cavity), the climatic conditions (location of the building) and the HVAC strategy (natural, fan supported or mechanical ventilation of the cavity).

Figure 3- Internal and external glazing of the Double Skin Facade[54]

Different panes materials and placement (in the inner or outer facades) can influence internal air temperature and air flow rate in case of a naturally ventilated cavity. That is why it is necessary for architect to have some knowledge about properties of glass materials[55]. Following the most common pane types used for double skin facades for the internal and external skins for better natural ventilation process.

i) Internal skin (façade)

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[54] **Lund Institute of Technology**, January, 2003, *Glazed office Building Energy use and indoor climate Project,* Department of Construction and Architecture, Lund, Sweden,. http://www2.ebd.lth.se/ebdhome/avd_ebd/main/personal/Project_home_page/default.html

[55] Double Skin Facades, Glass in Building, accessed 2008, http://www.glassinbuilding.com/double_skin_facades/

To have the most efficiency in natural ventilation, the internal skin could be consist of a thermal insulating double or triple float glass pane[56]. The gaps between the panes are filled with air, argon or krypton for more insulation. Moreover, it could be made from clear, low emittance coating, solar control glazing, as the Low-emittance coatings on the interior glass façade reduce radiant heat gains to the interior.

ii) External skin (façade)

It is usually made of single glass pane; it can be also a laminated glass instead. The most common exterior layer is a heat strengthened safety glass or laminated safety glass. For higher degree of transparency, double flint glass can be used in the exterior layer, since the number of the layers and the thickness of the panes are greater than in single skin construction[57]. However, the flint glass is more expensive than the normal one. Using Low-E coatings as external layers is not suggested as it can increase the temperature inside the cavity since they decrease the heat loses to the outside during the summer so it may be possible to overheat the cavity.

An experimental study was done by comparing 4 different double skin facade cases where different panes were applied in order to calculate the airflow, the temperatures in different heights of the cavity and other properties[58]. Table 3-1 is a description of panes applied for different types of double skin facades. Transmittance value (U-value) was measured for each case, as the transmittance value represents the overall thermal conductance from the outside to the inside covering all modes of heat transfer. It is the rate of heat flow over unit area of any building component through unit overall temperature difference between both sides of the component. Thus, as the U-value decrease gives the better solar resistance quality.

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[56] Lund Institute of Technology Project, January, 2003, *Glazed office Building Energy use and indoor climate,* Department of Construction and Architecture, Lund, Sweden. http://www2.ebd.lth.se/ebdhome/avd_ebd/main/personal/Project_home_page/default.html

[57] **Berhard Oesterle, Rolf-Dieter Lieb**, 2001, *Double-skin Facades: Integrated Planning*, Published by Prestel,

[58] **Harris Poirazis**, 2004, *Double Skin Façades for Office Buildings,* A literature review, report. PDF, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology ,Lund University, P44.

Glazing type	Case 1	Case 2	Case 3	Case 4
Outer glazing	**8mm clear float glass**	**8mm clear float glass**	**8mm clear float glass**	**6mm solar control glass**
Intermediate glazing	**4mm clear float glass**	**4mm clear float glass**	**6mm solar control glass**	**4mm clear float glass**
Inner glazing	**4mm clear float glass**	**4mm low-e glass**	**4mm clear float glass**	**4mm low-e glass**
U- values	**The highest U-values**	**Lower U-values than case 1-3**	**slightly lower U-values than case 1**	**Lower U-values than case 1-3**
Solar resistance	**Give less performance in the solar resistance**	**High solar resistance than case 1-3**	**Higher solar resistance than case 1**	**Has the highest solar resistance**
Air in the cavity	**Air in the cavity will have highest temperature**	**Less temperature than case 1-3**	**High temperatures but slightly less than case 1**	**Lowest temperature**
Interior space temperature	**It will increase**	**Low tempreture**	**Slightly less than case 1**	**Lowest temperature**
Natural ventilation strategy	**Not effective in natural ventilation strategy**	**Perform better than case 1-3**	**it will perform better than case 1**	**The most effective in natural ventilation**

Table 3- Description of glazing applied for different types of double skin facades[59]

From the previous table: to decrease the temperature of the air in the cavity is to use solar control glass and low-e glass in the interior glazing facades not in the exterior façade to decrease the heat loss to the interior.

b) Type and Position of shading devices

After selecting the appropriate glazing to the internal and external facades, so for more solar protection, shading devices are placed inside the cavity between the inner and outer facades. The material choice, the geometry and the positioning of the shading devices are important for the type of air flow,

59 Ibid.

the thermal properties of the cavity and for the visual comfort of the occupants. Venetian blinds or roller shades are considered probably the most popular shading devices that can be placed inside the cavity for double skin façades[60] (figure 3-28).

Blinds material properties (absorbance, transmittance and reflectance) should be considered in the design stage, since they influence the type of air flow and the thermal properties of the cavity[61]. Additionally, the position of the shading within this space also plays a major role in the distribution of the heat gains in the intermediate space. The exact position of the blinds inside the cavity should be calculated since the closer the blinds are to the interior pane, the warmer the inner layer gets. So it will be better placing movable sun shading devices in the intermediate of the cavity whose operation can be manual or automated for providing sun protection and improve the temperatures on the interior surface all over the year.

Figure 3- Venetian blinds in the intermediate cavity in the double skin facades[62]

It is claimed that the shading should be positioned in the outer half of the intermediate space. It should not be too close to the outer pane of glass, either, so as to avoid excessive heating up and thermal loading of this layer. Thus, for this reason and for proper ventilation purposes, it is recommended a minimum distance of 15 cm[63] between the sun shading and the external skin of the façade.

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60 Ibid

61 Ibid

62 Lund Institute of Technology, January, 2003,*Glazed office Building Energy use and indoor climate Project,* Department of Construction and Architecture, Lund, Sweden.
http://www2.ebd.lth.se/ebdhome/avd_ebd/main/personal/Project_home_page/default.html

63 ibid

c) The Cavity Geometry

The cavity space is an important aspect for extracting the heat gained as it is connected to the outdoor air to induce natural ventilation. Moreover, solar controls and shading devices are to be placed inside this cavity. Therefore, for efficient performance of the cavity, its depth should not less than 200 to 1000 mm[64]. An air cavity depth smaller than 200 mm significantly reduces the air change rate in the room behind a double-skin façade as it is used to fresh air intake and for exhaust air from internal spaces.

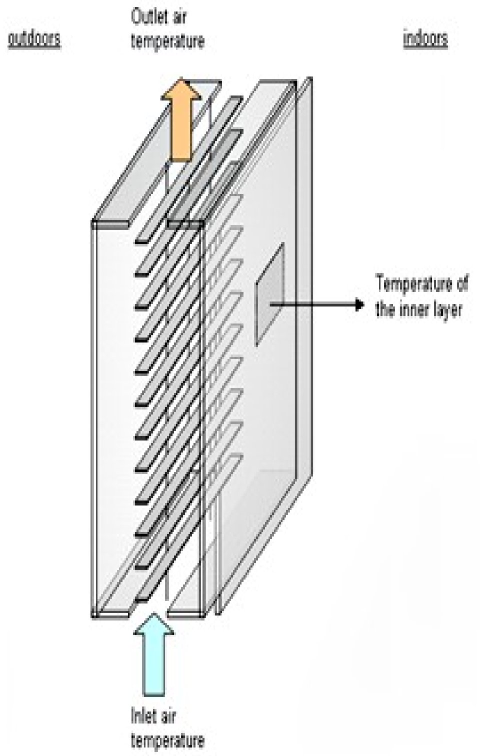

Figure 3- Cavity space components and geometry

Dimensions of the façade together with the openings determine the flow through the façade; narrower cavities result in higher flow resistance and smaller flow through the cavity and a higher increase in air temperature in the cavity[65]. Thus, in cold climates it is more suitable to use narrow cavities to limit the flow and increase the cavity temperature. While in the hot climates as the double skin façade should work as a screen for the heat gains from radiation and conduction in addition to increasing the flow rate, therefore, the cavity depth should be greater. Moreover, the cavity depth affects on the temperature of the inner layer, as airflow increases, the temperature will decrease (figure 3-29).

d) Size and position of the inlet and outlet openings of the cavity

When designing a double skin façade it is important to determine type, size and positioning of openings of the internal and external facades to the cavity. As they have great effect on the heat extraction performance by affecting on the following issues[66]:

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[64] ibid

[65] **Harris Poirazis**, *Double Skin Façades for Office Buildings,* A literature review, report. PDF, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology ,Lund University, 2004, P48.

[66] **Harris Poirazis**, 2005, *Introductory Report for the Glazed Office Buildings Project Internal Report. PDF*, Division of Energy and Building Design Department of Architecture and Built Environment, Lund

- The type of exterior openings affects the type of airflow and the air velocity in the cavity. However, openings that can be controlled are more expensive but they are very important for the façade design.
- The design position and size of the interior openings is responsible for the airflow rates in the indoors. It could be controllable windows or full height sliding or pivot doors if the cavity is used as a corridor.

3-3-2-5 Ventilation idea

Double skin facades can provide natural ventilation to the interior space and reduce the requirement for mechanical ventilation. Besides, they can improve the indoor air quality without noise, wind loads, and security constraints of naturally-ventilated single-skin façades. For the naturally ventilated double façade system, the natural ventilation strategies are driven into the building by wind pressure effect and stack effect (figure 3-30). These two strategies will be explained in the following section.

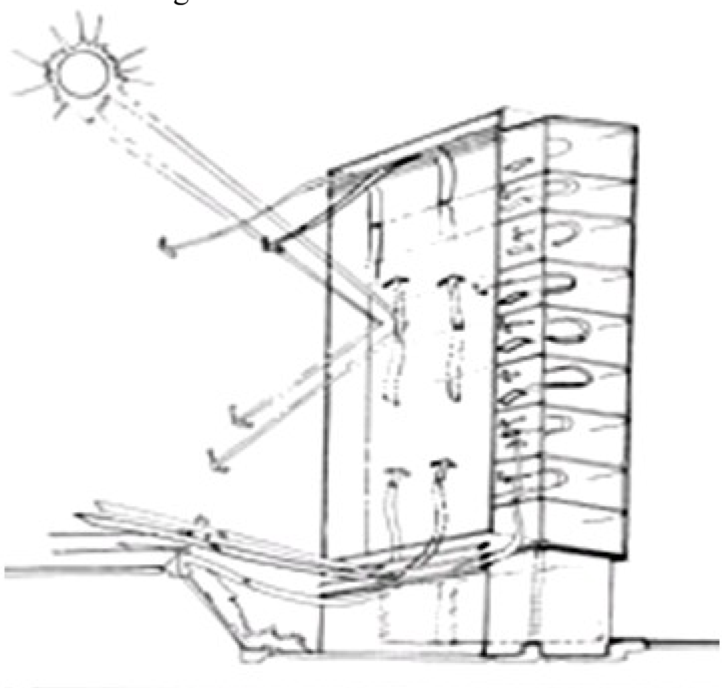

Figure 3- Sketch of the idea of natural ventilation in double skin façade building[67]

a) Wind Pressure ventilation

Wind pressure occurs when wind flows over the exterior façade and creates pressure difference between inlet and outlet openings which leads to internal air movement. Cross ventilation can also occurs if there are

University, Lund Institute of Technology, p77.

[67] Sustaining Tower Blocks, accessed 2007, http://www.sustainingtowers.org/SOA-present.htm

operable windows in the other side of the space, the warm air inside the space will move towards the openings on the double skin façade. Consideration must be given to: the pressure differences surrounding the building, the floor height, the position of the entrance, the position of every room in the building as well as the airflow resistance of the building[68]. Moreover, wind pressure ventilation may interfere with buoyancy driven natural ventilation. In high buildings where significant wind pressure differences occur over the widely spaced facade inlet and outlets, both systems will typically occur (figure 3-31).

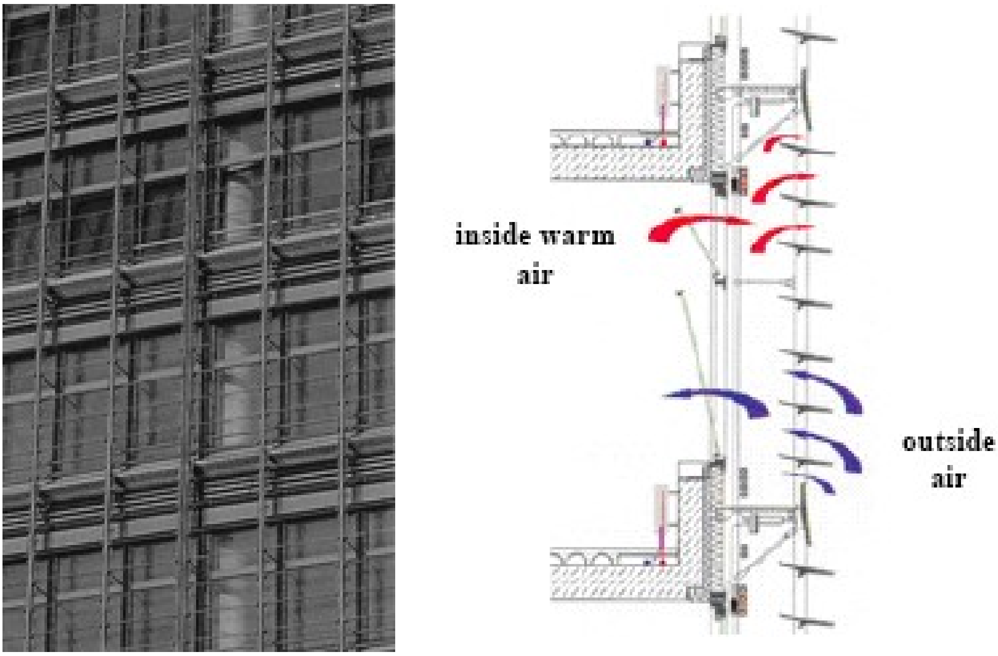

Figure 3- Wind driven natural ventilation in double skin façade (debis Headquarter postdamer platz)[69]

b) Stack-driven ventilation strategy

As air flows into the lower inlet, it is heated and becomes less dense, as a result, stack effect will be occurred and the air will flow from the outlet

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[68] **Paul Roelofsen**, *Ventilated Facades Climate Facade versus Double-Skin Façade*, EUROPEAN CONSULTING ENGINEERING NETWORK report.PDF, 2002.

[69] LBNL, High- Performance Commercial Building Facades, Technological Solutions, Double skin Facades and Natural Ventilation, accessed 2007, http://gaia.lbl.gov/hpbf/casest_b.htm

removing heat[70]. The effectiveness of ventilation driven by stack effect is determined by the exterior air temperature, height between the inlet and outlet openings, size of openings, and temperature of the louvers. Stack effect is more clearly in the shaft-box façades, as the air passes through multi-story vertical glass chimneys to openings at the top of it. The vertical height of the glass chimney creates stronger uplift forces due to the stack effect. However, the upper stories of the shaft could become hot, leading to increase heat gains and thermal discomfort. Idea of wind driven and stack ventilation strategies is clear in the next example the (GSW) Headquarters in Berlin (figure 3-32).

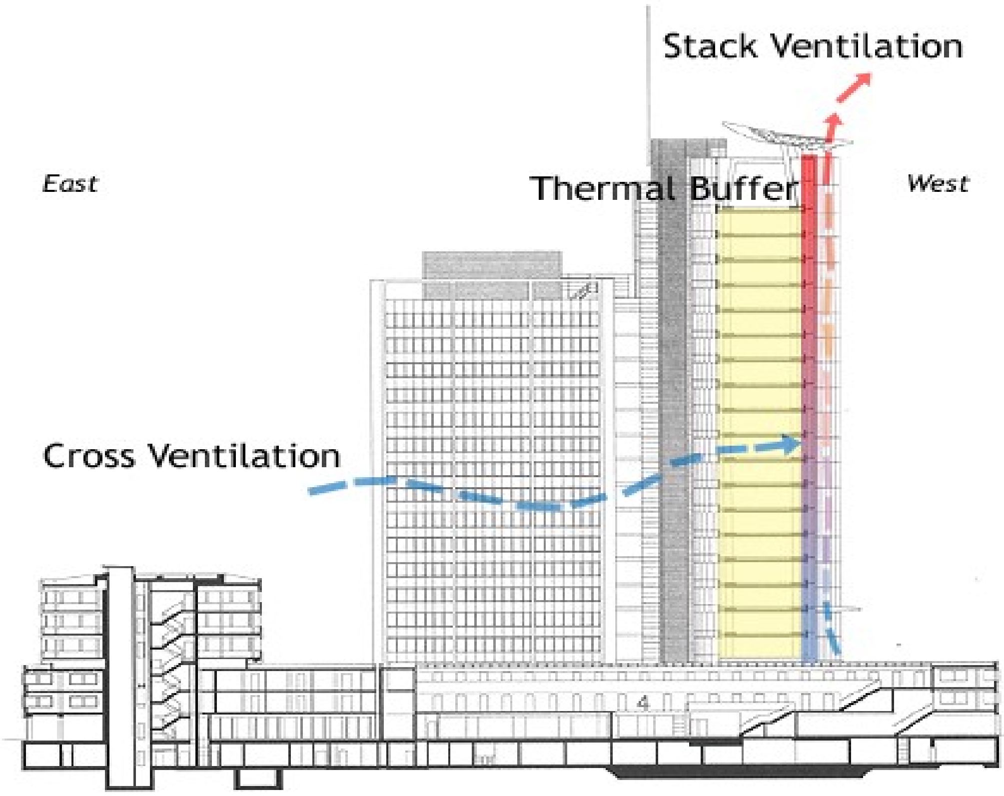

Figure 3- Sectional diagram showing wind- and stack-induced cross ventilation in double skin façade (Gemeinnützige Siedlungs-und Wohnbaugenossenschaft mBH (GSW) Headquarters, Berlin)[71]

3-3-2-6 System performance

[70] **Harris Poirazis**, *Double Skin Façades for Office Buildings*, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology ,Lund University, 2004, P37.

[71] LBNL, High- Performance Commercial Building Facades, Technological Solutions, Double skin Facades and Natural Ventilation, accessed 2007,
http://gaia.lbl.gov/hpbf/casest_f.htm

a) Summer performance

In very hot summer, heat inside a building is mainly produced by the penetration of the sun through transparent surfaces. In double skin facades when solar radiation is high, blinds within the cavity provide excellent solar control protecting the air inside the cavity from exterior environmental conditions. This can only cool the air inside the cavity by several degrees lower than the actual external temperature. Moreover, the cavity has to be well ventilated to prevent internal overheating (figure 3-33).

The external opening vents can be left open all night for improving the ventilation criteria and passive cooling. This natural ventilation process works during day time hours, but because of the high external temperatures it does not obtain the same cooling effect as at night[72]. The outer skin openings could be manually or automatically opened and closed. Double skin facades can provide interior space cooling by night ventilation; this will lower the interior temperature for the whole day providing thermal comfort and improve the air quality for the occupants. Moreover, night cooling can reduce the heat storage of the building structure materials and furniture.

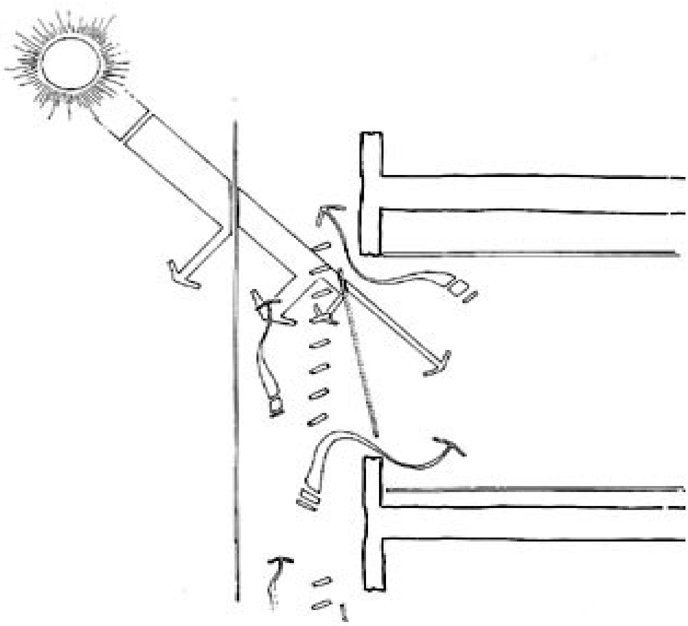

Figure 3- Idea of ventilation through the façade cavity in summer[73]

[72] **Brager, G.S., R. deDear**.. "A Standard for Natural Ventilation." ASHRAE Journal 42, 2000, p 21-29.

[73]Analysis, Double skin facade, natural ventilation, accessed 2008, http://www.battlemccarthy.com/Double%20Skin%20Website/analysis/doubleskinanalysis.htm

Mechanical fans could be also placed at the top of the cavity for better ventilation performance. This will significantly reduce the internal temperatures than outside temperature[74].

b) Winter performance

Double skin facades are differing from other traditional facades, beside their ability for natural ventilation in summer; it could make use of sun rays in winter. In contrast with summer, it would prefer to prevent solar rays from entering the room, in winter opposite process is happened, allowing the sun's heat to enter the building and remain inside. The air located in the cavity between the two glass skins is heated by sun rays in case of closing the outer openings; this leads to heat the air in the cavity to enter the space[75] (figure 3-34). This heated air reduces heat loss from the building and significantly improves the U-value of the building and lower the internal heat loss.

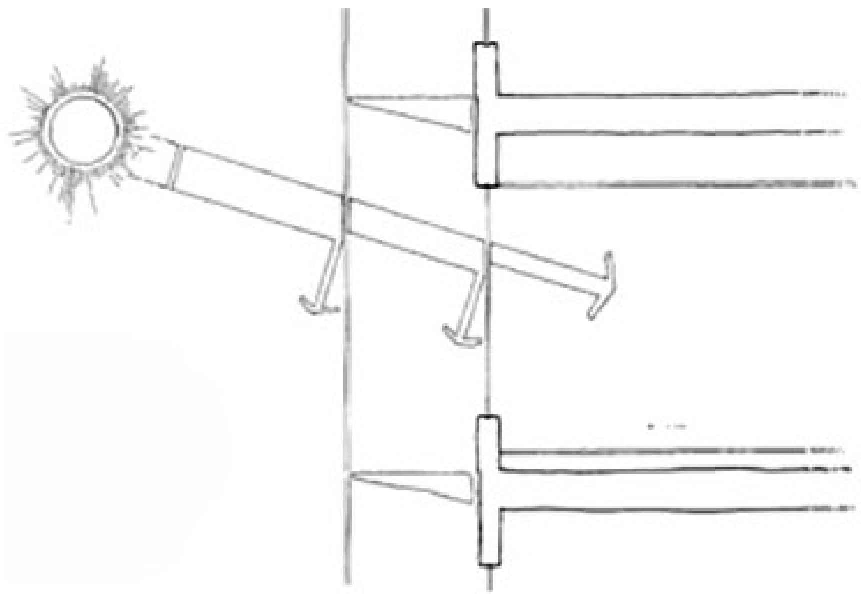

Figure 3- Winter performance in double skin facades[76]

[74]LBNL, High- Performance Commercial Building Facades, Technological Solutions, Double skin Facades and Natural Ventilation, accessed 2007,
http://gaia.lbl.gov/hpbf/techno_c2.htm

[75] Ibid

[76] Analysis, Double skin facade, natural ventilation, accessed 2008,
http://www.battlemccarthy.com/Double%20Skin%20Website/analysis/doubleskinanalysis.htm

3-3-2-7 Advantages and disadvantages of Double Skin Façades

a) *Better acoustic insulation and improve noise protection*
It considered one of the most important aspects for the double skin facades; it could be an excellent solution for external sound insulation, as it reduces the transmission from the outdoor sources in heavy traffic areas.

b) *Reduce the cooling and heating loads*
As the double skin facades provide natural ventilation to the interior, and as the external layer considered as an insulation wall to the interior space, so it can significantly reduce the cooling loads which leads to reduction of air conditioning costs. Double skin buildings are able to reduce energy consumption by 65%, running costs by 65% and cut CO_2 emissions by 50%[77].

c) *Provide thermal insulation*
Double skin façade system can provide greater thermal insulation due to the outer skin both in winter and in summer. During winter the outer skin reduces the airflow speed to the interior, while during summer it extracts the warm air inside the cavity preventing overheating problems.

d) *Provide transparency*
It provides transparency for glazed buildings especially commercial and office buildings by using bigger portions of glazing surfaces. Thus, it permits internal natural lighting almost all the day hours which will reduce the electric lighting.

e) *Low U-Value and g-value*
The two main advantages of the double skin façades are the low thermal transmission (U-Value) and the low solar heat gain coefficient (g value)[78].

f) *Low construction costs*
It has lower construction costs compared to solutions which provide the use of electrochromic, thermochromic or photochromic panes, these panes could change their properties according to climatic and environmental conditions.

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[77] Ibid

[78] **Harris Poirazis**, 2004,*Double Skin Façades for Office Buildings, Division of Energy and Building Design*, Department of Construction and Architecture, Lund Institute of Technology ,Lund University, P37.

g) Reduction of the wind pressure effects

Double skin facades can reduce the effect of wind pressure on the building especially for high rise buildings. Natural ventilation in a high-rise building could give attention to the following fears: a very force power might be required to open the room doors; the wind might stream from the room to the corridor, blowing papers; the wind might also make disturbing noises. But all these aspects are solved by the double skin construction. Thus, the double-skin façade reduces cross-ventilation problems even the upper workspaces can enjoy natural air control without having to fight wind gusts.

Disadvantages of double skin façades

a) Need higher construction costs compared to conventional façades

Double skin facades are considered to be more expensive than single skin façades, it need a proper construction to additional layer to the building and need controlling the air rate in the cavity in between the two layers which increase its construction costs[79].

b) Decrease fire protection

The exterior glazing layer reduces the ability for smoke ventilation and the air gap between the facades increases the risk of fire spreading between floors or rooms, but fire spread can be prevented in the air gap with horizontal and vertical partitions[80].

c) Reduction of building useful spaces

The intermediate cavity of the double skin façade can vary from 20 cm to several meters depending on the properties needed which results loss of useful spaces in the building. Thus, it is important to find the proper cavity width to decrease the unuseful places in the building.

d) Need additional maintenance and operational costs

Double skin facades have a higher maintenance, cleaning, servicing, and operating costs comparing to single layer facades.

e) Overheating problems if not properly designed

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79 **Harris Poirazis**, 2008,*Single and Double Skin Glazed Office Buildings, Analyses of Energy Use and Indoor Climate*, PHD thesis, Department of Architecture and Built Environment, Lund University Faculty of Engineering LTH, P 58- 61.

80 LBNL, High- Performance Commercial Building Facades, Technological Solutions, Double skin Facades and Natural Ventilation, accessed 2007,
http://gaia.lbl.gov/hpbf/perfor_c.htm

If it is not properly designed, it is possible that the temperature of air in the cavity increases and causes interior overheating. To overcome this problem, the cavity width should be well designed, the size of the ventilation openings should be increased to increase the stack effect.

f) Increasing airflow velocity

In multi storey double skin facades it is possible that the air flow velocity could be increased in the cavity incase of natural ventilated building, so the architect should calculate the outside wind pressure difference to overcome this problem[81].

g) Increasing construction weight

Additional skin increases the weight of the construction which increases the cost.

3-3-2-8 System application

RWE Tower, Ingenhoven, Overdieck, Kahlen & Partner, Essen, Germany, 1997

This building is 31-storey cylindrical tower that is depending mainly on natural ventilation. The most remarkable characteristic of the RWE tower is the use of glass double-skin on its all facades. The double skin allows natural ventilation in the tower during about 70% of the year without artificial cooling or heating.

RWE tower facades consist of inner and outer facades separated from each other by cavity of distance 50cm. The cavity can be partitioned by a movable glass panel at the partitioning wall of each individual floor. So that the wind circulating in the cavity is controlled, and in addition, controlling the sound transmission between the floors. Shading louvers, fish mouth cross section, and internal-external glazing facades are the double skin components that improve the performance of natural ventilation in this building (figure 3-35). These components will be explained as in the following section.

[81] Lund Institute of Technology, *Glazed office Building Energy use and indoor climate Project,* Department of Construction and Architecture, Lund, Sweden, January, 2003. http://www2.ebd.lth.se/ebdhome/avd_ebd/main/personal/Project_home_page/main/DoubleSkinFacades.hm

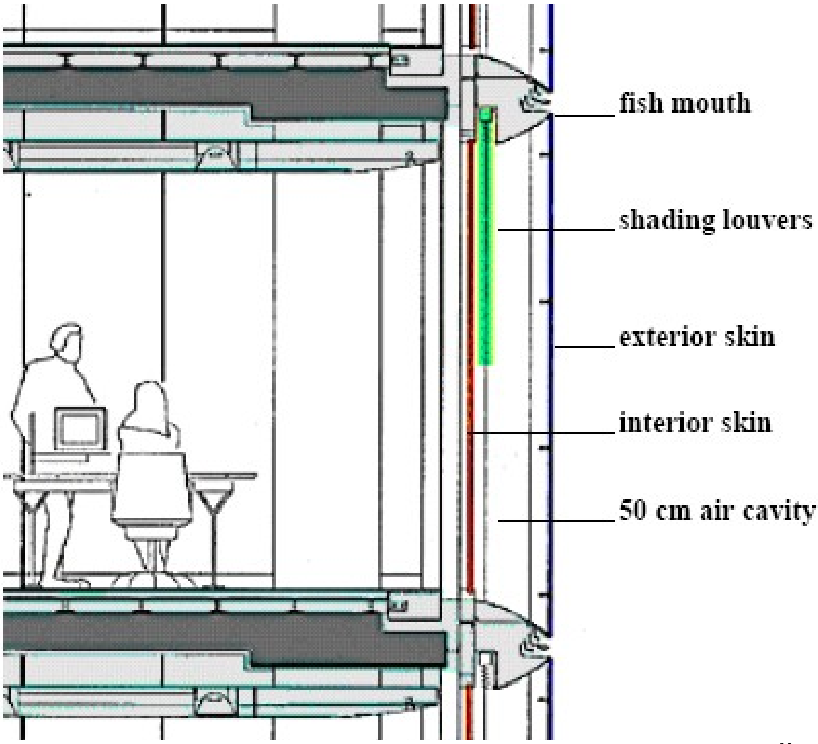

Figure 3- The structure composition of Double Skin Façade of RWE tower[82]

a) Inner and Outer glazed facades

The outer facade consists of 200cm x 360cm module made of extra clear fixed floating glazing[83].The glass is than coated with a low-E-coating in order to control solar radiation while still allowing for a clear view and natural lighting. The outer façade is continuous to the top of the building without the use of frames for the module, resulting in a lightweight transparent tower. Moreover the outer façade permits air circulation through corresponding slots. The inner facade is framing extending from the floor to the ceiling, it consist of a pair of glass panes made of iron float glass and filling the space in-between by argon gas for more heat insulation performance. It can be opened by some 15cm to control the natural ventilation[84] (figure3-36).

[82] Space Modulator: RWE Tower- Double skin Façade, accessed 2008, http://www.nsg.co.jp/spm/sm81~90/sm86_contents/sm86_e_2skin_txt.html

[83] Ibid

[84] Ibid

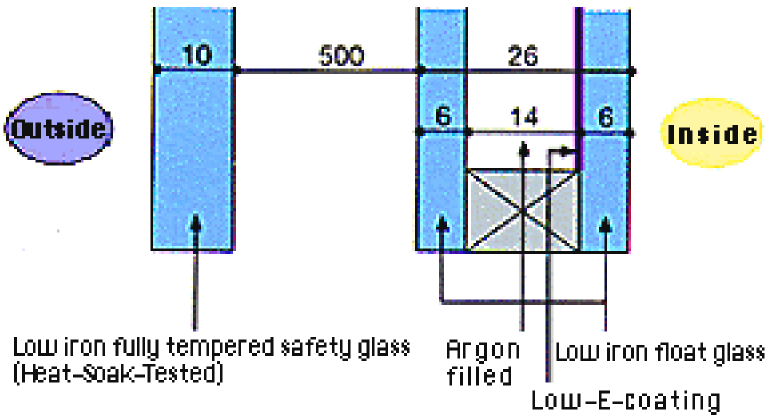

Figure 3- Composition of the Inner and Outer glazed facades[85]

b) Shading louvers

Aluminum shading louvers blinds of wide 80mm are installed inside the cavity, thy are remotely controlled. The blinds protects the inner façade from direct solar radiation and also prevent transmitting the heat to the interior of the room.

c) Fish-mouth section for absorbing and exhausting the air

Fish mouth sections are platforms which are placed in the interior space between the facades and built-in between stories connecting the inner and outer façades, as well as, they absorb and exhaust outside air. They are fixed alternately perforating the bottom and topsides as for absorbing the air to the interior cavity, small holes are presented on the upper part of some fish-mouth sections for intake the air. And the fish mouth sections which are responsible for exhausting the air are having small holes on its lower part exclusively for outtake the air, the absorbed and exhausted fish-mouths sections are placed diagonally[86] (figure 3-37).

85 Ibid

86 Ibid

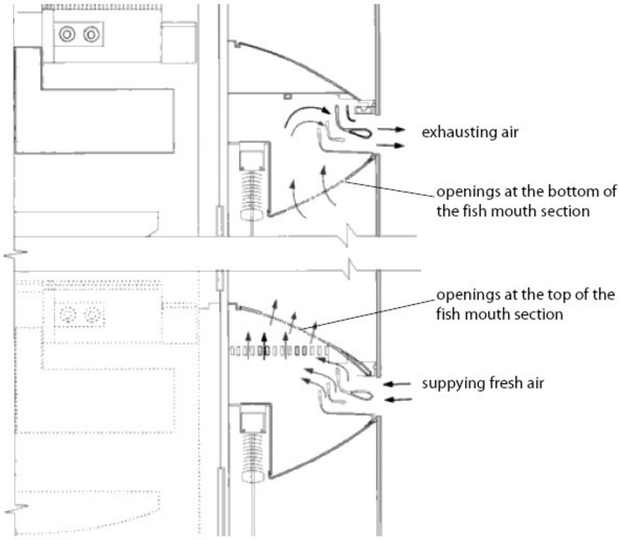

Figure 3- Cross section of the fish mouth[87]

Due to such a composition, the outside air from the intake "fish-mouth" is warmed inside the double-skin and diagonally ascends to be exhausted from the outtake "fish-mouth" at the neighboring section. This diagonal placement of the fish-mouth section aims at having longest path way for exhausting the air for increasing the air quality efficiency (figure 3-38).

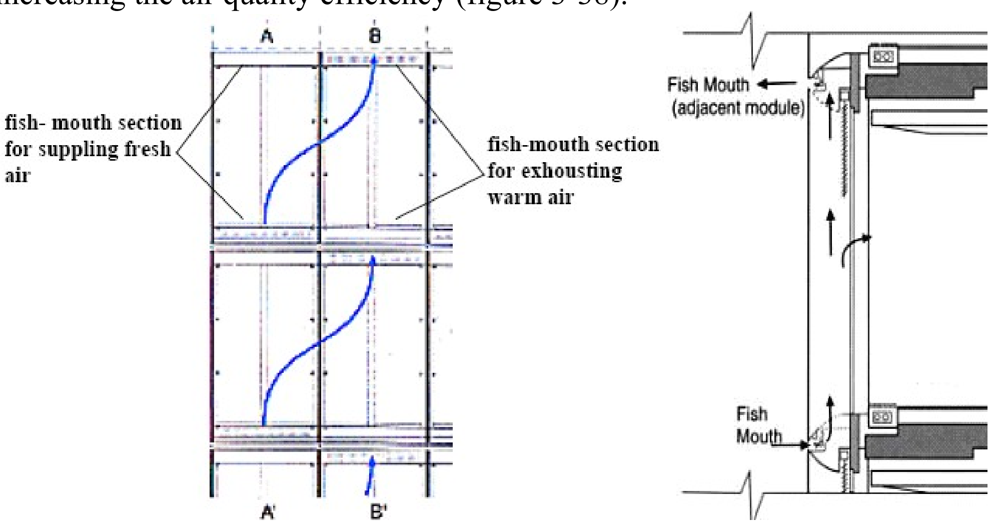

Figure 3- The diagonal performance of supplying and exhausting the air through the fish mouth tsecions[88]

[87] **George Baird**, 2001, *The Architectural Expression of Environmental Control Systems*, Published by Taylor & Francis, p202.

[88] Ibid

By raising the fish-mouth cover, it could be used as a footplate for cleaning, and is effective in preventing fire from spreading to upper or lower levels. Also, its gently curved bottom side is formed to reflect sunlight moderately. Due to the varying of the wind velocity according to the altitude, there is a difference in size between the fish-mouths sections above the 16th floor and those below it[89].

3-3-3 Interactive Façades

More complicated design approaches and technologies have been introduced to the building facades using new high-performance glazing, improved shading and solar control systems, and greater use of automated controls. These technologies are known as interactive facades, an interactive façade should respond intelligently and reliably to the changing outdoor conditions and internal performance needs. It should exploit available natural energies for lighting, heating and ventilation should be able to provide energy savings compared to conventional technologies, and at the same time maintain optimal indoor visual and thermal comfort conditions. As photovoltaic costs decrease in the future, these onsite power systems will be integrated within the glass skin and these facades will become local, non-polluting energy suppliers to the building[90].
There are so many technologies of interactive facades; the next section will explain briefly two of these facades as an approach that sould be studied in the future. These two facades are Nano vent-skin façade and Environmental responsive kinetic façade.

3-3-3-1 Nano Vent-Skin façade

Nano Vent-Skin is a conceptual personal project by Mexican-born Agustin Otegui aimed to trigger new approaches into greener and more energy efficient structures. A skin that transforms two of the most abundant sources of green energy on earth: Sunlight and Wind. The concept takes advantage of a structure's maximum available surface space. Plus, the stunning superstructure incorporates micro-organisms to soak up C02. Nano-structure components and working ideas are shown as follows:

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89 RWE Tower, Double skin, accessed 2009, http://www.hku.hk/mech/sbe/case_study/case/ger/RWE_Tower/rwe_index.html#3.4

90 **Stephen Selkowitz, yvind Aschehoug, Eleanor S. Lee**, November 2003, *Advanced Interactive Facades –Critical Elements for Future Green Buildings?,* Presented at GreenBuild, the annual USGBC International Conference and Expo.

- Outer skin of the structure that absorbs sunlight through an organic photovoltaic skin and transfers it to the nano-fibers inside the nano-wires which then is sent to storage units at the end of each panel.
- Wind turbines on the panel that generate energy by chemical reactions on each end where it mak contact with the structure. Polarized organisms are responsible for this process on every turbine's turn.
- Inner skin of each turbine works as a filter absorbing CO2 from the environment as wind passes through it[91].

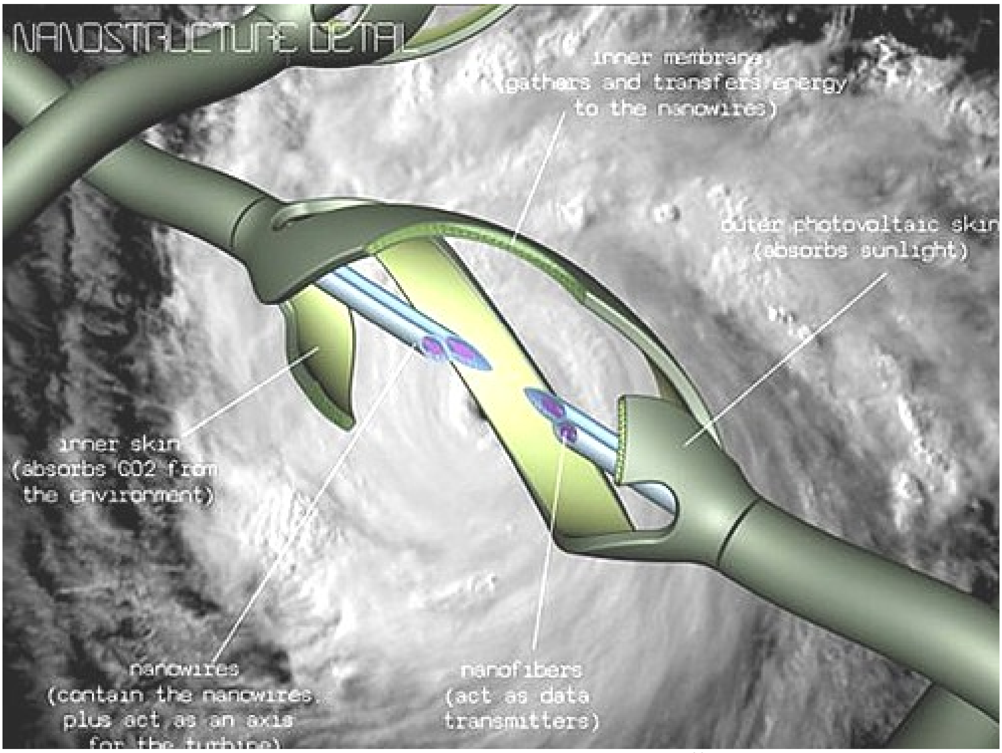

Figure 3- Nano vent structure detail[92]

In order to achieve the best outcome of energy, the blades of each turbine are symmetrically designed. With this feature, even if the wind's direction changes, each turbine adapts itself by rotating clockwise or anti-clockwise, depending on the situation.

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91 Nano Vent-Skin, accessed 2009
http://nanoventskin.blogspot.com/
92 Ibid

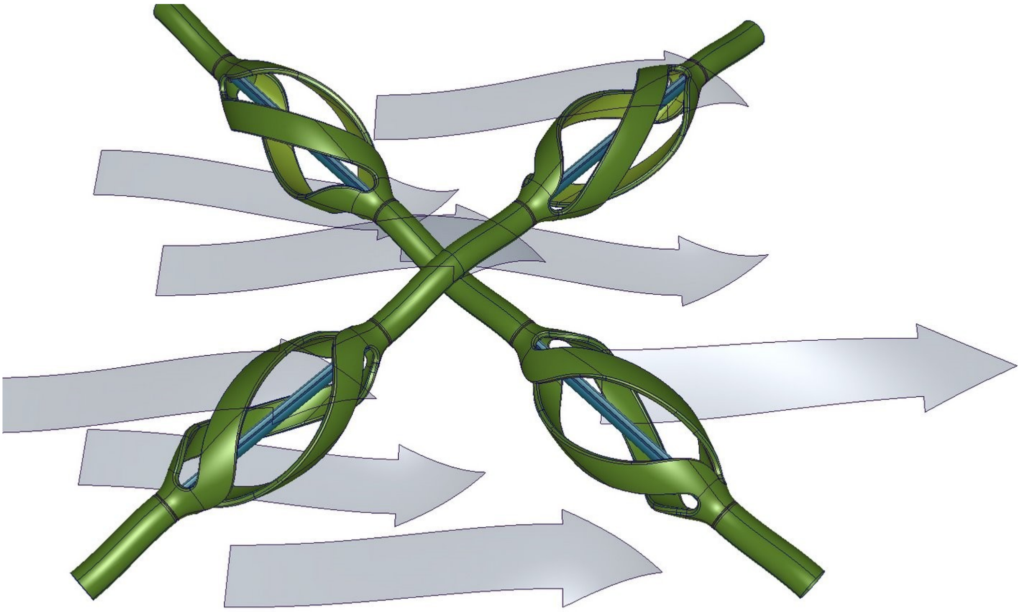

Figure 3- Wind turbines contact study[93]

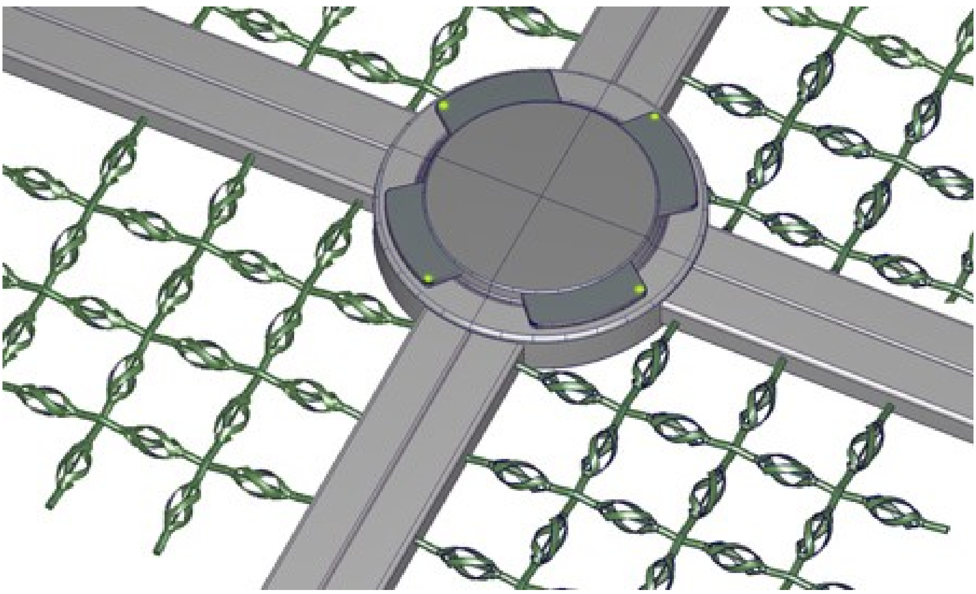

Figure 3- Storage units for power generation[94]

[93] Ibid
[94] Ibid

Figure 3- System application: Nano Vent-Skin Demonstrated in a conceptual Tower[95]

Figure 3- Nano vent skin could pass sun lighting and natural ventilation[96]

[95] Ibid
[96] Ibid

3.3.3.2 Environmental responsive kinetic facade

It consists of a hinged glass pane and spandrel panel laminated with photovoltaic cells. Magnetic control switch, actuators, and a thermal sensor are capable of the movement of the façade based on data received from the thermal sensor. Weather sensors on the facade respond to changes of wind, temperature and light conditions. By experimental study, it is found that even a small six degree angular shift of the façade can result in a twenty-five percent reduction in the amount of solar heat gain inside the building[97].

a) *Façade design objectives*

Two primary concerns are targeted within this facade design. First is the humanistic value: to maintain an optimal thermal comfort level for inhabitants within the building taking into account the external variable environmental behaviors. The second concern is the efficient and intelligent perform; kinetic facade system will absorb energy that is received by the façade as well as consume it in the façade movement.

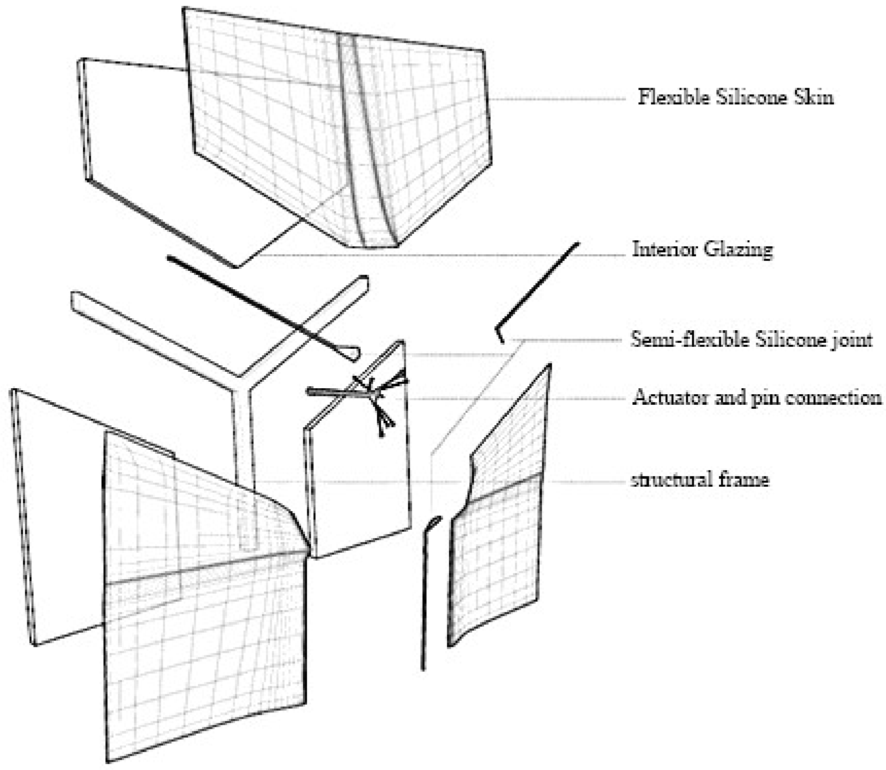

Figure 3- structural details of environmental responsive kinetic facade[98]

[97] Responsive kinetic façade, accessed 2009, http://www.core.form-ula.com/2009/04/15/som-sci-arc-on-cfresponsive-kinetic-facade/

[98] Ibid

b) Façade performance

The external skin of the façade will react to thermal conditions; the exterior skin opens and closes in order to regulate the temperature of the entire building in winter and summer months while the secondary ventilation on the interior skin gives local control to the temperature of each room. users of the building will be able to manually operate secondary ventilation and shading systems for the internal skin.

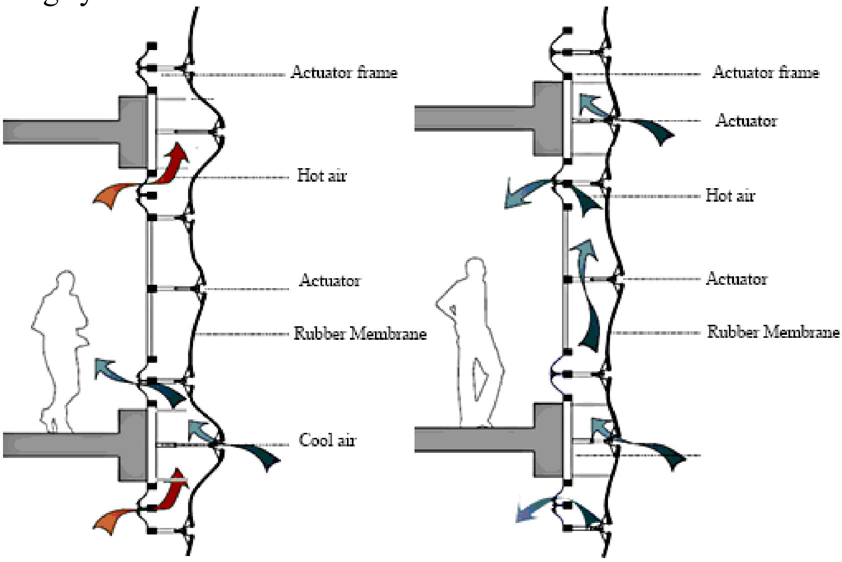

Figure 3- Kinetic facade response in summer month (left hand side) and winter (right hand side)

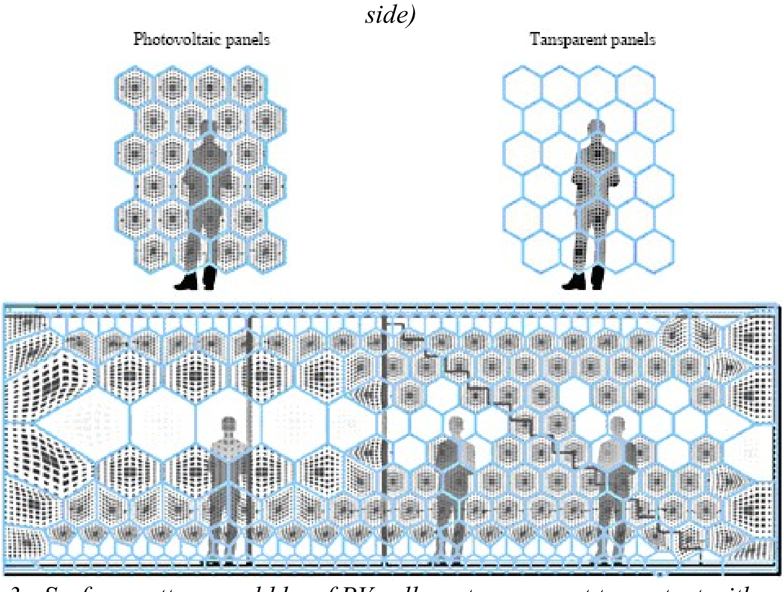

Figure 3- Surface pattern could be of PV cells or transparent to contact with outside[99]

[99] Ibid

3-4 Direct Benefits of Natural Ventilation for Internal Passive Cooling

Natural ventilation could be an appropriate choice when compared to conventional air conditioning. It (if well designed) can save substantial amounts of energy by decreasing or eliminating the need for mechanical cooling. It may also improve the building's indoor air quality. The following section discuses some benefits and limitations of natural ventilation as a passive cooling strategy.

a) *Improving the indoor air quality*
Natural ventilation improves the building's indoor air quality by getting red of the dust and other pollutants in the interior air to outside the building. This leads to more productively in their work.

b) *It has low investment and operating costs*
Natural ventilation systems operation costs are often less than that of traditional mechanical ventilation systems. it has zero running costs if it is used alone without backup air-conditioning system. Moreover, natural ventilation with advanced control involves less operating costs than traditional mechanical ventilation plant in a certain project ventilation budget. From the next graph (figure 3-47) natural ventilation cost is less than the mechanical ventilation by about 50%, while the mechanical ventilation and cooling exceed it by about 20%[100]. The natural ventilation operating costs can decrease by about 70 percent less than mechanical ventilation and cooling operating costs as it needs less maintenance, and zero electricity consumption except for the presence of automatic control systems.

[100] Window Master INC., *Natural Ventilation Fresh Air- simple and efficient*, Solutions for Natural Ventilation cataloge, accessed 2007, http://www.windowmaster.com/regado.jsp?type=page&id=52

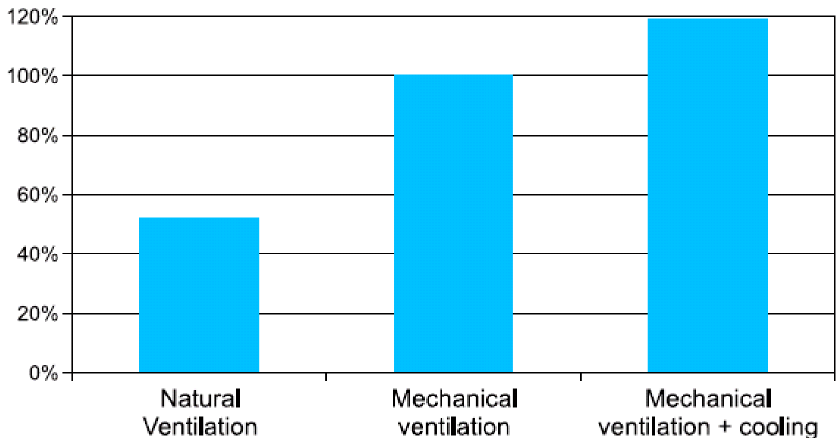

Figure 3- operating costs percentage for natural ventilation Vs mechanical ventilation[101]

c) *It requires no maintenance*
Natural ventilation systems requires no maintenance since it essentially contains no moving parts, indeed require no replacement. There could be additional maintenance incase of presence of controlling systems but it is very low compared with the conventional cooling systems maintenance requirements.

d) *It is zero energy consumption*
Natural ventilation use wind pressure and natural stack effect of air density, so it does not use any fossil fuelled energy but relies on controlling the wind power and the thermal rise of interior air. Natural ventilation can save substantial energy by decreasing or eliminating the need for mechanical cooling.

3-5 Conclusions

This chapter has proved that natural ventilation is an important cooling process alternative to mechanical air-conditioning in passive design buildings. It could offer controlling the indoor air quality with outdoor air and refreshing airflow for occupants providing health, comfort, and productivity. This chapter has given the designers the main utilizations for the natural ventilation process and its basic requirements. Moreover, it has described the system components, working idea, main architecture elements of three innovative natural ventilation systems (double skin façade, innovative wind catchers, and interactive facades) and there appliance in commercial buildings. It has proved that these

[101] Ibid

ventilation systems can enhance the passive cooling process as they can increase the ventilation efficiency, reduce the cooling loads, improve sound insulation against external traffic noise, reduce the carbon emissions and global warming, decrease the mechanical ventilation and air-conditioning systems, and minimize the energy and maintenance costs. This chapter also has presented the general methodology for designing a building to be totally or partially cooled by natural ventilation.

4-1 Introduction

In warm sunny climates, architects should control the amount of sun radiations reaching the building before designing it. The excess solar gain may results in increasing the internal solar gain and cooling loads which leads to increasing the company running costs. Presence of solar control glass and shading devices on the glazing facades could prevent excessive solar gain. They can also improve user visual comfort by controlling glare and reducing contrast ratios which often leads to increase satisfaction and productivity. Solar control and shading can be provided by natural landscaping or by building elements such as awnings, overhangs, and trellises. Some shading devices can also function as reflectors like light shelves, which bounce natural light for day lighting deep into building interiors without entering direct sun radiations. Shading devices could be: fixed or adjustable, vertical or horizontal and could be external or internal. Moreover, interior space could be protected from direct sun radiations by using solar control glazing materials in the building facades. This chapter will introduce the types of innovative solar control shading devices and glazing materials, as well as it will study their performance on blocking direct solar radiation from entering the space.

4-2 Architecture Considerations of Efficient Shading

Designing an efficient shading system varies with variation of many factors like: building location, orientation, site, and building usage. It is difficult to generalize the architecture considerations of efficient shading device as there are wide ranges of building types and climates. But the following considerations can come true:

- Exterior shading is most effective than interior shading in reducing the cooling loads, since the solar radiations have already enters the space incase of interior shading. However, the interior devices control the glare and permits visual comfort.
- The designer should carefully consider the durability on selecting the shading devices, with considering its maintenance costs.
- Shading devices affects natural light, but some solar control devices can make use of both natural light and shading like: the insulated glazing and solar control coated glazing.
- If shading attachments are not aesthetically acceptable, the architect can use the building form itself for exterior shading. So that to set the

window back in a deeper wall section or to extend elements of the skin to visually blend with envelope structural features.

The architect should consider the climatic conditions and comparative shading coefficients of shading devices before selecting the appropriate shading device[1] for a given building. These two considerations will be explained in the following section.

4-2-1 Climatic Conditions

The building requirements for solar protection or solar gain are determined in the first stage by the site climatic conditions. In very cold or very warm climates, shading decisions are really quite easy as the building design should have solar penetration or not. But in moderate climates, there will be times when solar radiation is of significant benefit as a heat source and times when it could be a problematic due to glare and overheating. The first key design issue in this case is to determine the time when temperatures go from being cold (that require heating) to warm (that require solar protection) and vice versa. Following some considerations for selecting an efficient shading device depending on the climatic conditions:

- Limit as much as possible the amount of east and west glazing.
- Consider shading on the roof even if there are no skylights since the roof is a major source of transmitted solar gain into the building.
- The architect should study the sun angles before selecting the efficient shading device.
- The design requirements for a shading device depend entirely on a building's use with the climate condition. For example, for a multi-storey open-plan office building in a relatively warm climate, the occupancy and equipment gains so much heat energy; this may means that heating is rarely required. In this situation, to avoid unnecessary loads, exterior shading devices should be selected to completely block sun radiations all year-round. While, in climates where summers are also relatively cold, the requirement may even be to allow full solar access all year-round.

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[1] **Donald Prowler and Associates**, *Sun Control and Shading Devices. PDF,* Revised and expanded by Joseph Bourg, Millennium Energy LLC, WBDG 2008.

4-2-2 Shading Coefficients

The Shading coefficients (SC) is the fraction of solar radiation that transmitted by the specified device, compared to the amount of solar radiation incident upon it. They are expressed as a decimal value without units between 0 and 1[2]. The lower the SC the less solar heat passes through, thus the more effective solar control device. The table below compares the Shading Coefficients (SC) of various shading devices.

Shading Device	SC
33mm clear float glass	**1.0**
Standard Double Glazing	**0.9**
Internal Venetian Blinds (fully drawn)	**0.5- 0.9**
Internal Curtains (fully drawn)	**0.4- 0.8**
Internal Roller Blinds	**0.4-0.8**
Heat absorbing glass	**0.7**
Vegetation and trees	**0.6**
Solar Control glass	**0.4**
External Blinds (fully drawn)	**0.2**
External Shutters (fully drawn)	**0.2**

*Table 4- **Shading Coefficients** (SC) of various shading devices*[3]

From the previous table, the maximum solar radiation is passed through clear float glass façade, this means that clear glass facades without shading device is considered inefficient for buildings located in sunny climates. While minimum solar radiations are transmitted through presence of external blinds, so it considered an efficient shading device that can be presented on building's glazed facades located in sunny climates.

4-3 Effectiveness of Different Shading Devices on Building's Facade

Proper shading greatly reduces the cooling loads for building having large areas of unprotected glazing. Choosing an effective shading device depend on the solar orientation of the building façade, For example, simple fixed overhangs are very effective on shading the south-facing windows in summer when sun angles are high. However, the same horizontal overhangs are ineffective at

[2] Shading: Solar Control, Ecotect WIKI, accessed 2009, http://squ1.org/wiki/Solar_Control

[3] Ibid.

blocking low afternoon sun from entering west-facing windows during heat gain periods in the summer[4]. While adjustable shadings are more flexible, they can be adjusted easily according to the sun direction to prevent the sun radiation from entering the space. The following section will study the performance of fixed and adjustable shading devices.

4-3-1 Fixed Shading Devices

Fixed shading devices are usually integral part of the building's structure; it depends mainly on the incident angle of the sun's rays. There are two types of fixed shading devices: Horizontal overhangs and vertical fins. Each one has its distinctive shade pattern on the building façades. Horizontal overhangs are most effective for southern windows. In summer they can block the sun radiation; in winter they can admit lower position radiations from the sun. However, fixed horizontal overhangs may cause some problems during the spring, as October is still considered a warm month but sun has law radiations, so it penetrates and causes overheating to the interior[5]. Fixed shades can not ensure complete adjustment of shading with changing the shade needs all over the day. But its advantage is that it needs no handling by the occupants as well as no maintenance is needed.

4-3-2 Adjustable Shading Devices

Adjustable shading devices have much better effectiveness than fixed ones. They can change their position manually or automatically with the changing pattern of the sun motion as well as, it can adapt to changing climatic conditions and shading needs. Adjustable shading devices allow the user to choose the desired level of shading. This could be particularly useful in spring and autumn when heating and cooling needs are variable. It is particularly useful for eastern and western elevations, as the low angle of the sun makes it difficult to get sufficient protection from fixed shading. It gives greater control while enabling daylight levels and views to be manipulated. Appropriate adjustable systems include sliding screens, louver screens, shutters, retractable awnings and adjustable external blinds.

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[4] Sun control and shading devices, accessed 2008, http://www.wbdg.org/resources/suncontrol.php

[5] **Baruch Givoni**, *Climate Considerations in Building and Urban Design*, publisher John Wiley and Sons", 1998 P62.

4-4 Shading Techniques

Shading techniques could be externally or internally to the building facades whatever it is fixed or adjustable system. The choice of appropriate shading device from the wide range of external and internal systems depends on the latitude, orientation, building type an overall design of the building. External shading devices are more effective than interior ones as they obstruct the sun radiations before it reaches the interior of the building.
Modern architecture is mainly subjected by glass and transparency; glazed facades create a visual connection between outside and inside. When talking about commercial places, it needs daylight, comfort environment, but it is strongly influenced by the sunshine. So, the solution is protecting the building from direct sun radiations with the permeation of natural daylight to enter.

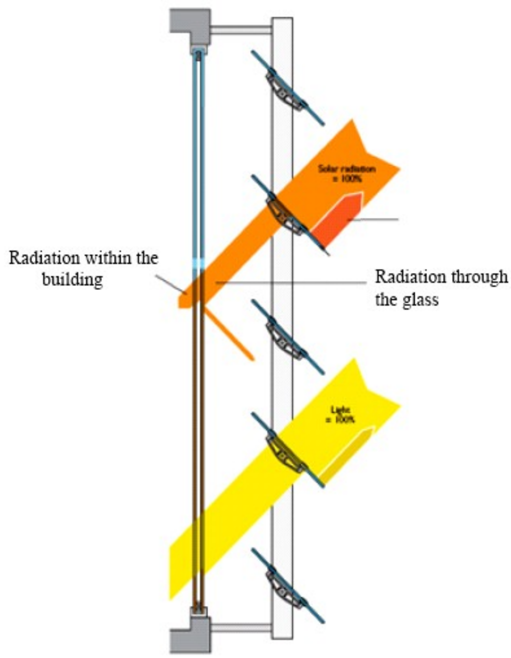

Figure 4- External controllable louvers are maximizing the daylight while minimizing the solar radiation[6]

This could be achieved by using innovative shading and solar control devices. Innovative external solar control louvers are considered the perfect way for blocking sun radiations from reaching the glazed facades.
They are very popular in modern architecture for many applications in industrial and commercial buildings. They can follow the path of the sun to reflect almost all sun radiations in summer or permit it in winter. Therefore, it optimizes the daylight level while minimize the transmission of sun radiations[7] (figure 4-1). Innovative solar control louvers could be classified according to its material into:

- Glass louvers
- Metal louvers
- Stretched fabric membrane louvers

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[6] Ibid.

[7] Colt International Limited, New Lane Havant, *Architectural solutions, solar shading systems. PDF*, 2005, P3.

4-4-1 Glass Louvers

Glass louvers are well known and widely used in modern architecture; designers select the glass louvers as outdoor shading systems to apply in commercial buildings. Due to its appearance and its physical characteristics, it is certainly one of the most interesting shading devices that can improve the building look, besides it offers a significant protection against sun heat. Glass louvers are operated by liner columns to full the whole façade; the columns could be controlled manually or automatically for providing shading and natural lighting for the interior space, as well as reducing the solar heat gain, lowering air conditioning running costs, and maximizing the entry of natural daylight. Glass louvers could be carried by many carrier systems depending on the spans and the function[8], some of the carrier systems will be explained in the next section.

a) *First carrier system*

It is applied for wider spans; it consists of a central aluminum tube along the length of the louver, it is ideal for continues facades and roofs. The glass slats width ranges from 300 up to 600mm[9] (figure 4-2). It has a various dimensions according to its carrier type, application, space, and transparency needed (table 4-2). Moreover, it could be applied horizontally or vertically (figure 4-3).

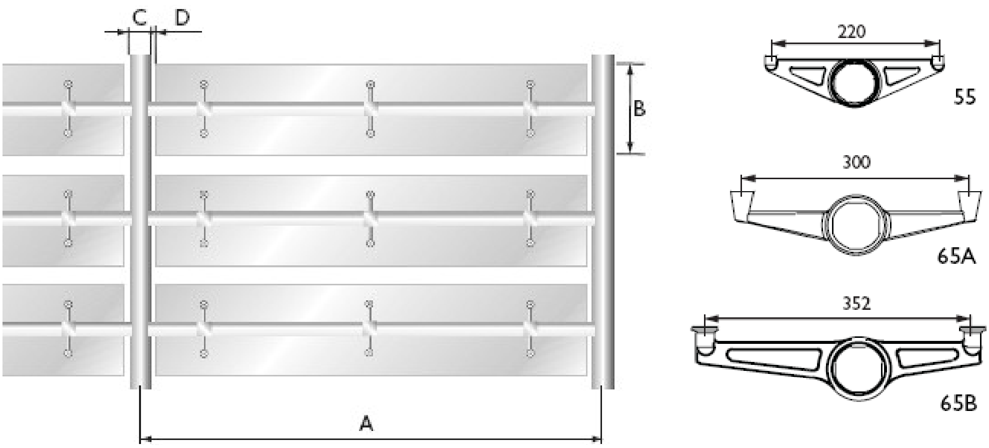


Figure 4- first glass louvers carrier system shapes[10]

[8] Ibid, p4.

[9] Ibid.

[10] Ibid

Dimensions	LS1 - 55	LS1 - 65A	LS1 - 65B
A mm (max)	2500	3300	3300
B mm	300 - 500	350 - 550	420 - 600
C mm	60	60	60
D mm	10	10	10
Angle of rotation °	0 - 100	0 - 100	0 - 100
Torsion tube Ø mm	55	65	65

Table 4- first glass louvers carrier dimensions according to the carrier type[11]

Figure 4- Applications for first glass louvers carrier system as horizontally or vertically, VW AutoCity, Germany

b) *Second carrier system*

This carrier system could be suitable for smaller spans; it has no fixation tubes in the middle of the glass louver, so it provides maximum daylight. This carrier system is available with slats width up to 500mm (figure 4-4); it has a various dimensions according to its carrier type, application, space, and transparency needed (table 4-3), and can be applied also with metal, fabric, or wood. It has a various applications (figure 4-5).

[11] Ibid

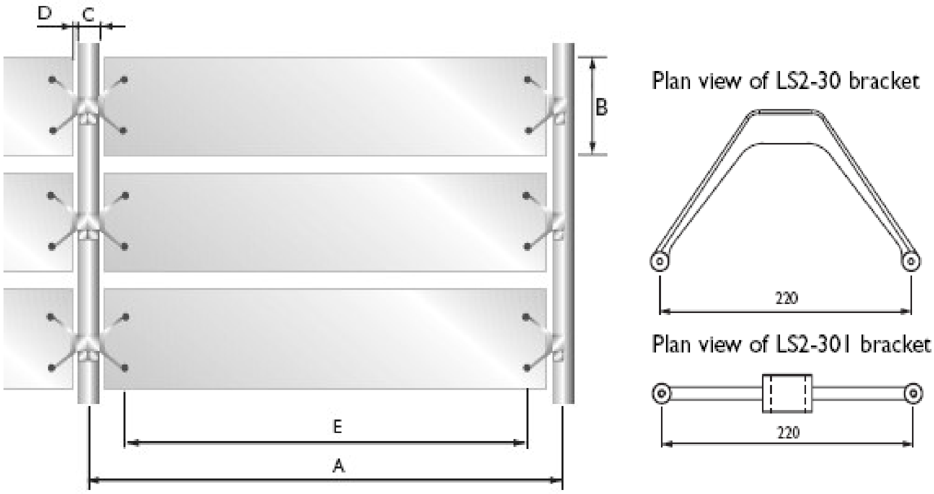


Figure 4- glass louvers second carrier system shapes

Dimensions	LS2-30	LS2-30I
A mm (max)	2000	2000
B mm	500	500
C mm	60	60
D mm	10	10
E mm	1700	1700
Angle of rotation °	0 - 100	0 - 100

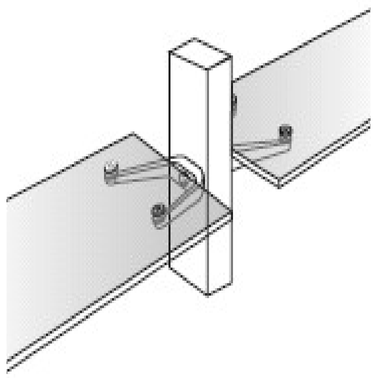


Table 4- second glass louvers carrier dimensions according to the carrier type[12]

[12] Ibid.


Figure 4- Applications for second glass louvers carrier system, BRE building, Garston[13]

c) Third carrier system

This system is a fully center revolving system, which provide maximum transparency. Louvers are supported at each end by a bonded and extruded end cap. It provides a back hang up design solution with hidden control mechanisms integrated within the main vertical supports (figure 4-6). This Glass slats are suitable for smaller spans of up to 1800mm in length and widths up to 600mm[14]. This louvers system is ideal for horizontal or vertical applications. This carrier system is also suited for use with metal, fabric, wood, and acrylic louvers (figure 4-7). Angle of rotation is 0-100°.

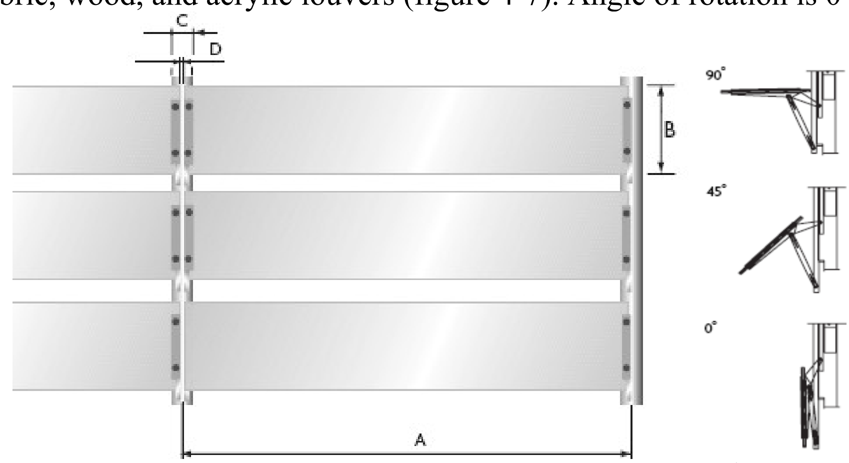


Figure 4- Horizontal glass louvers third carrier system [15]

[13] ibid

[14] ibid

[15] Ibid.

Dimensions	LS4
A mm (max)	1800
B mm	600
C mm	65
D mm	10
Angle of rotation °	0 - 90

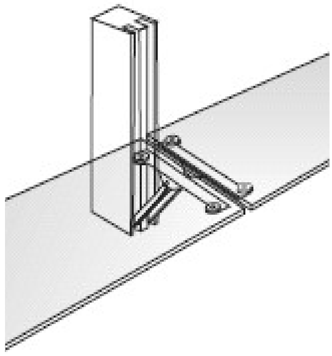


Table 4- glass slats performance[16]

Figure 4- Applications on third glass louvers carrier system

Glass louvers are available in various colors, surface finishes and coatings to meet specific design requirements.

- Mirrored glass louvers
- Photovoltaic glass louvers
- Prismatic glass louvers

4-4-1-1 Mirrored glass louvers

These glass louvers upper surface is treated with a reflective coating, this system can fully or partially block direct sun light. It is applied in a wide range in modern commercial buildings (figure 4-8). It redirect the sun radiations to light the interior space, it could be fixed or movable, vertical or horizontal system.

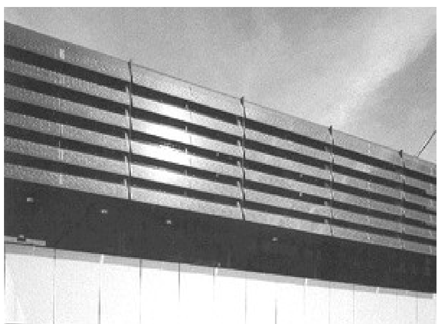
[16] Ibid.

Figure 4- Movable aluminum mirrord louvers, Bruntland Center, Toftlund, Denmark[17]

4-4-1-2 Photovoltaic glass louvers

This is an innovative passive sun-tracking system, and absolutely environmentally friendly, as its function on the basses of an energy generating derivation. In this system the glass louvers are incorporated with photovoltaic cells which are integrated into the glass. This system generates electricity besides blocking direct sun radiation from entering. It is available in widths up to 600mm, and supported spans up to 4m depend on wind loads[18].

The most perfect orientation for locating the PV shading louvers is on the south direction façades. The tilt angle of the PV shading louvers changes with the sun movement to efficient shade the interior space and for energy generation as well (figure 4-9). Shadowing from nearby buildings and trees will decrease the efficiency of the energy generation. Moreover photovoltaic louvers require not much maintenance other than cleaning which could be done occasionally to remove dirt as typically PV cells have a life of 25 years.



[17] **Deo Prasad and Mark Snow**, *Designing with solar power – A source book for Building Integrated Photovoltaics (BiPV)*, p 70.

[18] Colt International Limited, New Lane Havant, *Architectural solutions, solar shading systems*. *PDF*, 2005, P15.

Figure 4- Applications of photovoltaic shading louvers, **Heraeus, Frankfurt**[19]

4-4-1-3 Prismatic glass louvers

Prismatic louvers can offer an optimum protection against direct sun radiation and glare. It reflects solar radiation and at the same time redirects the daylight to enter the space despite affording the required degree of glare protection. Its principal begins when rays of light strike the hypotenuse face of a right-angled prism at 90°, it diffuses daylight, on the other hand, enters the room without any interference (figure 4-10). The louvers is controlled and rotate to track the sun light, as the sun changes position in the course of the day, the control system tilts the prisms so that direct sunlight is always incident at 90°. Its path also varies with the seasons, thus, this system permits maximum daylight entering the space. It considered the most suitable shading device for appliance in workspaces as to shade the interior space with the possibility of presence of possible daylight all over the working hours.

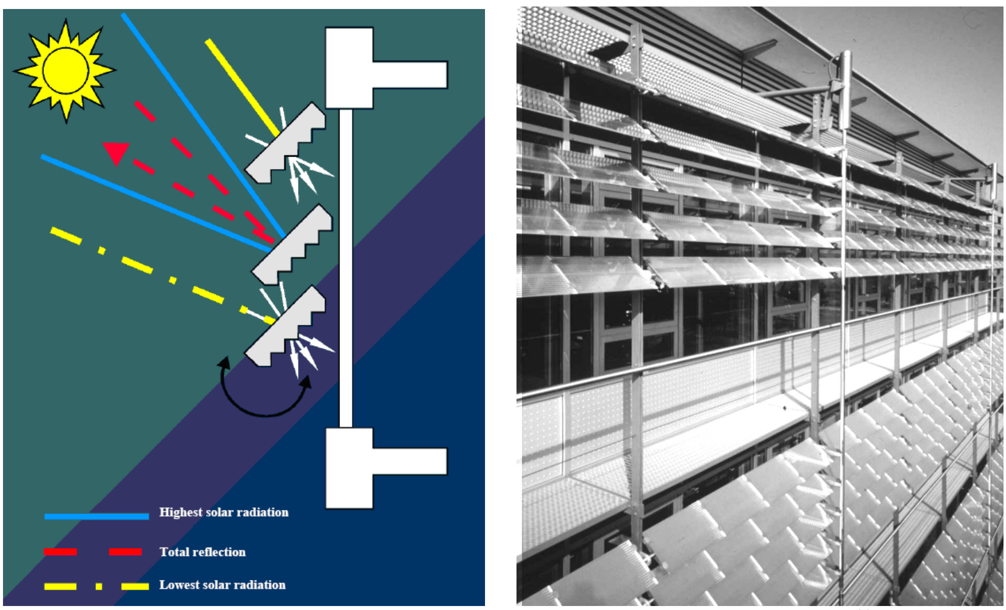


Figure 4- principle and application of the prismatic shading louvers[20]

4-4-2 Metal Louvers

Metal louvers are solar shading louvers that may be installed vertically or horizontally in front of the building glazed facade or roof. Metal louvers could be fixed or adjustable offering greater design flexibility. Controllable louvers

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[19] Ibid.

[20] BOMIN SOLAR GmbH, Daylight guidance and sun shielding, Data sheet.PDF, p4. from website, http://www.bomin-solar.de/English/prismalite_e.htm

are more efficient to reduce the over shading that can happen with fixed louvers. It can offer a great degree of solar control without compromising light levels when it linked to a sun tracking controller, as they can be moved to the optimum shading angle depending on the sun angle. The louver angel could be changed with the sun to decrease as much as possible the solar radiation entering the space (figure 4-11). On cloudy days the louvers will automatically opened to maximize daylight entry, As the light sensors send signals to the control system to fully open the fins to allow maximum natural daylight and vision to the outside at all times.

Figure 4- Automatically controlled metal louvers rotation with sun angels 0-90 degree[21]

[21] Colt International Limited, New Lane Havant, *Architectural solutions, Shadometal PDF*, 2005, P15

Figure 4- Application of metal louvers shading devices, Zurich Airport[22]

Aluminum louvers could be an efficient shading system when installed on top of skylights. It has various forms and coatings depending on the building design and application, following two forms for the aluminum louvers:

4-4-2-1 Perforated aluminum louvers

It is manufactured from extruded aluminum alloy with stainless fixings. The metal louvers prevent the solar radiation from entering the space, but, nevertheless, it reduces also the daylight entering to the space (figure 4-13). Perforated extruded aluminum louvers can reduce solar heat gain, increase the entrance of fresh air, minimize internal glare whilst it also maximize the use of natural daylight.

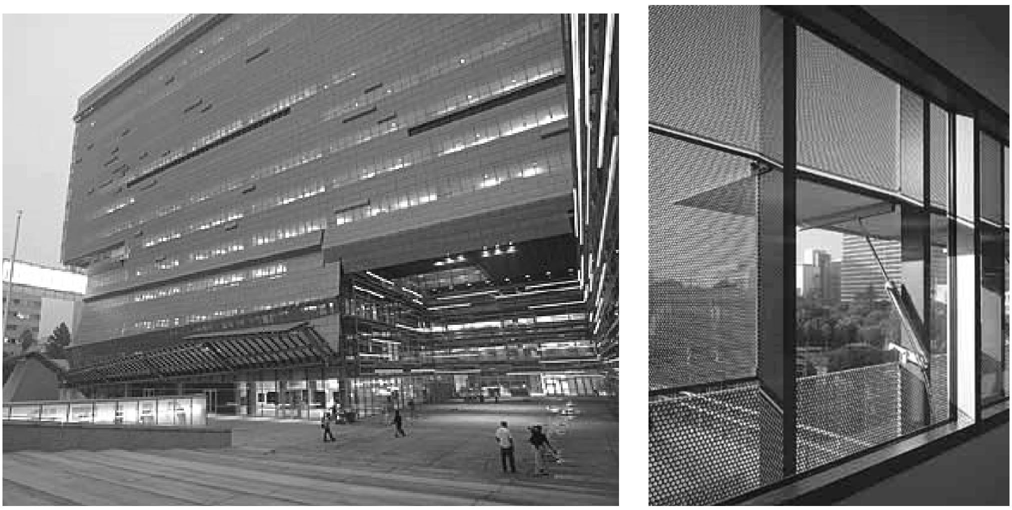

Figure 4- Controllable perforated aluminum solar shading louver Caltrans District 7 Headquarters, Los Angeless[23]

The façade along Main Street features an innovative double skin of glass behind perforated aluminum panels. The panels open and close mechanically timed with the movement of the sun and weather conditions, shielding the interior from the sun, and giving office workers changing views to the outside. When they are heated, air around them rises; this fact helps drawing cooler air from ground level. Each day, about 1,000 louvers in front of windows are opened and closed.

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[22] ibid, p1

[23] C.**C. Sullivan,** Stick-built robotics, Architectural Record magazine, july 2009.

4-4-2-2 Coated metal louvers

Sun control metal louvers could be coated by a variety of coatings like: Polyester powder coating, Anodizing coating, and Fluoropolymer painting. They are used to increase the louver efficiency, reflectivity, and durability. Each of these finishes not only protects louver materials from the environmental stresses of direct sun, temperature, and weather, but also they give the louvers a significantly appearance and performance, following a brief explanation of each of these coatings:

- Powder coating: in this process the material is being pre-treated in tanks of acid to clean the outside faces. The aluminum is then spray coated with polyester based powder, which is heated up to produce a protective film.
- Anodized: in this process aluminum surface is treated electrochemically during the extruding process to produce a hard, translucent film of aluminum oxide forming a protective coating. Different extruded sections and sheet materials can give different shading results, and for this reason, powder coating will give a more consistent finish[24].

4-4-3 Stretched Fabric Membrane Louvers

Stretched fabric membrane shading louvers are unique and alternative solar shading solution. It consists of a special fabric which is stretched between two sides of a louver support frame. The fabric is manufactured with a weave to prevent glare and solar heat gain. The fabric can also diffuse light and allow high external vision[25]. It considered a light weight solar shading system, which could allow large spans to be constructed without the need for additional supporting framework (figure 4-14). This system attracts the designers to apply as shading system on modern architecture for its unique shape.

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[24] ibid

[25] Colt International Limited, New Lane Havant, *Architectural solutions,* Shadotex, Membrane Solar Shading System. *PDF*, 2005, P2.

Figure 4- Application of Fabric membrane stretch shading louvers onto the building glass façade, Baader Bank, Germany [26]

The fabric membrane shading system can be presented in a various colors and fabric materials. This variety in materials like: PVC coated polyester membrane, Teflon glass fiber membrane, Silicon glass fiber membrane, Ethylene tetrafluoroethylene ETFE (colored or translucent), and ETFE (screen printed). The architect should decide the suitable fabric membrane shading material according to the percent of light transmittance needed, percent of sun radiation transmission, and the fabric thickness. The following table (table 4-5) presents the fabric performance level of each of these membranes.

Fabric	Radiation transmission	Light transmission	Thickness	weight
Teflon Glass Fibre (white)	**approx. 11%**	**approx. 7%**	**0.64mm**	**0.67 kg/m2**
PVC Coated Polyester (white)	**approx. 4%**	**approx. 2%**	**0.45mm**	**0.65 kg/m2**
PVC Coated Polyester (grey)	**approx. 2%**	**approx. 2%**	**0.45mm**	**0.65 kg/m2**
Silicon Glass Fibre	**approx. 20%**	**approx. 10%**	**0.25mm**	**0.35 kg/m2**
ETFE (white, translucent)	**approx. 80%**	**approx. 70%**	**0.20mm**	**0.35 kg/m2**
ETFE (printed)	**approx. 36%**	**approx. 34%**	**0.20mm**	**0.35 kg/m2**

[26] ibid

Table 4- Fabric performance levels for various colors and fabric materials[27]

4-4-4 Controllability of Solar Control Louvers

The controllability of the louvers movement can be either electrical or non electrical. The non electrical control could be manually or by automatic system. Automatic non electrical thermo-hydraulic control and automatic electrical control systems will be explained in the next section.

4-4-4-1 Non electrical thermo-hydraulic controlling system

Thermo-hydraulic controlling system is a self sun-tracking device; it is designed to control the external shading louvers. The unique feature in this system is that it controls the louvers without the use of electrical power or digital electronic devices.

a) *System working idea*

This system is formed from two fiber-reinforced polymer absorber tubes fixed to the top and the bottom of a single louver vertical section. Each louvered section, together with its thermo hydraulic drive, forms an independent system integrated onto the facade. The tubes are targeted towards the sky and are connected with a hydraulic cylinder. The tubs are filled with special thermo-hydraulic fluid. When the sun moves across the building, one tube is more strongly irradiated to sun and heats up more than the other tube[28]. Thus, the difference in temperature between the two fluids in the two tubes generates a difference in pressure, which causes expanding or contracting the fluid in each tube. This causes the hydraulic cylinder to move and restores the equilibrium to the louver system. The fluid expands or contracts in the tube, depending on the sun. This leads to rotate the louvers into optimal shading position throughout the day. When there is no sun, the fins reverse the operation and generally the louvers are fully opened (figure 4-15). This system could be applied in various applications in different climates with different shading louvers as it depends only on the sun radiation (figure 4-16).

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[27] Colt International Limited, New Lane Havant, *Architectural solutions,* Shadotex, Membrane Solar Shading System. *PDF*, 2005, P4.

[28] Colt International Limited, New Lane Havant, *Architectural solutions, solar shading systems*. *PDF*, 2005, P19.

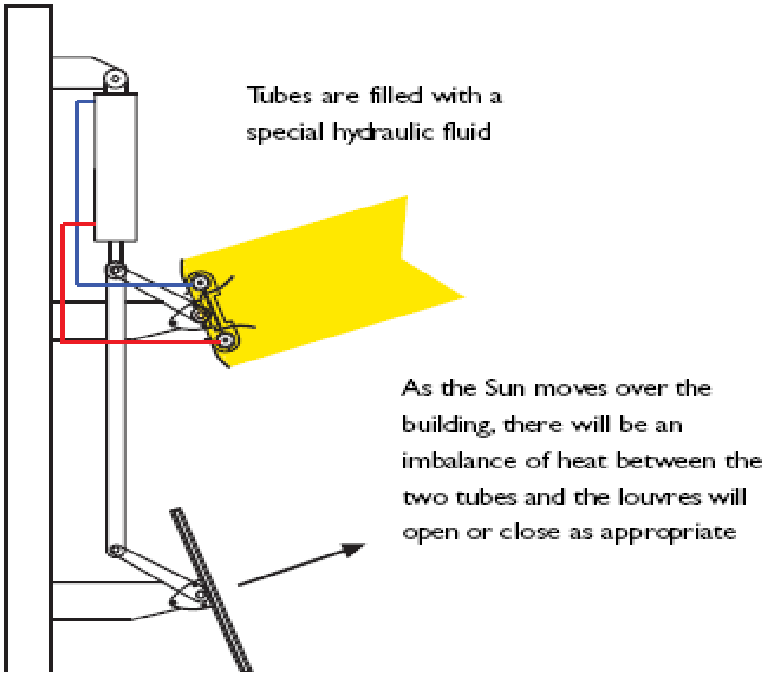

Figure 4- thermo hydraulic control system for the horizontal shading overhangs[29]

Figure 4- application on thermo hydraulic shading overhangs, the Johnston Press building in Sheffield, England[30]

[29] ***Mark Piepkorn***, *Colt's Facade Shading with Passive Control*, green source magazine, August 06, 2007 From website: http://greensource.construction.com/products/articles/070806FacadeShading.asp

[30] Ibid.

b) *system features and benefits*

- This system is installed easy and fit to any external controllable shading louvers system.
- This system can be operated to any weather conditions cold or warm.
- It has no noise transmitted through its operation.
- It requires no additional electrical energy source or electrical controlling systems.
- It is easy to be installed as there are no interfering wires.
- A single system could control up to 50m2 of solar shading louver.
- It is environmentally friendly.
- It requires little maintenance, just periodic cleaning and a simple annual service.
- In cloudy weather, the louvers are opened completely to permit natural light to enter.

4-4-4-2 Electrical controlling system

In this system the electric control operation adjustment of motors could be manual switches or automatic. Automatic controlled system consists of various sensors and has a fully controlling over the internal climate. Its operation is according to the outside climate, as it can increase or reduce the amount of air supplied to the interior by closing or opening the windows. Moreover, the sensors control the shading of the building according to the movement of the sun by rotating the louvers with the sun directions as the computer determines the optimum position of the sun. Fully automatically controls adjust the shading louvers to maintain the optimum internal requirements of the space.

a) *System working idea*

The louvers are driven by motor(s) and one gear per vertical louvers strip. When there is direct radiation on the façade, the motor send data to the holder of the gear which being retracted and pull smoothly the rod of the louvers downwards so the louvers is closed and block sun from entering. Moreover, The opposite operation is done in cloudy days, the motor is adjusted to open the louvers to permit natural light and ventilation, the motor send data to the gear and the holder is extracted to push the louvers rod upward so that the louvers is being opened (figure 4-17). The field for one motor shouldn't exceed (7 m long x 5,4mhigh)[31]. All motors may be controlled by one control unit. One motor can drive up to 4 gears (figure 4-18).

[31] Bomin solar GmbH, Innovative Systems made by BOMIN SOLAR, Movable or fixed Glass Scale Louvers, BOMIN GSL for inside and outdoor purposes, Aeration and sunshading system, PDF, 2002, P3.

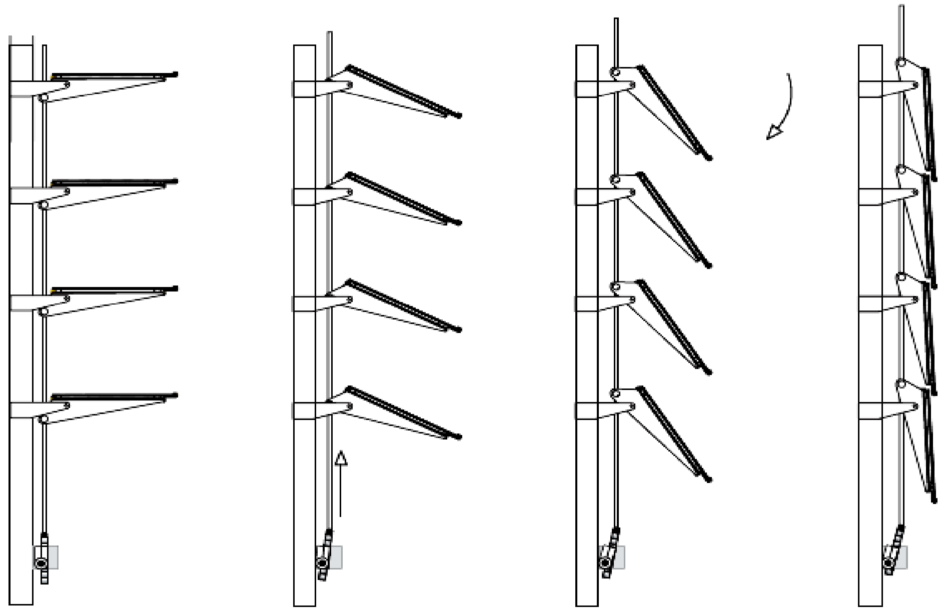

Figure 4- System operation of the automatic control in sunny and cloudy days to open or close the louvers[32]

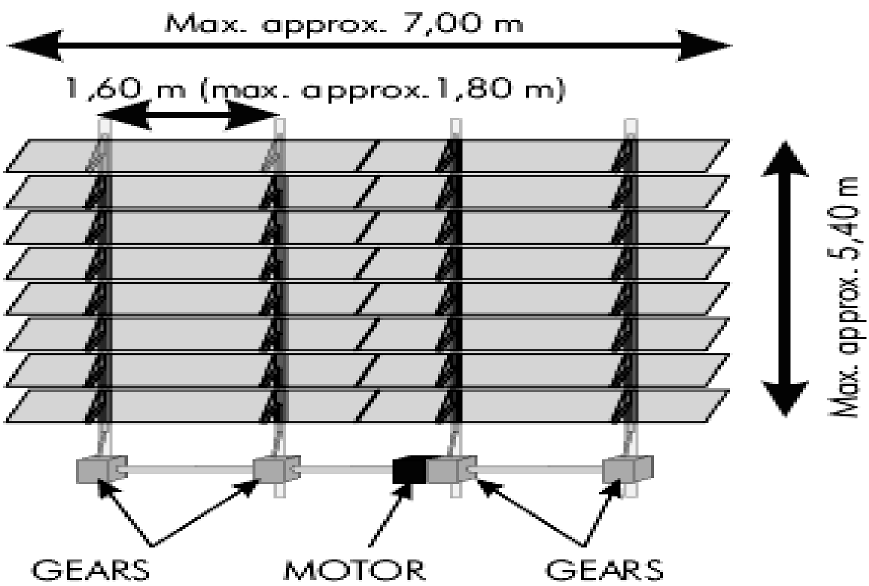

Figure 4- Functional principal of one motor to control shading louvers[33]

[32] Ibid.

[33]Ibid, p5.

The system can be used to open some shading louvers in certain area of the façade while the other parts of the façade are being closed depending on circumstances of each part of the façade. In other option is to use manual controller to some parts of the façade while the whole façade could be automatically controlled (figure 4- 19).

Figure 4- some parts of shading is opened while others is closed[34]

4-4-4-3 Stick-built robotic controlling system

New researches are directed to using robots as part of a design strategy that encourages the environmental control. Robot friendly environments within the building enclosure are proposed. Detail design issues are discussed, including the relationships that might occur between robots, building users and maintenance engineers[35]. These small robots could detect building facades, regulating energy usage and indoor conditions in order to close windows, check thermostats, and adjust blinds.

[34] ibid

[35] **Gage, S., Thorne, W.,Edge,** 2005, *monkeys-the design of habitat specific robots in buildings*, *Technoetic Arts*, Vol. 3 No.3, p169.

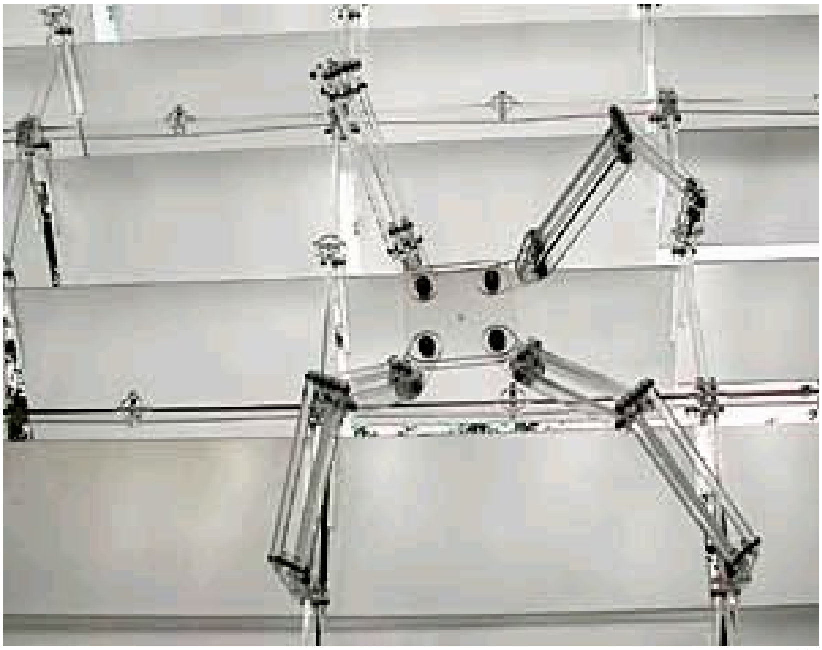

Figure 4- Stick-built robotic controlling system for solar control louvers[36]

4-4-5 System Application

Phoenix Main Public Library, Arizona

This building contains a combination of solar control movable aluminum louvers and fabric fins. Fabric louvers works as sunscreens on the library's north elevation which helps controlling solar gain in summer. They are automatically controlled, as it is opened when the sun shines to maximize the entering of daylight, while it is closed automatically when the sun rises to shade the building façade. At the south façade there are computer controlled aluminum horizontal louvers while at the north façade there are controllable vertical fabric louvers (figure 4-21). These louvers are automatically controlled all over the year, so that they can admit 100% of solar radiation through the winter months from October to March, and 10% of solar radiation through the rest of the year. This results in overall decreasing of 2.7% in space conditioning loads, with a 1.2% increase in cooling and a 4.7% decrease in heating[37].

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[36] Ibid

[37] Thermal performance of a desert monuments, **Vital Signs Project: Phoenix Central Library,** strategies and results, accessed 2009, http://arch.ced.berkeley.edu/vitalsigns/workup/phoenix_lib/phoenix_results.html

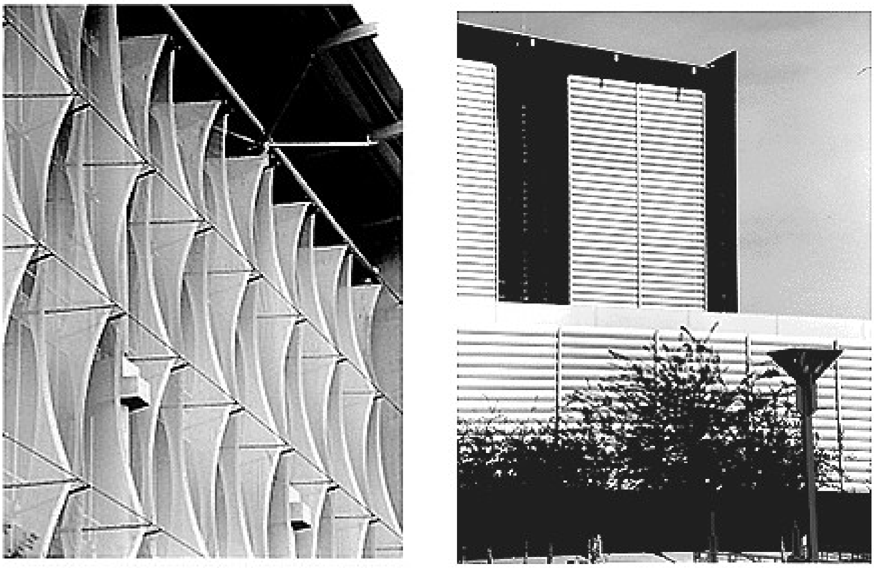

Figure 4- controlled fabric louvers (left) computer controlled Aluminum horizontal louvers (right)[38]

4-4-6 Benefits of Innovative Shading Louvers

- It blocks direct sun radiations from entering the space, at the same time, enhances daylight levels and reduce levels of glare.
- All innovative louver systems are durable and reliable with low maintenance needs.
- Louver panels are available in various configurations, materials, finishes and coatings to meet the requirements of almost modern projects.
- These solar control systems could enhance the interior natural passive cooling strategies by reducing the interior cooling loads and ventilation requirements.
- It can be able to be used in any time of the year according to its controllability.
- It considered as a modern and unique design used for modern architecture.
- It is ideal for large and small spans as it has a light weight construction.
- All principal components and coatings are manufactured from corrosion-resistant.
- It can be either fixed or movable louvers.

[38] Ibid

4-5 Insulation: Solar Control Glazing

Glazing materials vary greatly, depending on location of the facility, building usage, and even the glazing placement on the exterior walls. Glazing materials should be carefully selected as it has a significant effect on internal heating and cooling requirements, as it control the type and amount of radiation that passes through it[39], this issue will be deeply explained in chapter four. Some issues should be taken into consideration before selecting the glazing material, are:

a) Shading devices could be sited onto the glazing facades in order to control the direct solar radiations from entering to the space. Moreover, presence of solar screens that intercept solar radiation or films that prevents infrared transmission while allowing good visibility.
b) Coatings for the glazing minimizes the conductive energy transmission.
c) Much heat is also gained through a window's frame. For optimal energy performance, specify a low-conductivity frame material, such as wood or vinyl. If metal frames are used, the architect should make sure that the frame has thermal breaks and insulations. In addition to reducing heat gain, a good window frame will help preventing condensation, even high-performance glazing may results in condensation problems if those glazing are mounted in inappropriate frames.[40].
d) Windows with two or three glazing layers can decrease the emittance of direct heat radiations. Filling the spaces between the glazing layers with an inert low-conductivity gas, such as argon, will further reduce heat flow to the interior space as well.

Glazed facades are widely used in commercial buildings; it could be an efficient day lighting solution. But it could be also a source of discomfort to the internal spaces, as it permits direct solar radiation to enter to the space and so increase the internal solar gain. The primary strategy to control heat gain is by blocking direct solar radiations from entering the interior space while allowing reasonable visible light transmittance for views and lighting.
Various techniques are available to control the amount of internal solar heat gain through facades, it includes the use of external and internal shading devices (which have been explained previously), and using solar control glazing. When selecting the appropriate solar control glazing type the architect should consider the local climate. In winter the solar radiation entering from the

[39], **E.M. Okba**, May 2005, Santorini, Greece, ‚*Building envelope design as a passive cooling technique*, International Conference "Passive and Low Energy Cooling for the Built Environment", P1.

[40] US. Depatment of Energy, Energy effeciancy and Renewable Energy, Glazing, accessed 2007 http://www1.eere.energy.gov/buildings/commercial/fenestration.html

glazed facades can be considered as a benefit while in summer months solar radiation that is not blocked by the shading devices could be regarded as a disadvantage if it enters the building as it can cause overheating. Using a solar control glass with shading systems will help decreasing the sun radiation penetration through the glass facades and so, helps to increasing the internal passive cooling. For selecting the approperiat glazing, architect should know well the glass properties. Glass transmits solar radiation from the sun by three mechanisms, reflection, transmission and absorption[41] (figure 4-22).

- *Reflectance:* it is the proportion of solar radiation at near normal incidence which is reflected by the glass back into the atmosphere[42]. This reflectance coefficient should be maximized for efficient solar control glass.
- *Absorbance:* it is proportion of solar radiation at near normal incidence which is absorbed by the glass. It should be minimized so that to minimize the solar radiation entering the space for decreasing the cooling loads.
- *Transmittance:* it is the proportion of solar radiation at near normal incidence which is transmitted directly through the glass. The transmittance coefficient for the selected glazing material for the façade should be minimized to minimize the direct radiation transmitted from the glass to the interior.

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[41] **Harris Poirazis**, 2008, *Single and Double Skin Glazed Office Buildings, Analyses of Energy Use and Indoor Climate*, PHD thesis, Department of Architecture and Built Environment, Lund University Faculty of Engineering LTH.

[42] Solar Control Glass, accessed 2008, http://www.patent-glazing.com/glass%20solar%20control%20intro.htm

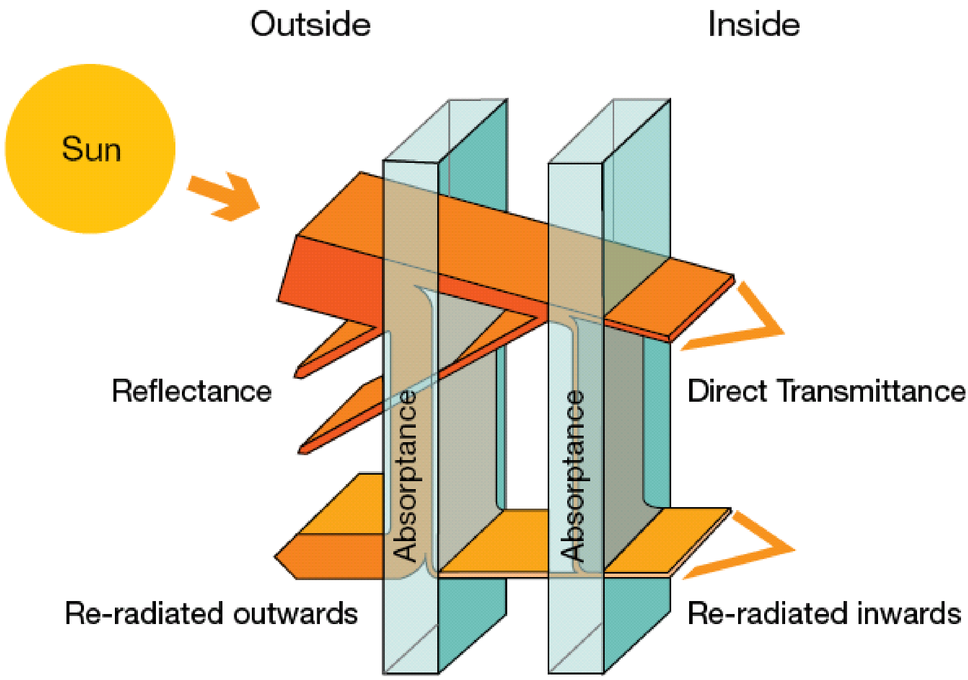

Figure 4- Transmittance, Reflectance and Absorbance of a typical double glazed unit[43]

In residential buildings, optimum window design and glazing specification could reduce energy consumption by 10%-50% below accepted practice in most climates. In internal-load dominated commercial, industrial, and institutional buildings, properly specified fenestration systems have the potential to reduce lighting and HVAC costs by 10%-40%[44]. Today, the rapid development of the solar control glazing technologies provide excellent opportunities to combine natural lighting, solar gain reduction, and high thermal resistance in a single window. The next section will presents five solar control glass types and its performance, it includes:

- Insulated glass
- Tinted glass
- Surface coated glass
- Complex glass
- Smart glass

[43] Ibid

[44] Gregg D. Ander, FAIA, Windows and Glazing, accessed 2008 http://www.wbdg.org/resources/windows.php

4-5-1 Insulated Glass

Glass is considered a relatively poor insulating material, but multiple panes of glass with air spaces in between can improve the insulating value. Clear single glazing allows the highest transfer of solar energy and permits the highest daylight transmission. Double-glazed panes of clear glass separated by an air gap can reduce heat loss by more than 50 percent [45] in comparison to single glazing (figure 4-23). Although heat transfer coefficient (U-factor) is reduced significantly, the solar heat transmittance and light transmittance percent for a double-glazed unit with clear glass remain relatively high.

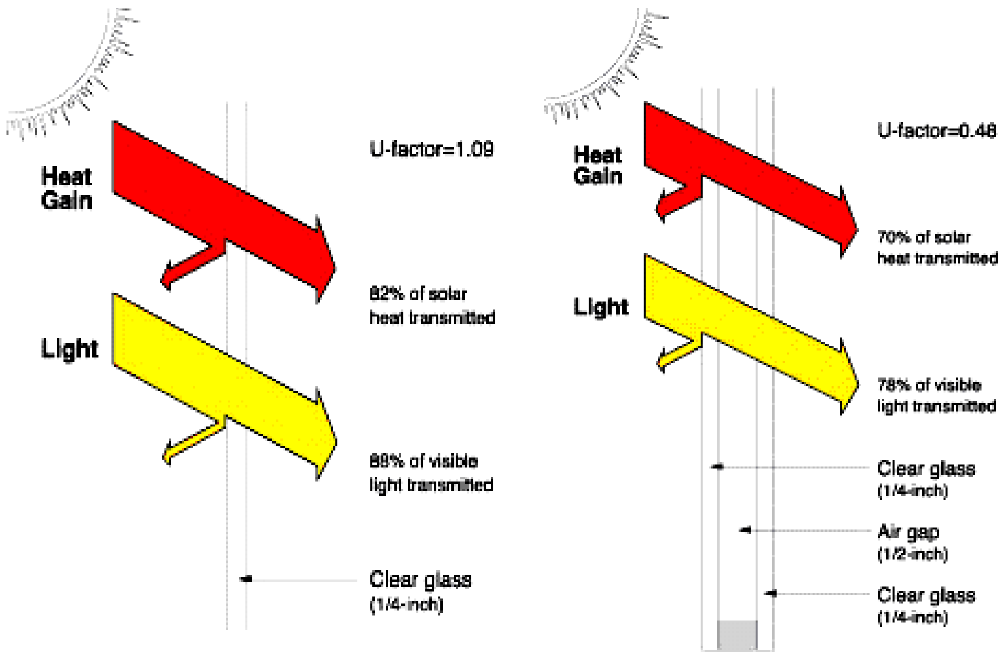

Figure 4- Clear single glass performance (left) and clear double glass performance (right)[46]

For the improvement of the solar insulation, low conductance gas can be used to fill in the gap of the multiple glass units instead of air or increase the number of glass panes could also increase the insulation value. Moreover, suspended plastic film can be placed inside the gap to improve the insulation efficiency. These improvements in the double glass insulation system could be achieved by presence one of these items or the combination of all items:

[45] **M. Santamouris, D. Asimakopoulos**, 1996, *Passive Cooling of Buildings*, published by Earth scan. p338.

[46] Commercial windows, accessed 2009, http://www.commercialwindows.umn.edu/materials_glazing1.php

4-5-1-1 Low-conductivity gas

Insulation performance could be improved by reducing the conductance of the air in the space between the layers. This could be achieved by filling the space with a less conductive slow-moving gas like Helium, Argon, or Nitrogen. These gases minimizes the convection currents within the space, reduces conduction and the so reduces the overall heat transfer between the interior and exterior.

4-5-1-2 Multiple Panes

As the insulation increases by adding a second pane to the single glazed unit, therefore, by adding a third or fourth pane of glass further increases the insulating value of the window as seen in the next figure. As each additional pane of glass increases the insulating value of the assembly, it also reduces the visible light transmission and the solar heat gain coefficient[47] (figure 4-24). However, Additional panes of glass increase the weight and thickness of the unit, which makes the mounting and handling will be more difficult and transportation more expensive.

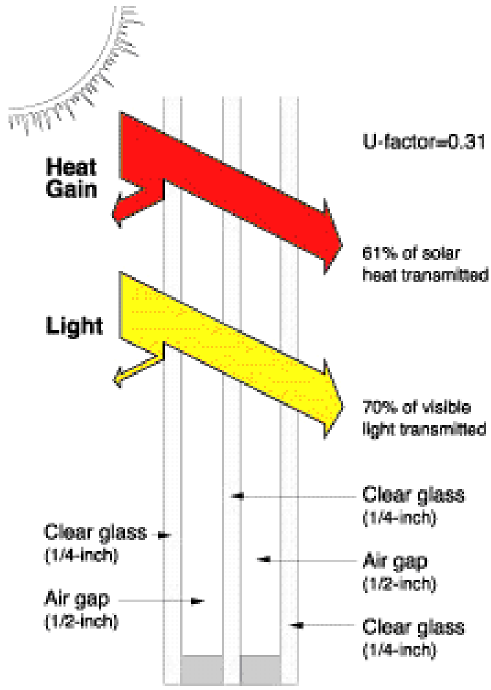

Figure 4- multiple glass panes increase the thermal insulation and decrease solar transmittance[48]

4-5-1-3 Suspended Plastic Films

An innovative direction for increasing the insulation performance for the multilayered glass panes is based on substituting an inner plastic film in the middle layer of the glass. Plastic films divide the inner space into multiple spaces so it can decrease the U-factor of the unit. Low-e coating can be applied to the plastic film to lower the solar heat gain, however, the visible light transmitted could be decreased. Moreover, increasing the number of plastic films in the inner space can decrease the heat gain. Therefore, the combination of multiple glass panes and plastic films with low-E coatings and gas fills will

[47] Ibid

[48] Ibid

achieve very low U-factors and low-solar-gain, this will results in reducing the cooling loads (figure 4-25).

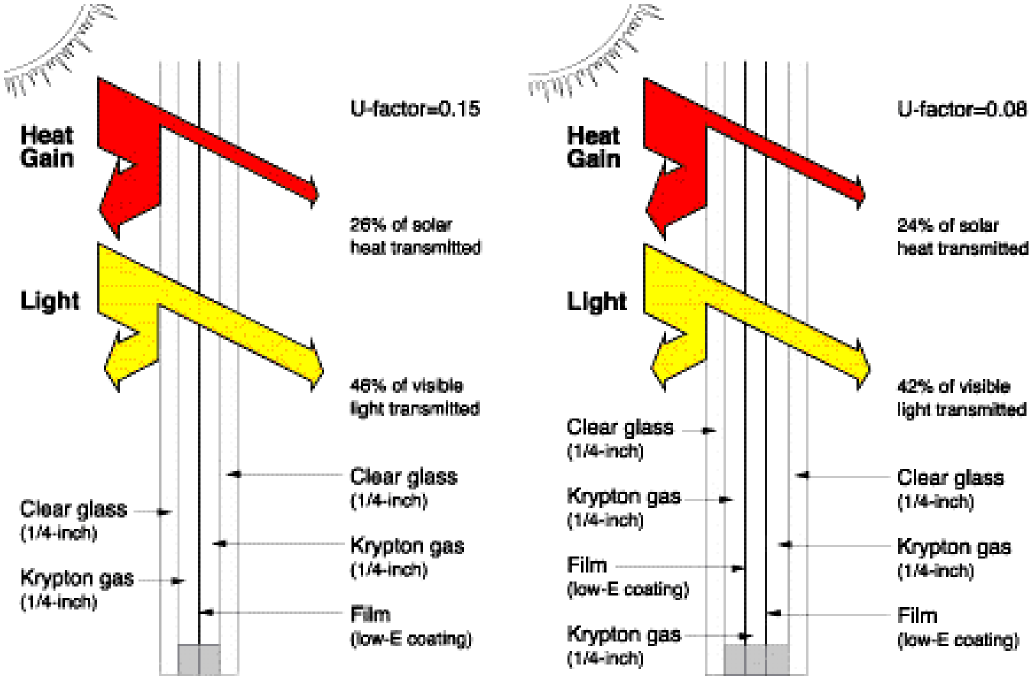

Figure 4- Combination of multiple glass panes and plastic films with low-E coatings and low conductance gas fills[49]

4-5-1-4 Heat mirror glass

Mirror film is a low-emissivity coated film product suspended in triple insulating glass panes for increasing the insulating and shading performance (figure 4-26). Due to its higher resistance value and higher solar control it is a best solution to increase the internal comfort in winter and summer. It could block 99.5% of ultraviolet radiation and 85% of near-infrared radiation[50]. Therefore it could save the heating and cooling costs by reducing the heat loss in winter and heat gain in summer. Moreover, due to its higher R-value it has a higher sound control than other glazings.

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[49] Commercial windows, accessed 2009, http://www.commercialwindows.umn.edu/materials_glazing1.php

[50] ibid

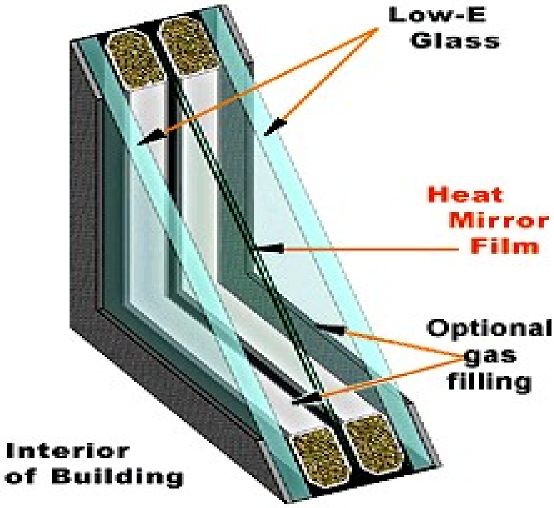

Figure 4- Heat mirror glass cross section[51]

Heat Mirror units are produced with a wide range of glass products including clear glass, tinted glass and low-e glass, taking advantage of film based coatings and glass based technologies to create superior insulating performance, outstanding solar control, while at the same time blocking UV radiation, and reducing outside noise more effectively than double pane glass[52] (figure 4-27).

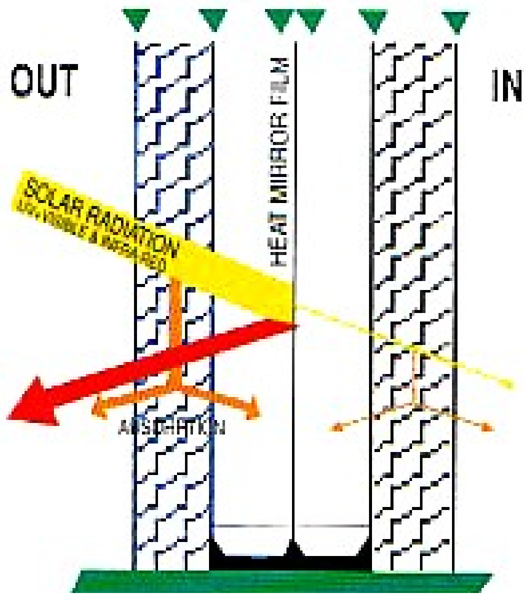

Figure 4- Solar radiation and daylight performance in heat mirror glass[53]

It has a variety of films provide varying levels of visible light and solar control to meet the different requirements of the commercial projects.

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[51] High Performance Windows, Heat Mirror Insulating Glass,accessed 2008, http://greendesignbuild.net/HighPerformanceWindowReview.aspx

[52] ibid

[53]Niradia enter prices, Inc, Heat Mirror Glass Units, accessed 2008, http://www.niradia.com/heatmirror.html

4-5-2 Tinted Glass

Tinted glass generally results of colorants added to the glass during the production process. Some tints are also produced by adhering colored films to the glass following the production process. It is characterized by high absorptive coefficient, especially of the long-wave radiation; about 35-75% of incident radiation could be absorbed[54] (figure 4-38). Tinted glass is available in many colors: gray, green, bronze or blue. Their solar control properties and color vary with thickness whilst their reflectance is slightly less than clear float glass. Tinted glass decreases the direct sunlight entering the space so the primary usage of tinted glass is reducing glare from the bright outdoors and reducing the amount of solar energy transmitted through the glass. Architects should carefully specify different tints and their application as it can impact the window heat loss or heat gain.

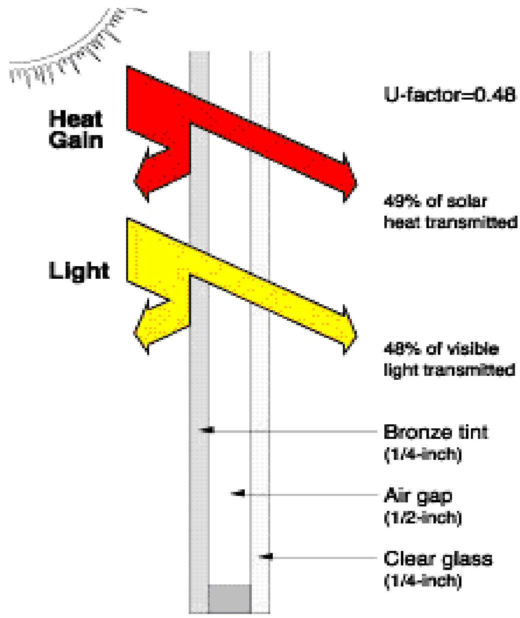

Figure 4- Double glazing with bronze tinted glazing[55]

To solve the problem of reducing daylight in traditional tinted glazing, glass manufacturers have developed *high-performance tinted glass*. This glass preferentially transmits the daylight portion of the solar spectrum but absorbs

[54] **M. Santamouris, D. Asimakopoulos**, 1996, *Passive Cooling of Buildings*, published by Earth scan.., p338.

[55] Commercial windows, Window Materials & Assemblies: Glazing Materials, accessed 2008, http://www.commercialwindows.umn.edu/materials_glazing2.php

the near-infrared part of sunlight (figure 4-29). These glazing have a light blue or light green tint and have higher visible transmittance values than traditional bronze or gray-tinted glass, but have lower solar heat gain coefficients. Because they have a higher absorptive coefficient so they are best used as the outside glazing in a double-glazed unit. They can also be combined with low-E coatings to enhance their performance. Tinted glazing is more common in commercial windows than in residential windows.

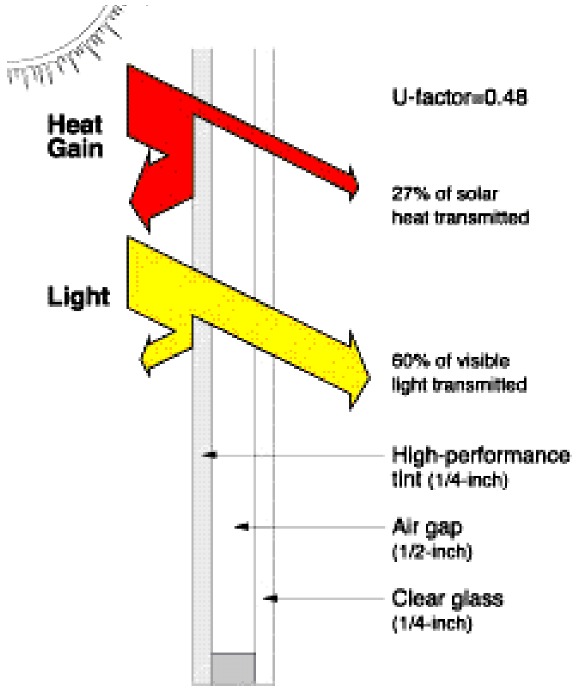

Figure 4-   High performance tinted glass on the outside layer[56]

4-5-3 Surface Coated Glass

In this type of glass, the glass is coated with a special coating that is designed to reduce the amount of solar radiation transmittance to building. It reflects and absorbs heat as well as filters light and reduce glare. Therefore it reduces the need for air-conditioning and blinds. Glass could be coated (according to its application) by two coatings for reduction of heat transmission: heat reflective coating and low-E coating.

[56] Ibid

4-5-3-1 Heat-reflective coatings

It is manufactured through coating several layers of metal oxides on a transparent float glasses or tint glasses. The reflective coatings available in various metallic colors: silver, gold, and bronze. The solar heat gain coefficient can be reduced by varying degrees, depending on the thickness, reflectivity of the coating, and its location on the glazing unit (figure 4-30).

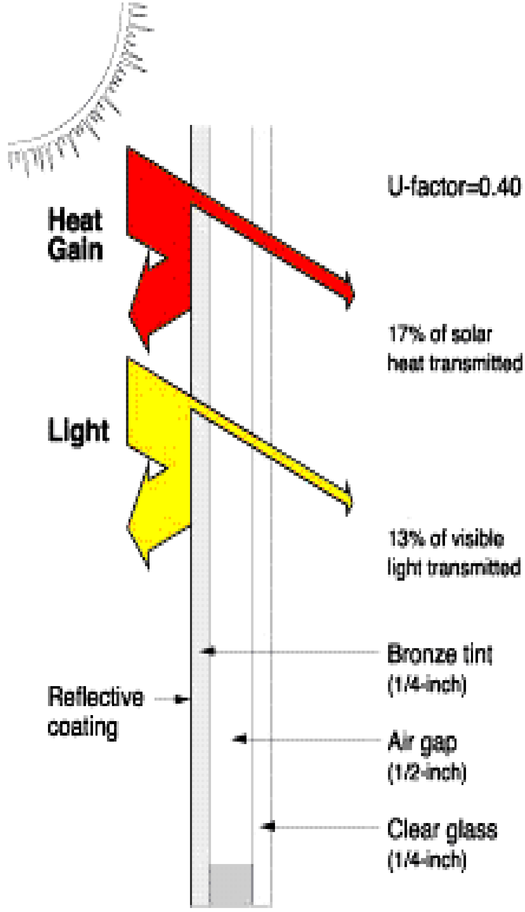

Figure 4- Double glazing with bronze tinted and highly reflective coating[57]

It can effectively control the building heat loss, with energy-saving rate of 50% -60%[58]. Some reflective coatings are durable and can be applied to exposed surfaces; others must be protected in sealed insulating glass units[59]. In this glass type, the daylight transmittance is usually more than the solar heat gain coefficient. Reflective glazing is usually used in commercial buildings for large windows, for hot climates, or for windows with substantial solar heat gains. It is used by many architects for its glare control and uniform exterior appearance.

4-5-3-2 Low-E Coatings

Emissivity of glass is the ability of the glass to radiate the heat or light energy. This emission of radiant heat is one of the important components of heat transfer for a glass window. Reducing the window's emittance can greatly improve its insulating properties. Low-E coatings are specially designed coatings often based on metallic oxides; they are applied to one or more surfaces of insulated glass. They transmit specific desirable wavelengths and reflects other wavelengths. It is used to optimize energy flows for solar heating, daylighting, and cooling.

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[57] Commercial windows, Window Materials & Assemblies: Glazing Materials, accessed 2008, http://www.commercialwindows.umn.edu/materials_glazing2.php

[58] **M. Santamouris, D. Asimakopoulos,** 1996, *Passive Cooling of Buildings*, published by Earth scan. p338.

[59] Ibid

A low-E coating glass is designed to minimize summer heat gains, but allow for some daylighting, it blocks ultraviolet and near-infrared radiation, as well as blocking long-waves radiated from outside objects, such as pavement and adjacent buildings[60]. Thus, low-E coatings maintain a low U-factor and reduce the total solar heat transmittance percent while providing high levels of daylight transmission (figure 4-31).

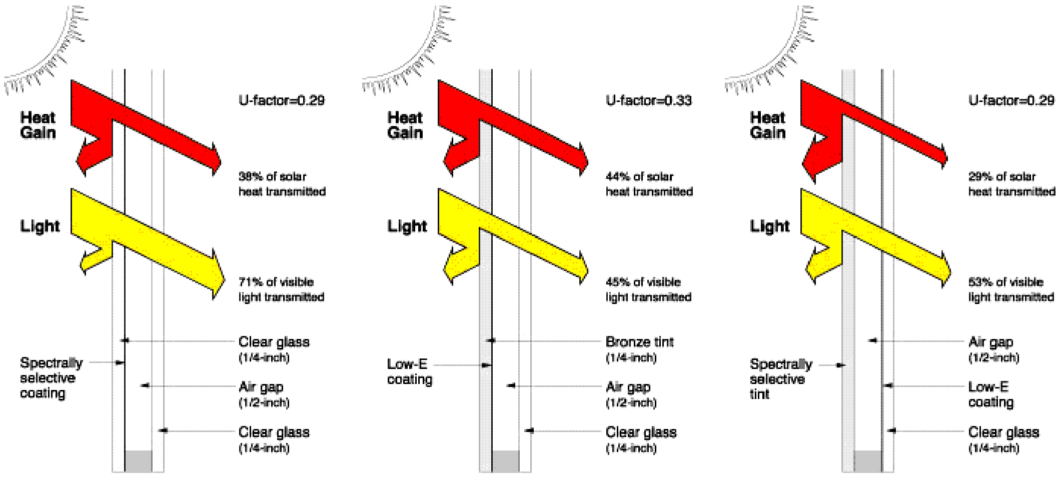

*Figure 4- **Solar radiation percent in low-E coated double tinted and clear glass*** [61]

From the previous sections, transmittance (T), reflectivity (R), and absorptance (A) of sun light and solar radiation varies with the variation of the glass type, number of glass panes, its thickness, color, and presence of coatings on it. The following table presents the T, R, A and the shading coefficient of different thicknesses of clear float glass, reflective coated glass, and tinted glass in order know how to select the suitable glazing unit for a particular application. The architecture should select glazing panes that have maximum light transmittance, minimum solar radiation transmittance, absorptance, and shading coefficient for construction a passive design building.

[60] Ibid

[61] Ibid

Glass type /glass thickness	Sun light		Solar radiation			Shading coefficient		
	T	R	T	R	A	Short wave	Long wave	Total
Clear float 6mm	**0.89**	**0.08**	**0.82**	**0.07**	**0.11**	**0.94**	**0.04**	**0.98**
Clear float 12mm	**0.82**	**0.07**	**0.67**	**0.06**	**0.27**	**0.77**	**0.10**	**0.87**
Reflective silver coated 6mm	**0.10**	**0.38**	**0.08**	**0.32**	**0.60**	**0.09**	**0.17**	**0.26**
Reflective bronze coated 6mm	**0.10**	**0.19**	**0.06**	**0.21**	**0.73**	**0.07**	**0.20**	**0.27**
Reflective blue coated 6mm	**0.20**	**0.20**	**0.15**	**0.21**	**0.64**	**0.17**	**0.21**	**0.38**
Tined green 6mm	**0.72**	**0.06**	**0.46**	**0.05**	**0.49**	**0.53**	**0.19**	**0.72**
Tined blue 6mm	**0.54**	**0.05**	**0.46**	**0.05**	**0.49**	**0.53**	**0.19**	**0.72**
Tined bronze 6mm	**0.50**	**0.05**	**0.46**	**0.05**	**0.49**	**0.53**	**0.19**	**0.72**
Tinted grey 6mm	**0.42**	**0.05**	**0.42**	**0.05**	**0.53**	**0.48**	**0.21**	**0.69**

Table 4- Thermal-Optical properties of different glass types[62]

Where T is Transmittance factor, R is Reflectivity factor, A is Absorptance factor

4-5-4 Complex glazing

A French start-up has developed a new technology of complex glazing for facades. Complex glazing is a half-transparent insulated glass with an integrated fixed Venetian blind and a fully effective solar collector. It has to be integrated in the façade as a glass unit in standard windows or facade profiles on commercial buildings[63].

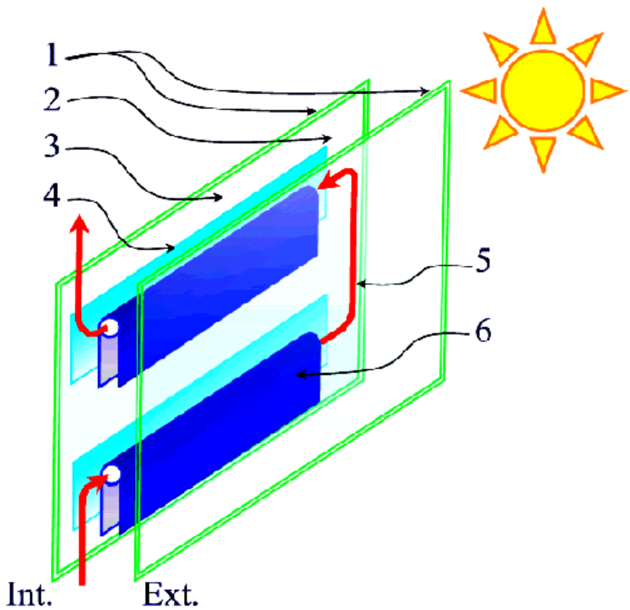

Figure 4- Complex glazing components[64]

[62] **M. Santamouris, D. Asimakopoulos**, 1996, *Passive Cooling of Buildings*, published by Earth scan. p339.

[63] France patent, *Advanced glazing for facades with an integrated solar control and solar thermal collector*, 2007.
From website: http://www.technology-market.eu/tee/Profiles/06_FR_GECA_0G4K.html

[64] Ibid

4-5-4-1 Glazing components

This complex glazing transforms solar energy in a new way to contribute energy as form of hot water, it is composed of:

1- Extra white Float laminated glass
2- Krypton gas
3- Low-E coating
4- Mirror strips coating
5- Cupper Aluminium strips with solar selective absorber.
6- Absorber

4-5-4-2 Working principal

When sun shines some of the solar energy reflected, some absorbed through the glass and the rest transmitted and directly intercepted by the aluminum strips. The mirror strips beside the interior glass limit the passive solar income and reflect it to the absorber. Solar energy is hen transferred with water circulation into the cupper serpentine to a storage place for sanitary or heating use.

4-5-4-3 Functions

- Top insulation.
- Daylight.
- Fixed solar control.
- Very effective solar thermal collector.

4-5-5 Electrically Switchable Smart Glass

Electrically switchable smart glass is type of glazing which changes light transmission properties when voltage is applied.Smart glass is a glass that could be manually or automatically switched to control the amount of light, glare and heat passing through a window. Glass facades with this smart technology reduce the need for air conditioning during the summer months and heating during winter. Electro-chromic glass is one of electrically switchable smart glass which changes its light transmission properties in response to voltage and thus allows controlling the amount of light and heat passing through.

4-5-5-1 Working principal

In electro-chromic windows, the electro-chromic material changes between a colored, translucent state (usually blue) and a transparent state. An amount of electricity is required for changing its state but once the change has been effectuated, no electricity is needed for maintaining the particular shade which has been reached. Darkening occurs from the edges, moving inward, and is a slow process, ranging from many seconds to several minutes depending on window size. Electro-chromic glass provides visibility even in the darkened state[65]. Electro-chromic Smart Glass consists of two electrodes separated by an ion conductor. Transparent conductors form the contacts. When the power supply is switched **off,** the rod shaped suspended particle molecules align, light passes through and the smart glass panel clears (figure 4-33). When the power supply is switched **on** the rod shaped suspended particle molecules are randomly oriented blocking light and the smart glass becomes dark blocking up to 99.4% of light.

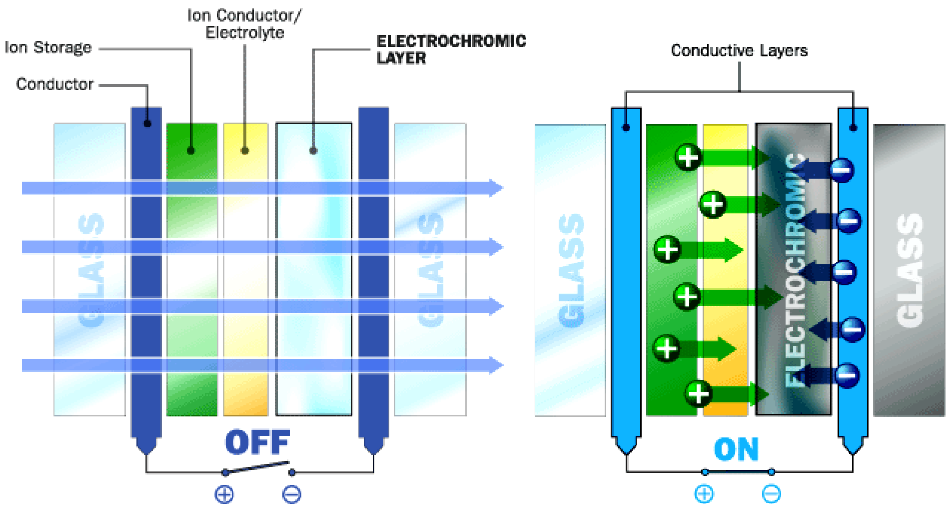

Figure 4- Electro-chromic glass status when electricity is switched on or off[66]

4-5-5-2 Advantages

Electrical switchable smart glazing has proved its effectiveness in many commercial usages; it has been shown to improve health and well being due to these advantages[67]:

- Instant and precise control of light
- Energy Savings on cooling & lighting costs
- Eco friendly, reduce building carbon emissions
- Elimination of the need for expensive window dressings like electronic louvers; blinds and solar shades used in architectural applications

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[65] Electro Chromic, accessed 2009. http://loop.ph/bin/view/Openloop/ElectroChromic

[66] Ibid

[67] **Smart glass international Ltd**, 2009, *Electronically switchable smart glass handbook*, p10.

- High durability, solid-state technology with no moving parts to wear out or break
- Large sizes of any shape can be produced
- Stable color characteristics for the life of the unit
- Wide working temperature range from -20°c to +70°c – Ideal for exterior applications
- Ambient temperature control
- Low maintenance material
- Wide light transmission ranges
- Reduces uncomfortable and glare feeling
- High UV stability
- Long life – tested to in excess of 100,000 cycles

4-5-5-3 Controls

Electrically Switchable Smart Glazing has a wide range of controls to allow high range of flexibility to the space user. It could be controlled by:

- Manually with a dimmer switch
- Wall switch
- Remote control
- Movement sensor
- Light sensor
- Timer

4-5-5-4 Applications

It could be applied for Roof lights, building facades, sunroofs, board rooms, meeting rooms, doors, conference rooms, offices, or media rooms.

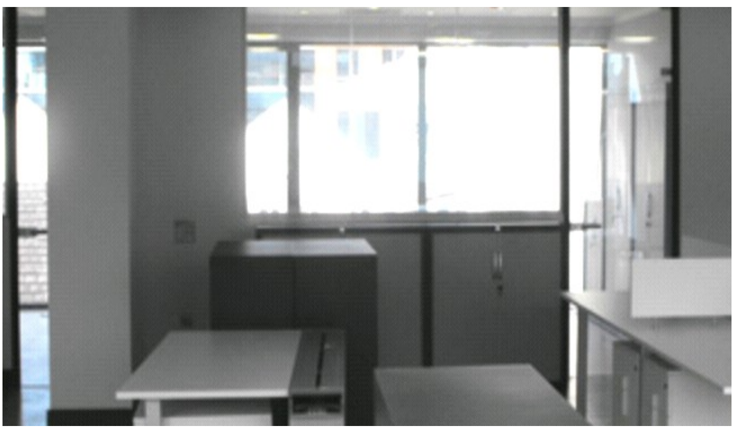

Figure 4- Application of switchable smart glass in corporate headquarters: when it is switched off (full transmission for light)[68]

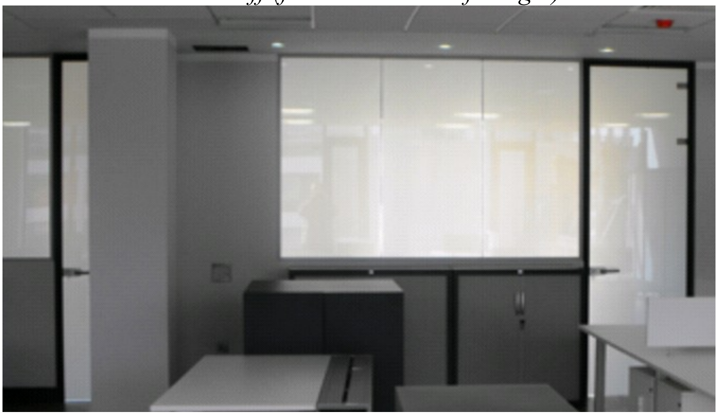

Figure 4- Application of switchable smart glass in corporate headquarters: when it is switched on (partial transmission for light)[69]

4-6 Conclusions

Well designed shading devices and glazing units are considered to be the most effective ways controling the internal conditions of modern glass façades commercial building. They can decrease the penetration of the solar radiations, reduce the building peak heat gain and, thus, decrease the cooling loads. Moreover they can improve the natural lighting quality. This can eliminate the need for mechanical air conditioning, and thus reduce the building running costs. It has been reported that shading devices could reduce the annual cooling energy consumption by 5% to 15%[70] depending on the climate, building location, and the applied shading system. Thus, they could be efficient solutions for a natural passive cooling design in sustainable commercial buildings.

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68 SmartGlass Solar Control, accessed 2009, http://www.smartglassinternational.com/products-services/spd-smartglass-solar-control/

69 Ibid

70 Sun Control and Shading Devices, by Don Prowler, FAIA , Donald Prowler and Associates Revised and expanded by Joseph Bourg, Millennium Energy LLC, accessed 2008. http://www.wbdg.org/resources/suncontrol.php

5-1 Introduction

Offices are spaces to provide the working environment for a large proportion. One of the important needs of workplaces design is to enhance the relationship between employees and the surrounding environment in order to increase the annual productivity. This could be achieved through: embracing new ways of working, enhancing the indoor environment, and creating a healthy and interesting working environment. Surveys and studies were conducted to evaluate the existing workplaces to confirm new accommodation requirements in order to increase their productivity. Problems identified with the current workplaces include poor environmental conditions and high levels of energy consumption when compared with other building sectors. To overcome these problems a new trend (concerning the environmental exhaustions, global warming, and consequential climate changes) will be a key issue for today's generation of commercial buildings design, these problems is considered to be the result of excessive greenhouse gas emissions generated from burning of fossil fuel. This chapter will illustrate the efficiency of passive cooling and sustainability strategies as away to decrease the energy consumption, eliminate greenhouse gas emissions, and enhance the indoor environmental quality through presentation of three modern large scale sustainable office buildings as case studies.

5-2 Introducing Natural Passive Cooling and Ventilation Strategies to Sustainable Office Buildings

Most energy consumption in office buildings is for cooling, ventilation, and lighting purposes, office equipments use significant portion of energy as well. It was detected that the annual energy consumption in office buildings varies between 100 and 1000kWh per square meter[1], depending on geographic location, building usage, building envelope structure, presence of HVAC systems, and lighting equipment. Therefore, applying passive cooling strategies to office buildings will have a great effect on decreasing the energy consumption and running costs. Moreover, a new concern of natural passive cooling and ventilation systems is due to different problems associated with the usage of conventional air conditioning and the serious increase of the absolute energy consumption of buildings. Some of these problems are:

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[1] **Kimmo Kuismanen**, 2007, *Climate and Ventilation*, project by ECONO.PDF, p8.

- *More electricity demand*: it creates the need to build additional power plants, thus, increasing average costs of electricity.
- *Indoor air quality problems:* recent studies for air conditioned buildings have shown that illness is relatively higher than those non-air conditioning buildings.
- *Electric control failure:* the compressor and fan controls could be exhausted, especially when the air conditioner turns on and off frequently, as it is common when a system is oversized.
- *Insufficient maintenance:* if the filters and air conditioning coils become dirty, the air conditioner will not work properly.

The following section presents three sustainable office buildings in different locations having different climates as case studies for the appliance of various passive cooling and sustainability strategies in each. This could help evaluating the efficiency of applying the sustainability principals on large scale office buildings.

5-3 Council House 2 (CH2), Melbourne, Australia

Location: Melbourne, Australia
Client: City of Melbourne
Architect: City of Melbourne + Design Inc Melbourne
Construction year: 2004- 2006
Rating and awards: CH2 has been the recipient of a range of awards in Environmental Planning or Conservation: National Awards for Planning Excellence 2007 (Planning Institute of Australia), Sustainable Design: Global Innovator's Awards 2007 (CoreNet Global), Greenhouse Expenditure Award: Eco-Buy Awards 2006 (Green Building Award), World Environment Day Awards 2005 (United Nations Association)[2].

Figure 5- Exterior overview, Council House 2 (CH2), Melbourne[3]

5-3-1 Background

[2] City of Melbourne, council House 2, Introduction, accessed 2008 http://www.melbourne.vic.gov.au/info.cfm?top=171&pg=1933
[3] Ibid

Commercial buildings in Australia generate more than 35 million tones of CO_2 per year[4]. Melbourne city aims at achieving zero emissions for the city by year 2020. A major contribution to this strategy is the reduction in energy consumption of commercial buildings by 50%. Therefore, the City of Melbourne decided to construct the CH2 building as a new office accommodation project. It considered a sustainable office building which was officially opened in August 2006; it becomes a model of environmental and sustainable design for commercial and governmental buildings in Australia (figure 5-1) that aims at:

- Reducing greenhouse gas emissions arising from the Council's operations;
- Driving cultural change across all government agencies in energy management and the integration of environmental considerations;
- Displaying energy reduction targets and realize carbon dioxide (CO_2) savings through cost-effective actions, without compromising productivity and working conditions;
- Assisting on holding down electricity costs over the medium term through integration of some ecological components like: passive heating, passive cooling, power generation, material conservation, water conservation, and creating a comfort indoor environment.
- Using some new design strategies and technologies that respond to Melbourne's environmental conditions, which were not applied in the Australian commercial buildings before.

5-3-2 Overview on Climatic Conditions

Melbourne city is the capital of the state of Victoria in the southeastern part of Australia. Its climate is classified as temperate climate with warm to hot summers. However, the weather in Melbourne is highly inconsistent, and is sometimes described as "four seasons in one day"[5]. It considered being colder than other mainland Australian state capital cities in winter. Its lowest average temperature is about 6 °C in July, while maximum temperature is about 46°C in February. Melbourne commonly enjoys extended periods of shiny sun, mild weather, clear skies and low rainfall. This variability in weather and environmental conditions had been taken into consideration before designing the CH2 building.

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[4] According to the Property Council of Australia (2001),
from website: http://www.melbourne.vic.gov.au/info.cfm?top=269&pg=3166

[5] Welcome to Melbourne, Melbourne's weather and climate
http://www.melbourne.vic.gov.au/info.cfm?top=269&pg=3166

5-3-3 Effect of Climatic Conditions on Building Design

CH_2 is a 10 storey building with a long east-west floor plane divided into various layered zones. The northern edge of the space is considered open plan workstations with access to natural light from windows. The southern edge is allocated to meeting rooms, separated from the workstations by a circulation corridor. Services and other common areas, including toilets, lifts, external staircases, and kitchens, are located in the cores at the eastern and western ends (figure 5-2). In CH_2, the open plan arrangement allows a degree of connection to the outside for all workers, while vertical interconnection possible via balconies and external stairs[6].

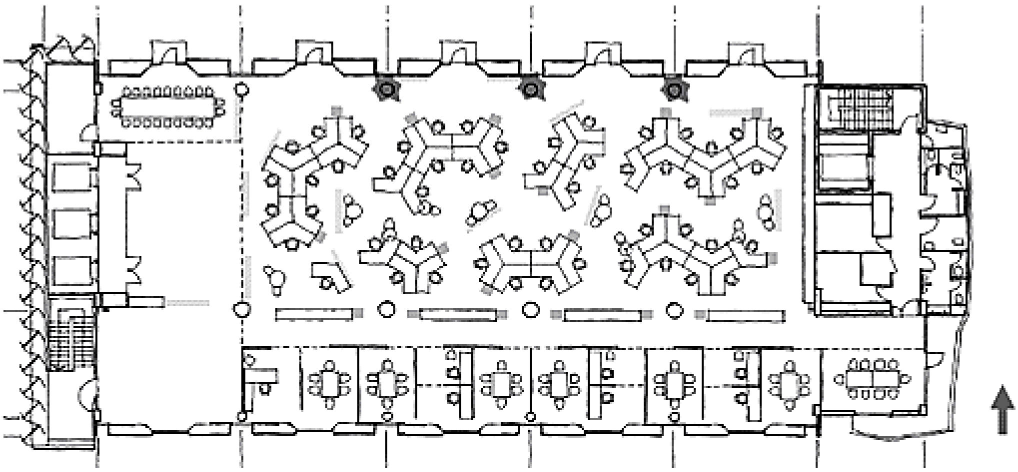

Figure 5- plan of a typical floor[7]

For efficient cooling design, vaulted concrete ceilings are placed in offices. Outside night air cools the 180mm-thick pre-cast vaulted concrete ceilings. The ceilings store this coolness because of their high thermal mass. This coolness radiates back into the office space during the day and contributes to the cooling needs of the offices, thereby reducing air conditioning plant energy loads by up to 14 percent in summer. The vaulted concrete ceilings in offices (figure 5-3) have the following variety of significant benefits:

- Enhancing the air stratification in the offices by keeping warmed air further away from occupants.
- Optimizing natural light by locating shafts at the highest point of the vault.

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[6] **Scott Drake**, 2007, *Workplace Environment: people, the built environment, technology, and processes*. PDF, Faculty of Architecture Building and Planning, p8.

[7] Ibid

- Increasing the surface area of the ceiling, thereby increasing the thermal mass of the concrete and improving the heat absorption characteristics.
- Providing a void for the collection of the exhaust air, avoiding the need for an array of surface-mounted metal ducts[8].

Figure 5- Interior view of vaulted concrete ceiling[9]

5-3-4 Passive Cooling Strategies

The main and most important consideration in any office building design in summer is the cooling and ventilation requirements. Heat load is generated from many sources: people, lighting, computers and other equipments, and heat gain through windows or through the fabric of the building. CH2 office building cares about this issue as the main issue in the design. It has perfect solutions to overcome the cooling problems by applying some passive cooling strategies through the presence of some elements:

- Radiation: Chilled ceiling panels and Chilled beams
- Evaporation: Evaporative cooling towers
- Ventilation: Night purge, Solar stack ventilation and High performance energy efficient facades
- Shading techniques

[8] City of Melbourne, Council House 2, cooling system, accessed 2008, http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944
[9] Ibid

5-3-4-1 Radiation: Chilled ceiling panels and Chilled beams

CH2 is designed to maintain the offices temperature between 21ºC-23ºC as a mean of air and radiant temperatures. To control the indoor temperature level, chilled ceiling panels and beams are placed on the ceiling of offices to allow efficient cooling the air inside the offices, this process allows significant energy saving.

a) *Chilled ceiling panels*

The internal heat generated from the occupants and equipments are absorbed into the building construction and the replaced air is cooled through the chilled panels (figure 5-4).

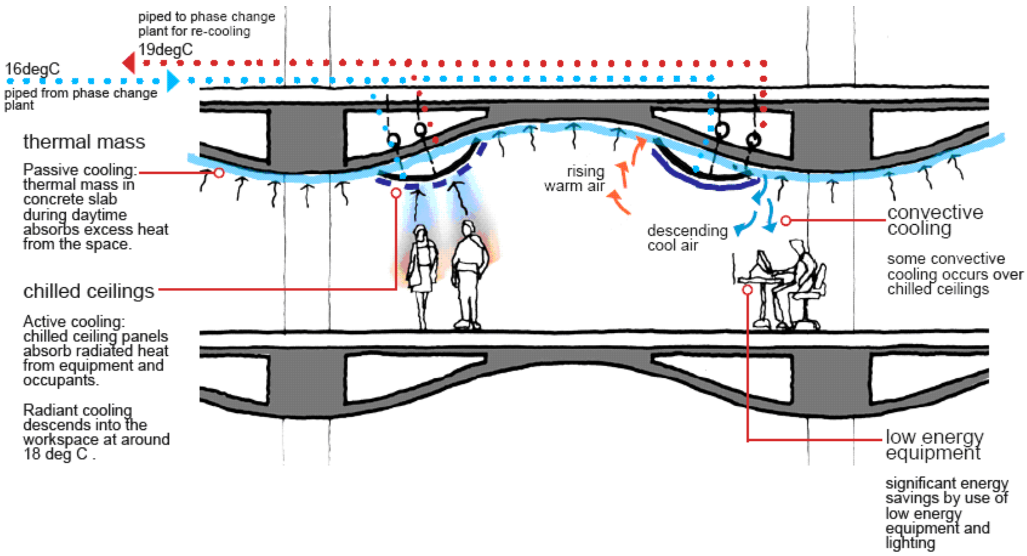

Figure 5- Chilled ceiling panels placed onto the ceilings [10]

[10] City of Melbourne, Council House 2, cooling system, accessed 2008, http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944

Figure 5- Interior view: Radiant ceiling panel[11]

Chilled water for radiant cooling is supplied by three large chiller tanks in the basement. Each contains about 10,000 small stainless steel balls filled with a form of Phase Change Material (PCM) (Appendix D) that can freeze at 16°C[12].

b) Chilled beams

Warm air coming from the ceiling is dragged down to be cooled by chilled beam and producing a curtain of cool air over the window decreasing the internal heat gain (figure 5-6), (figure 5-7).

Figure 5- Chilled beam as detailed in prototype office[13]

[11] Ibid

[12] Ibid

[13] **Dominique Hes**, 2004, *Design snap shot 16:chilled panels and beams.* PDF, p3. From website: http://www.melbourne.vic.gov.au/info.cfm?top=171&pg=4113

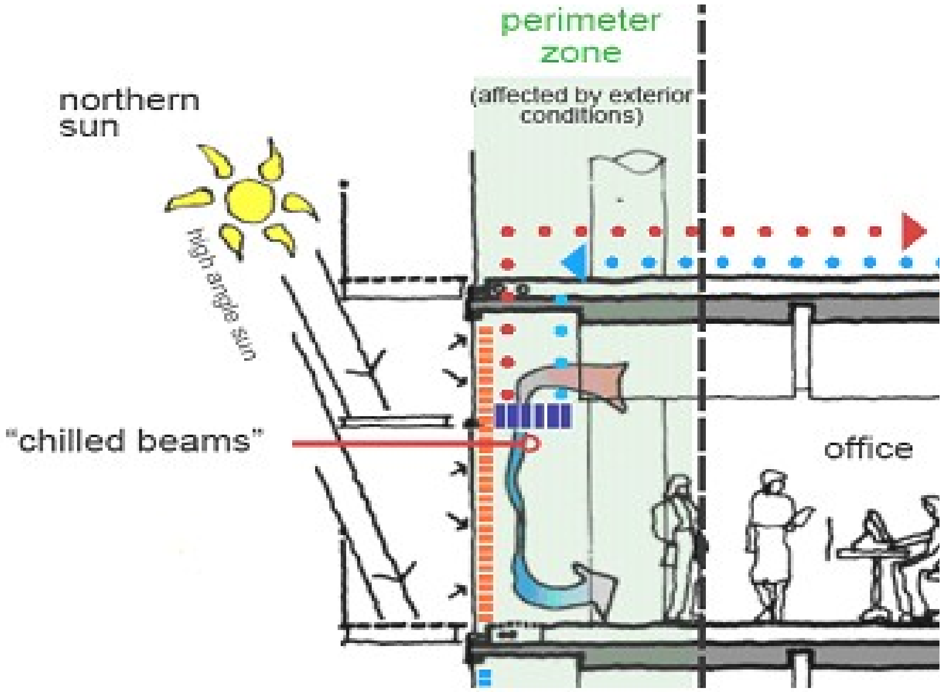

Figure 5- Chilled water runs through radiator coils to absorb heat gained from glass facade[14]

5-3-4-2 Evaporation: Evaporative cooling towers (Shower towers)

On the south façade, there are five shower towers that condition the air in the ground floor by evaporative cooling. They are made of durable lightweight fabric material, 13-metres tall and 1.4-metres in diameter (figure 5-8). Water inside the towers falls and cools the air which has entered to the tube from the top of the tower.

Figure 5- Five evaporative shower towers on the south façade to cool the ground floor[15]

Water is put through the cooling towers on the roof. Using a trickle evaporative cooling process heat is dissipated to the air. As the air falls within the tower, it is cooled by evaporation from the shower of water and about 0.5-0.7°C is removed.

[14] Ibid

[15] City of Melbourne, Council House 2, cooling system, accessed 2008, http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944

The cool air is supplied to the retail spaces. They act as conventional evaporative coolers without the need for a fan to drive the air supply. The air is dragged down by friction caused by the water falling under gravitational force, and also by the downdraft created by the evaporative cooled denser air. This in turns pull the cool air to enter to the ground space to feed into the ground floor lobby, shops and arcade (figure 5-9).

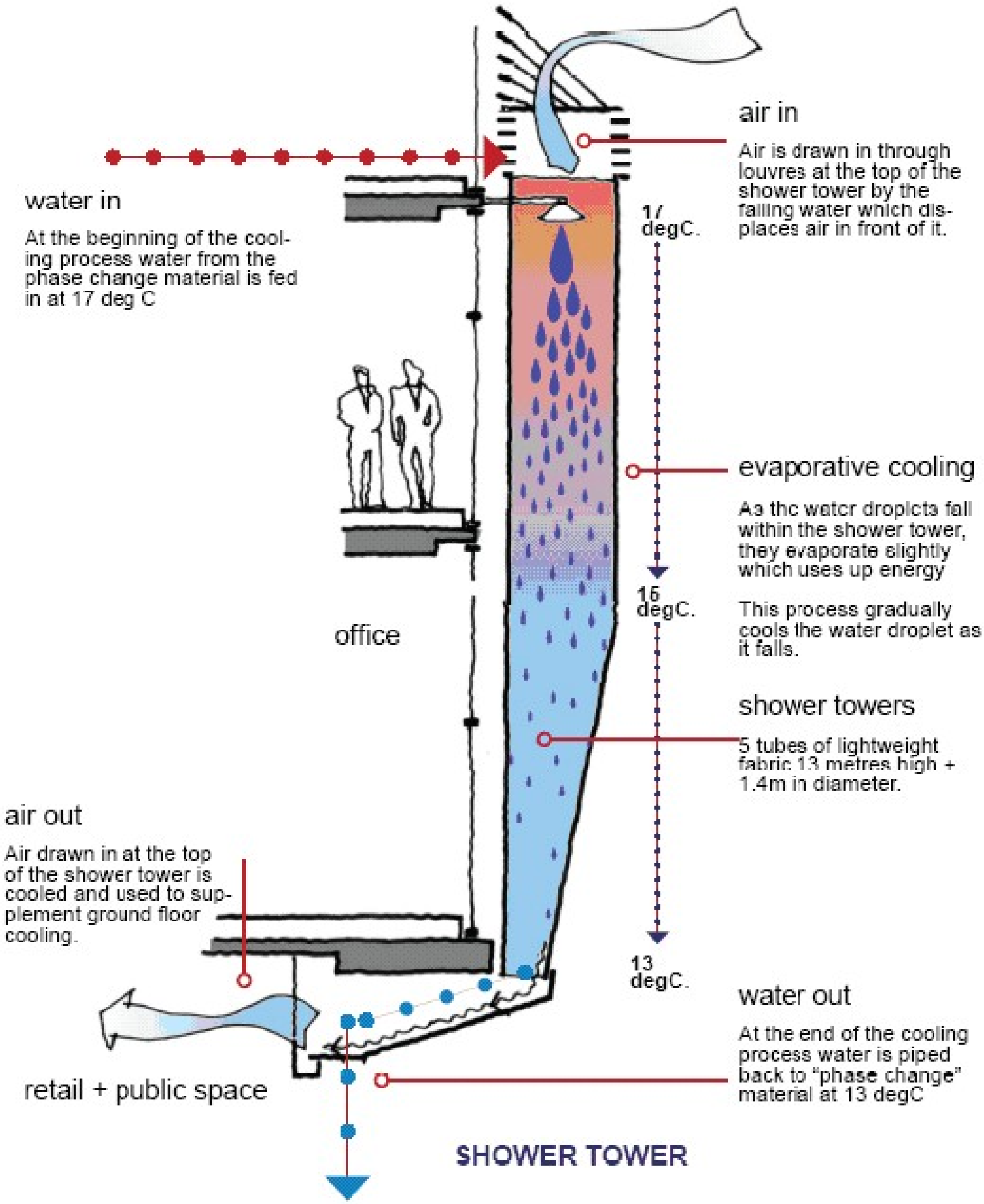

Figure 5- Evaporative cooling tower working process[16]

[16] Ibid

The evaporative towers also used to assist the cooling of offices by pre-cooling the water returning from the chilled ceiling panels before it enters the phase change tanks in order to assist the phase change material to last longer before melting (figure 5-10). In winter, when the night air is very cool, the water that returns to the basement will be cold enough to re-freeze the PCM balls without the need for chillers.

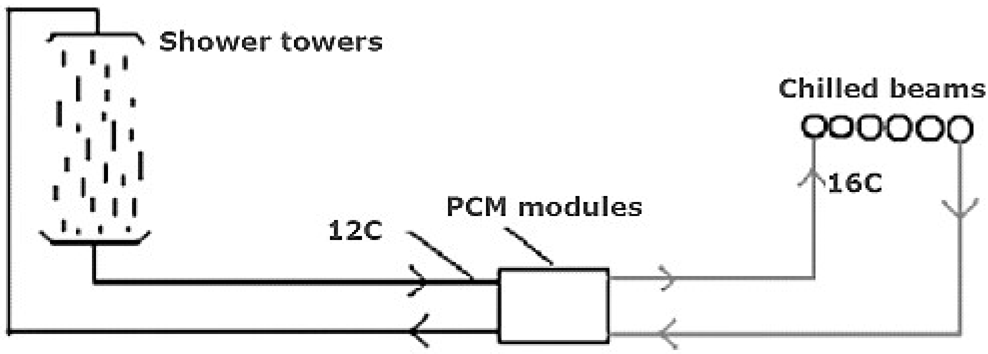

Figure 5- A schematic shows how the PCM storage facility used with the various cooling systems in the CH_2 building[17]

5-3-4-3 Ventilation: Night purge, Solar stack ventilation and High performance energy efficient facades

a) Night Purge

In Melbourne, night air is significantly cooler than daytime air. When the external temperature falls below than that of the internal concrete ceilings, the low points of the vaulted ceiling is automatically opened. The night cooled air enters through the windows in the north and south facades and the warm air flow out of the space by stack effects through the exhaust air shafts in the vaulted ceiling, this cooling system called night purge (figure 5-11).

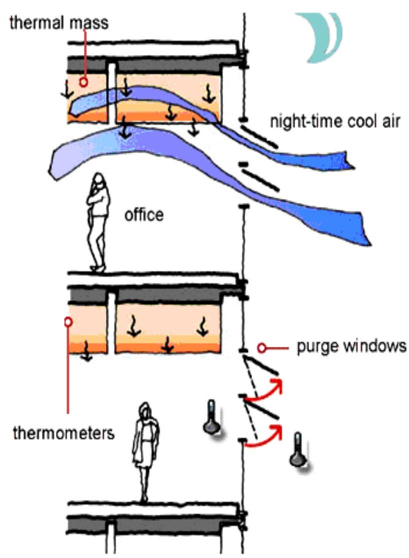

Figure 5- Thermal mass and night purge idea[18]

[17] **Dominique Hes**, 2004, Design snap shot 15: Shower Towers. PDF, p3.

[18] Ibid

Wind turbines installed at the top of the solar stacks will further enhance the effectiveness of night-time purging, by inducing an extra volume of cool nighttime air to come in contact with the thermal mass (figure 5-12). Night cooling is automatically controlled by the aid of automatic control temperature sensors in the concrete ceiling. Automatic sensors are placed on the ceiling to control opening and closing the ceiling openings according to the external and internal concrete temperatures. If the temperature of the concrete falls below a set level (usually about 20°C in summer) the windows will close and stop the night purge. This is to prevent the ceilings becoming too cold. In winter this set point is raised to approximately 24°C. In very high-wind situations, the purge windows on one side of the building remain shut and the wind-driven turbines maintain the purging air flow[19]. Mechanical cooling may be used as required to provide the equivalent night purge benefits when a passive night purge is not available.

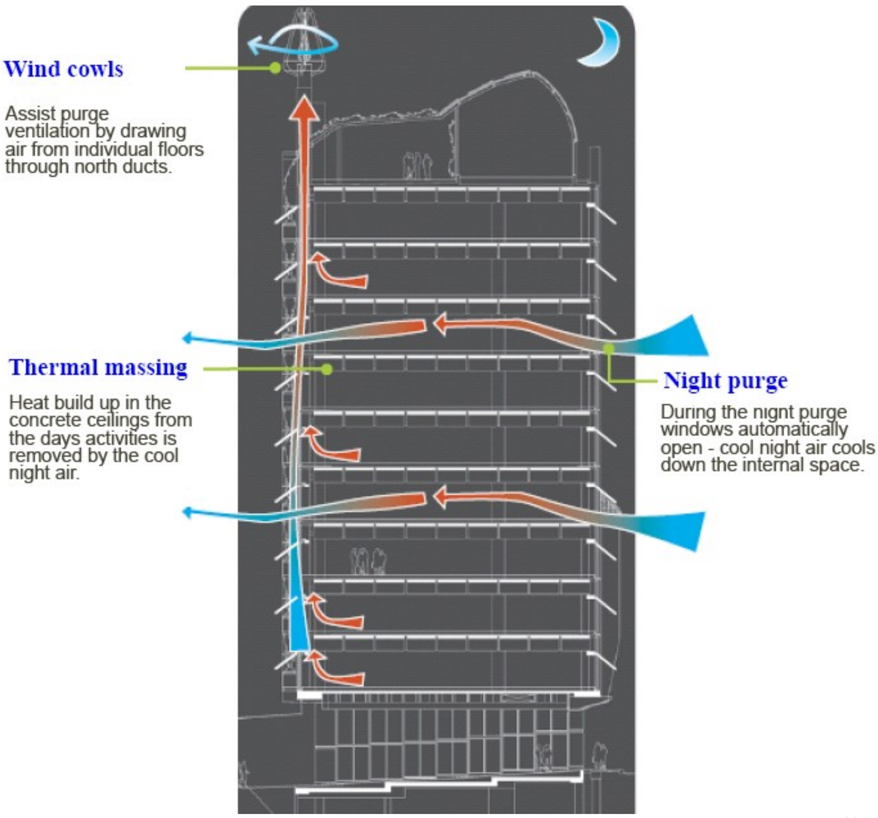

Figure 5- Schematic section shows the night cooling mode in CH2 building[20]

[19] Ibid

[20] Melbourne city government, Fact sheet: How the building work?. PDF, accessed 2008 From website: http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944

b) Solar stack ventilation

In CH2 the air intake is 100 percent filtered outside fresh air, it is tunneled down to the offices through vertical supply ducts on the south façade which in turns supply air to the offices through vents in the offices floor (figure 5-13). These vents can be adjusted by the users for comfort. The temperature of the interior is approximately constant; it is about 20 degrees.

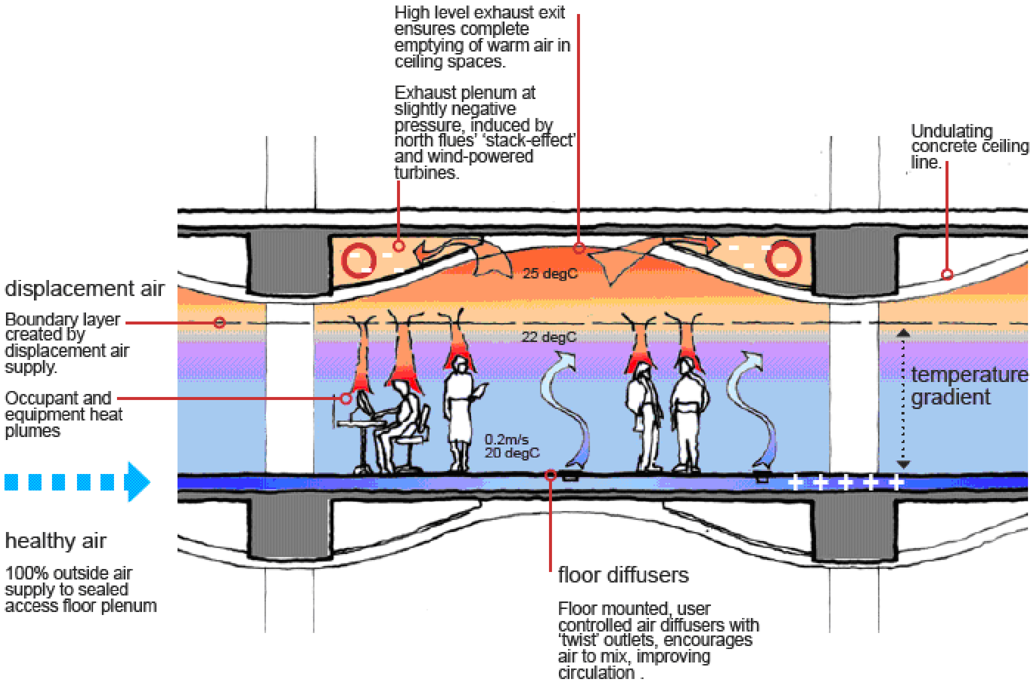

Figure 5- Air is supplied to offices from south façade ducts through floor diffusers and exhausted through ducts in the ceiling and then to the north ducts[21]

CH2 building has six dark colored solar stacks ducts which are installed in the north façade. These solar stacks are designed as part of the exhaust path for the office daytime ventilation and night cooling systems (figure 5-14). Therefore, air is only used once and then exhausted by natural convection into the voids in the offices ceilings to the exhaust air ducts and then to the atmosphere (figure 5-15). This means that there are two complete air changes every hour in CH2; this creates healthy, comfortable, and productive interior spaces[22].

[21] Ibid

[22] Ibid

Figure 5- Solar stack ventilation ducts on north façade (right) and south facades (left)[23]

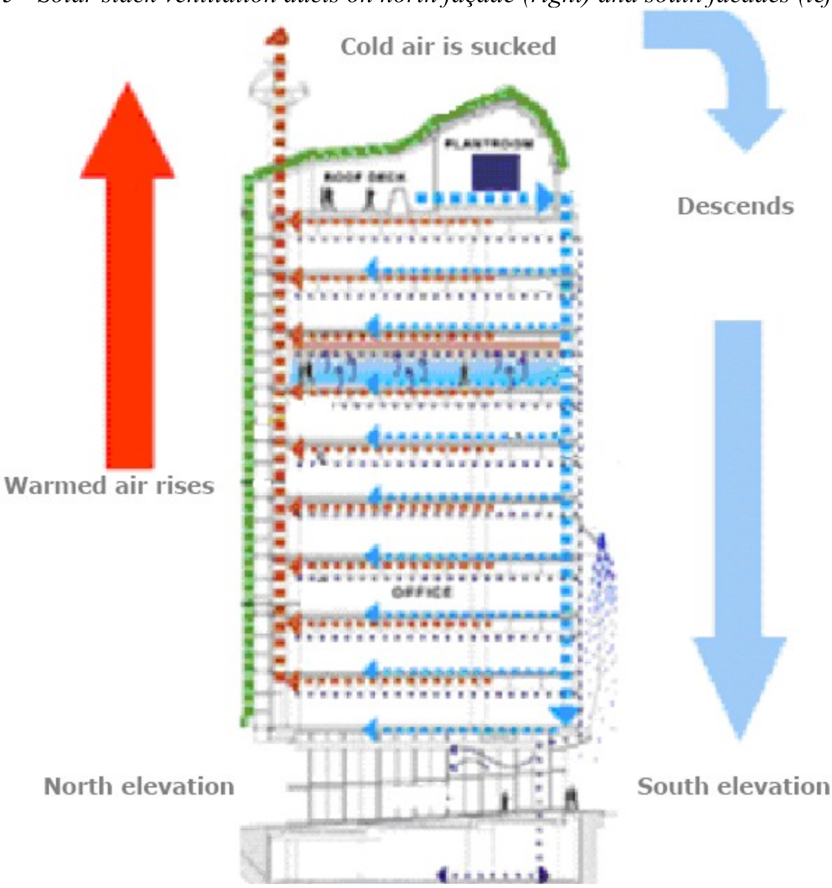

Figure 5- Fresh air supply and exhaust process through Ventilation stacks situated on the north and south facades of the building. [24]

[23] **Dominique Hes**, 2004, *Design snap shot 06: Shower Towers.* PDF, p4.

[24] City of Melbourne, Fact sheet: How the building work?. PDF, accessed 2008
From website: http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944

c) High performance energy efficient facades

Windows on the north and south facades are treated by some features to assist the interior cooling process. They considered as barriers to the internal heat gain into the building in summer, while prevent heat loss from the interior in winter. The windows existing in this building have some features to assist the cooling process, they are as follows:

- Double glazing to protect the internal space from heat gain.
- Timber windows frames which are a low conductor of heat when compared with aluminum, so it reduces the heat gain to the interior.
- Each window has blinds in the upper and lower part of the window, the blind can be set at the optimum level up the windows to protect from the direct sun rays without reducing the amount of natural light.
- External plants on the northern façade to the full height of the building. These plants provide both, protection from the sun's direct rays and help control glare by diffusing light.
- A splayed framing is connected to the windows to decrease the contrast between the very bright outside light and the internal dark wall.

5-3-4-4 Shading techniques

The western façade is shaded by shutters made of recycled timber (figure 5-16); it protects the offices from the afternoon sun while enabling views for the occupants and permits natural light to enter the building.

Figure 5- Exterior view, movable shading shutters on the western facade[25]

The shutters are opened when the sun is in the eastern or northern sky, and are closed only when the sun is in the west[26]. The shading shutters move automatically by a pre-set computer program according to the position of the sun on the sky. In cloudy weather, the shutters are totally opened to permit maximum natural light and ventilation.

[25] Ibid

[26] Ibid

While in direct sun radiations, the shutters are fully closed to block the sun radiations from penetrating through the slats. The movement of the shutters is hydraulically operated by using vegetable oil. The power required to operate the shutters is produced by the solar photovoltaic cells on the building's roof.

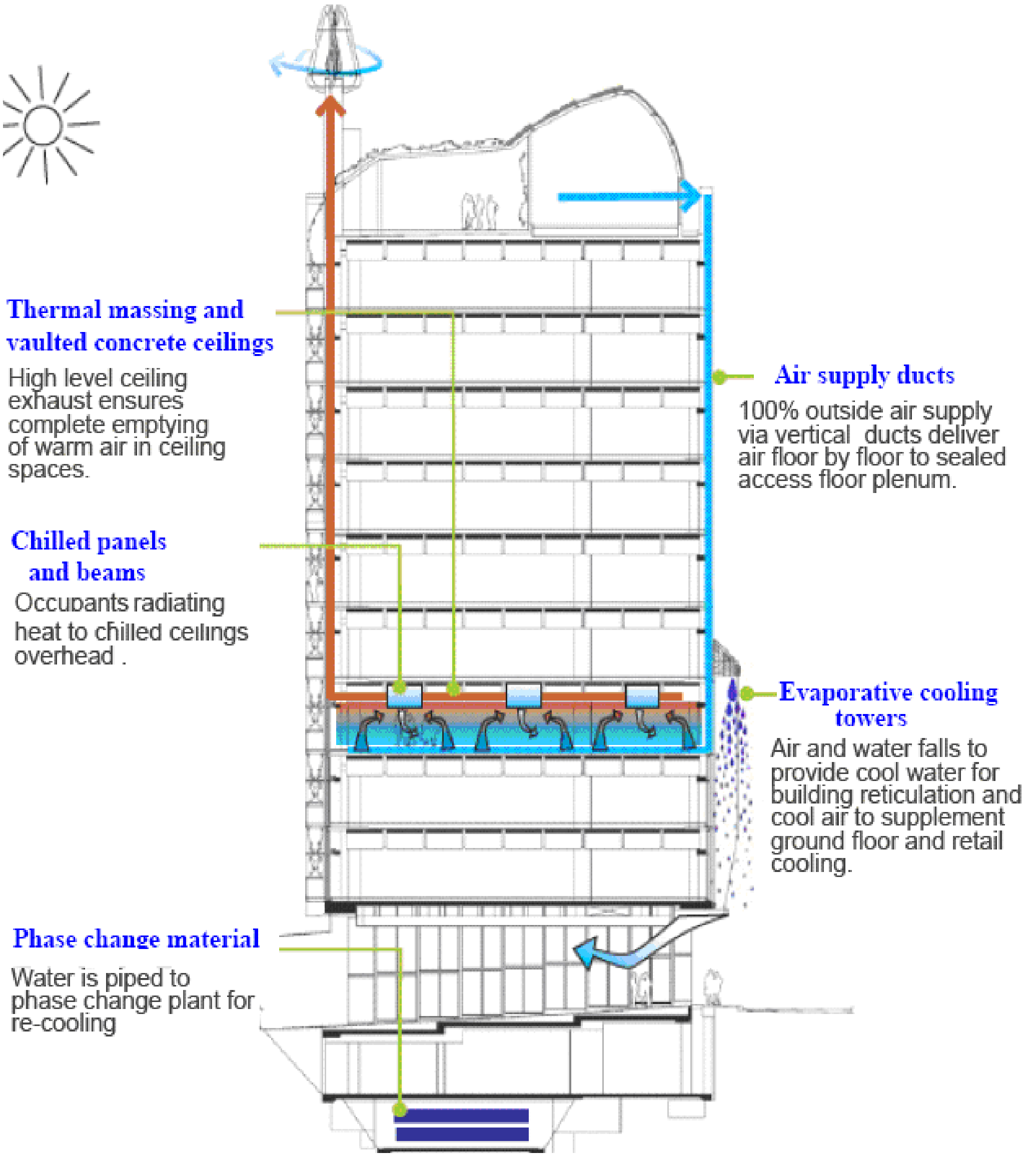

Figure 5- Schematic section for all passive cooling strategies in CH2 building[27]

[27] City of Melbourne, Fact sheet: How the building work?. PDF, accessed 2008 From website: http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944

5-3-5 Energy Efficient and Sustainable Features

The CH2 building has investigates how the integrated design of passive systems has the potential to deliver significant savings to the City of Melbourne with better environmental conditions to building occupants as well. It is expected to consume less than 50%[28] of current levels for Melbourne office buildings. In addition to passive cooling, Ch2 building has the potential to achieve a zero energy building by using some innovative ecologically sustainable strategies that includes:

- Energy conservation: Natural lighting, Efficient heating mode, and Energy generation.
- Water conservation
- Materials conservation
- Indoor environmental quality

5-3-5-1 Energy conservation: Natural lighting, efficient heating mode, Energy generation, and Green facades

a) Natural lighting

The CH2 building target is to maximize the natural daylight penetration to the inside spaces while reducing electrical lighting (figure 5-18). When the sensors detect the need of artificial light, energy efficient lamps will be turned on automatically and its lighting is adjusted when there is a percent of natural light available in the room. Moreover, the system is supplied with individually controlled lamps at workstations to give the occupants the freedom to control the light in their environment. Efficient natural lighting is achieved through the following issues:

- Windows location: The building windows is located in a way so that to take maximum advantage of natural daylight. Windows are located at the highest point of the curved concrete ceilings. Moreover, windows on the north and south facades are larger on the lower floors than the upper ones as lower floors receive less daylight.
- Glazing: The glazing is specified to have a visible light transmittance above 50%, with a solar transmittance below 35%.[29].

[28] **C.K. Cheung**, 2005, *CH_2 Energy Harvesting Systems: Economic Use and Efficiency*, Built Environment Research Group (BERG) School of Architecture and Building, Deakin University, Geelong, Victoria, Australia, 2005, p1.

[29] Ibid

- Lighting shelves: Steel lighting shelves are fixed internally and externally on the north façade to indirect the sunlight and reflect maximum natural light onto the ceiling so that to reduce the need of artificial light.
- Movable timber shutter: Shading timber shutters remain open to catch maximum daylight when there is no direct sun light, and closed incase of direct sunlight. Controlling systems are being used to close the parts having direct radiation or to open parts those having no direct radiations.
- Glare control: CH2's windows treatment incorporates some features to control glare by using of reveals: the air supply and exhaust ducts on both north and south facades. And by using External planting on the northern façade
- Daylight sensors: Daylight sensors are provided on the north and south facades; they can monitor the amount of daylight coming in and adjust the artificial light required according to the amount of natural light entering the space.

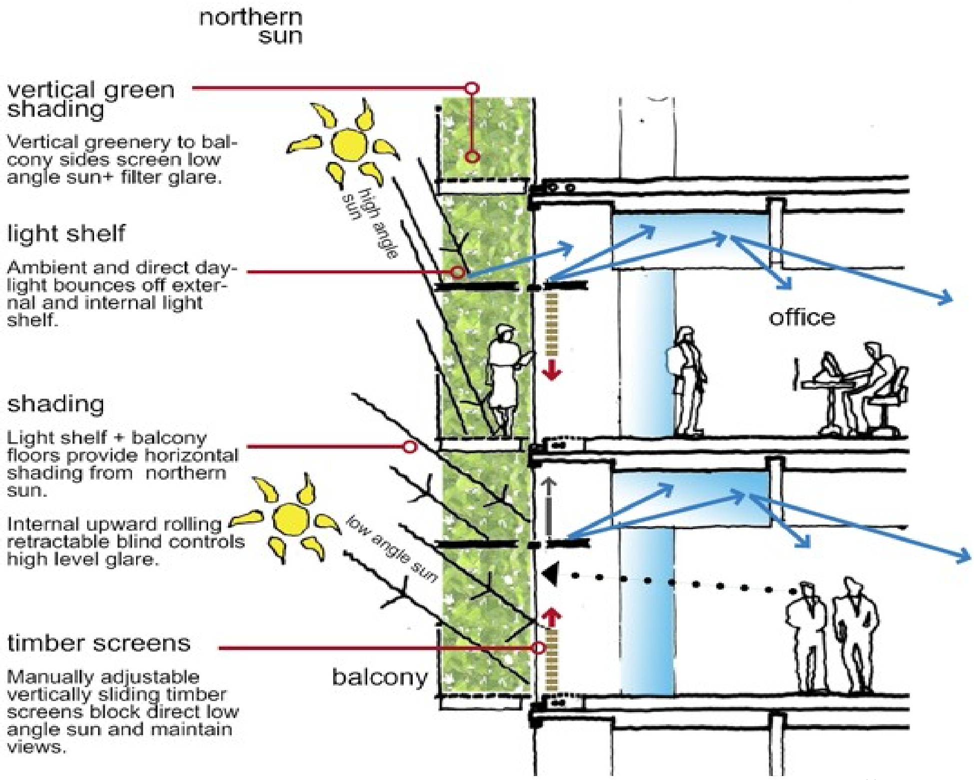

Figure 5- Sketch for maximizing day light strategies on the north facade[30]

30 City of Melbourne, Fact sheet: How the building work?. PDF, accessed 2008

b) Efficient heating mode

The temperature of air entering CH2 through the floor vents is usually around 20°C. This provides a basic ambient temperature control which is supplemented by additional cooling through the chilled ceiling panels or heating through hydronic heating. In winter, when additional heating is needed CH2 is in heating mode, additional heating is provided by hot water through an under floor hot water pipes located around the perimeter windows where heat loss is concentrated. In the floor, a timber grille is located beneath each window (figure 5-19) to protect the office area from cold by forming a warm air barrier around the perimeters, which rises into the space naturally using buoyancy, not fans.

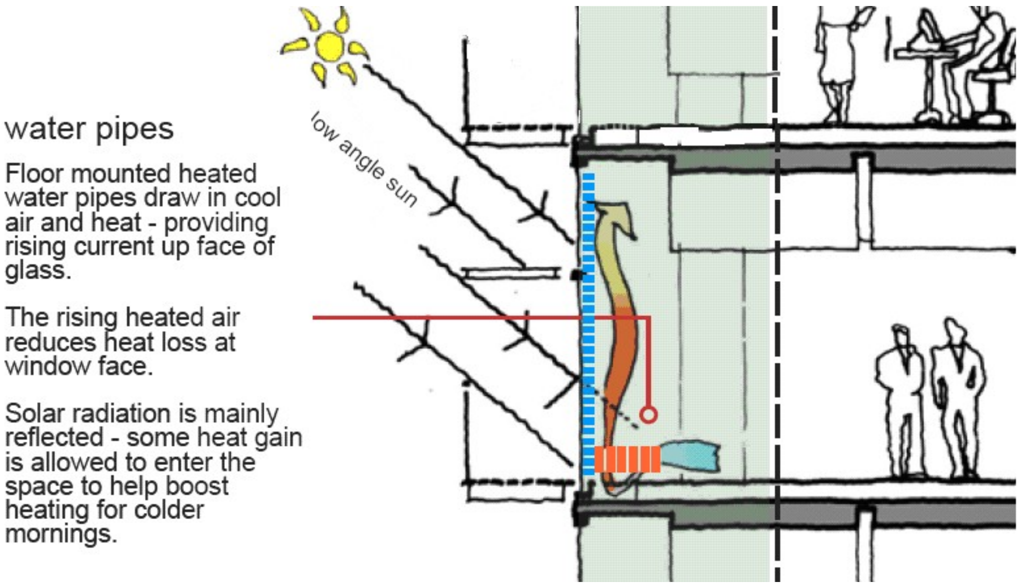

Figure 5- Winter mode in CH2 building at the north and south facades[31]

c) Energy generation

The CH2 is 100 % green power as it uses the following energy generation systems to achieve the self need energy.

- Natural gas micro-turbine: Energy efficient natural gas micro-turbine located on the roof, it is used to generate electricity. The co-generation plant has much lower CO_2 emissions than coal-fired electrical generation and provides electricity about 40% of the

From website: http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944

[31] Ibid

building's needs[32]. It generates much waste heat which could be used for warming water and conventional heating in winter.

- Wind-driven turbines: The CH2 contains six wind-driven turbines that enhance stack ventilation by about 30 per cent over an open stack. The wind turbines are predicted to improve the night purge ventilation of the building by about six percent on windy nights. In addition, wind turbines also operate as electricity generators during the daytime.
- Solar Power - Photovoltaic cells: About 26 m² array of photovoltaic cells are located on the roof to generate electricity from the sun's energy. The amount of energy generated is approximately equivalent to that required to power the movement of the Western timber shutters[33].
- Solar hot water panels: CH2 includes 23 solar panels and a gas boiler which supplements 75% of CH2's domestic hot water. The solar hot water panels captures and uses solar energy to heat about 2000 liters of hot water per day to supply showers and basins[34].

5-3-5-2 Water conservation

Low rainfalls and high temperatures have a great effect on reduction of Melbourne's water supplies and will have a long-term impact on the water supplies of Melbourne. This makes the government to implemented water restrictions and a range of other options including: water recycling and water consumption awareness schemes for the city. CH2 is considered a good example of the overall water conservation design. The strategy for CH2 has established a total water consumption design performance target of just less than 31 liters per day per person. Water conservation implemented by CH2 is achieved by applying three strategies:

- Water recycling
- Rainwater harvesting
- Innovative water saving plumbing fixtures

a) Water recycling

The CH2 uses efficient systems to purify the gray water and recycling it to be use in other purposes such as plant irrigation, street cleaning and toilet flushing. The water is collected in a storage tank with a capacity 15

[32] Ibid

[33] Ibid

[34] **C.K. Cheung**, 2005, *CH_2 Energy Harvesting Systems: Economic Use and Efficiency*, Built Environment Research Group (BERG) School of Architecture and Building, Deakin University, Geelong, Victoria, Australia.

kilolitres which is located in the basement. The wastewater treating system used an innovative micro-filtration system with ceramic filters; this system is unique and efficient for many applications in any building type. Moreover, Recycled water is being used in the cooling towers to reduce the water consumption.

b) Rain water harvesting
The building has been designed for the total roof area to be used for capturing rainwater. The rainwater collected is used in conjunction with the recycled water for toilet and urinal flushing, landscape watering, cooling towers and for off-site uses such as fountain top-up and street tree irrigation.

c) Water saving plumbing fixtures
Efficient low flow fixtures, automatic control fixtures, sensors, low flow toilets, low flow showerheads and waterless urinals have been installed for further reduction in water consumption.

5-3-5-3 Materials conservation
The building contains about 88% recycled contents[35], which is durable, environmental, low cost, and recyclable materials which are presented in:

a) Timber western shutters
The timber shutters on the western façade contains 100 % Recycled and untreated timbers, so it requires minimal maintenance.

b) External metal cladding (steel)
The building has external cladding with steel which is good durable material and more recyclable than other materials.

c) Structural Concrete
41% of concrete aggregate was reclaimed aggregate. About 58% of cement used for in-sit concrete and 17% of cement used for pre-cast concrete was replaced with an industrial waste product.

d) Wastes reduction
During the construction period, CH2's recycled about 80% of the construction wastes, and reused it in the building process.

[35] Ibid

5-3-5-4 Indoor environmental quality

For CH2, the space environmental condition is specified by these parameters:

- Air temperature level: it is predicted to be between 21 to 25 °C as this range can reduce the need for space conditioning.
- C02 levels: The C02 level of the indoor offices is constantly monitored, as the space is continually supplied by fresh air so the C02 level will be decreased to the minimum.
- Non toxic materials: Building materials have been selected so that to minimize the harmful emission gases and indoor pollutants such as Volatile Organic Compounds (VOCs).
- Green façades and roof: The northern green façade is made up of planter boxes situated to the east and west of each northern balcony provide a micro climate to various building spaces[36]. In western facades, winter gardens are presented inside the façade in order to encourage air movement and provide occupants access to the nature (figure 5-20).

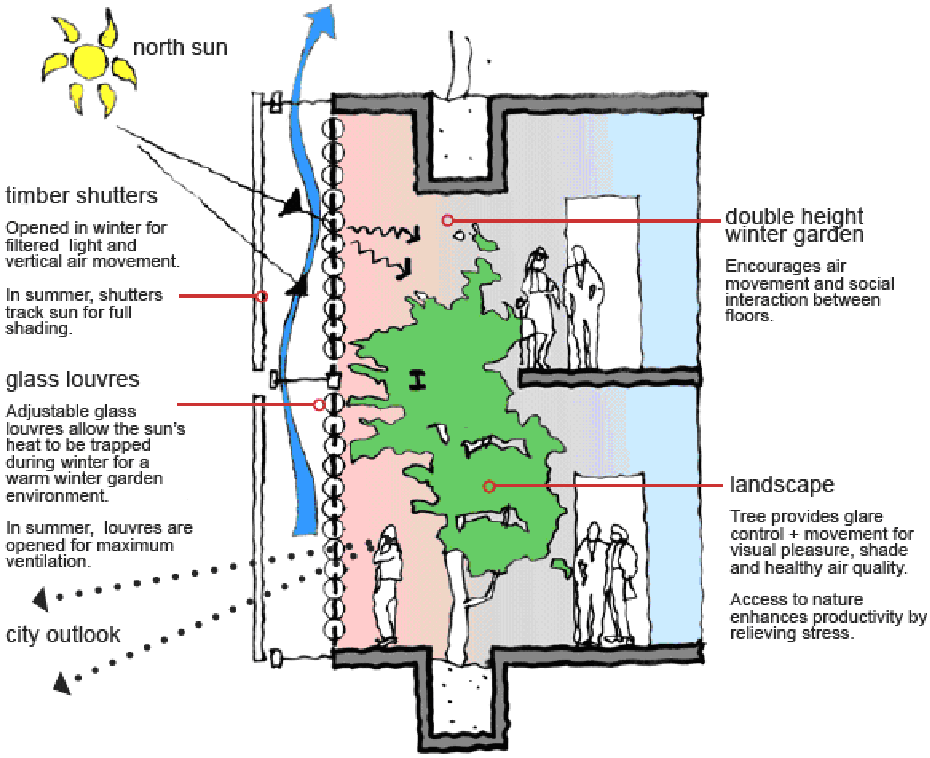

Figure 5- Winter gardens in the western façade[37]

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[36] **Dominique Hes**, 2004, *Design snap shot 07: design features,* PDF.
From web site: http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=4113&pg=4094

[37] City of Melbourne, Council House 2, cooling system, accessed 2008, http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1944

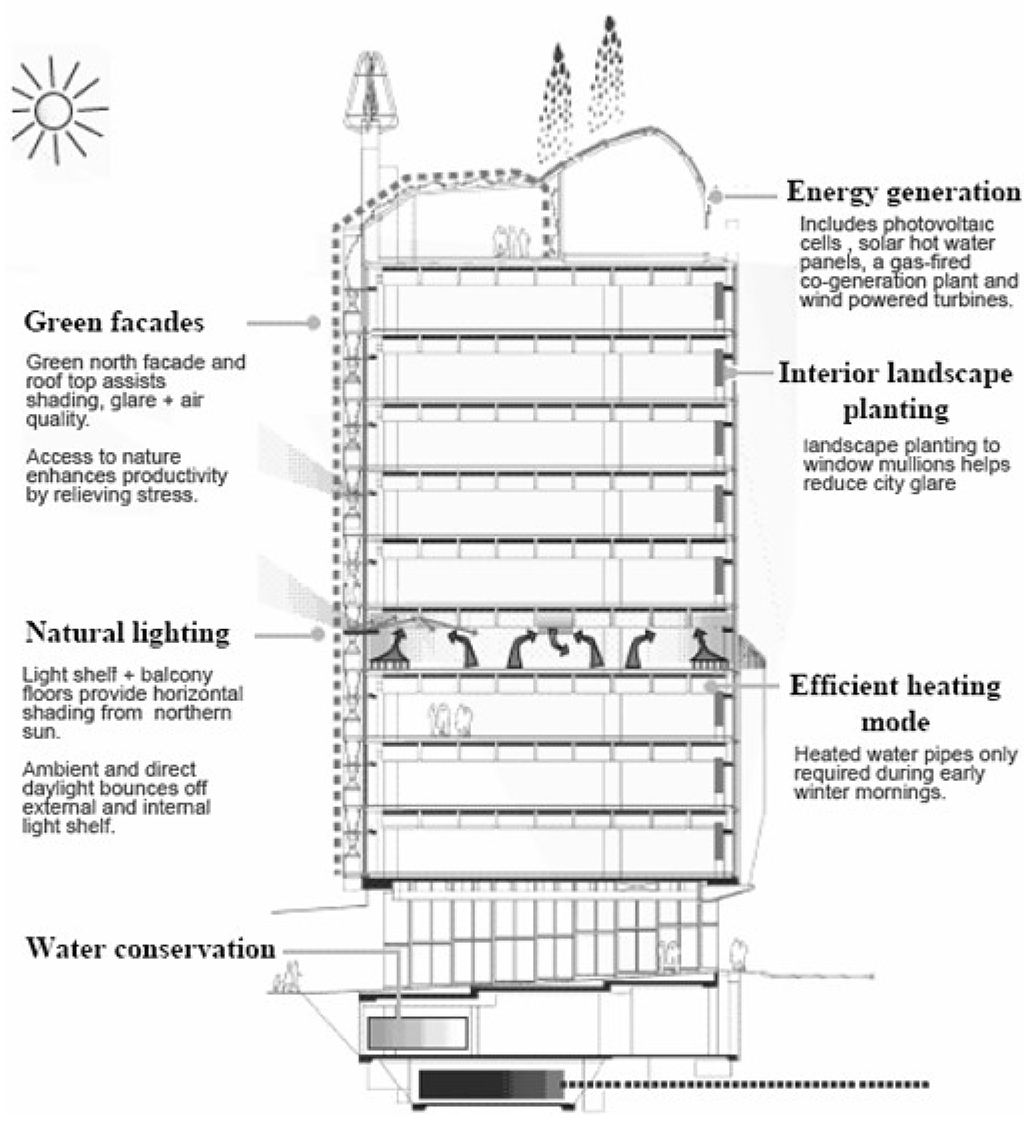


Figure 5- Schematic for the energy efficient and sustainable features in CH2 building[38]

5-3-6 Building Performance

The previous passive design and sustainable strategies are working together to achieve energy efficient, comfort, and productive environment. When compared to the existing Council House, it is expected to have the following benefits:

[38] Ibid

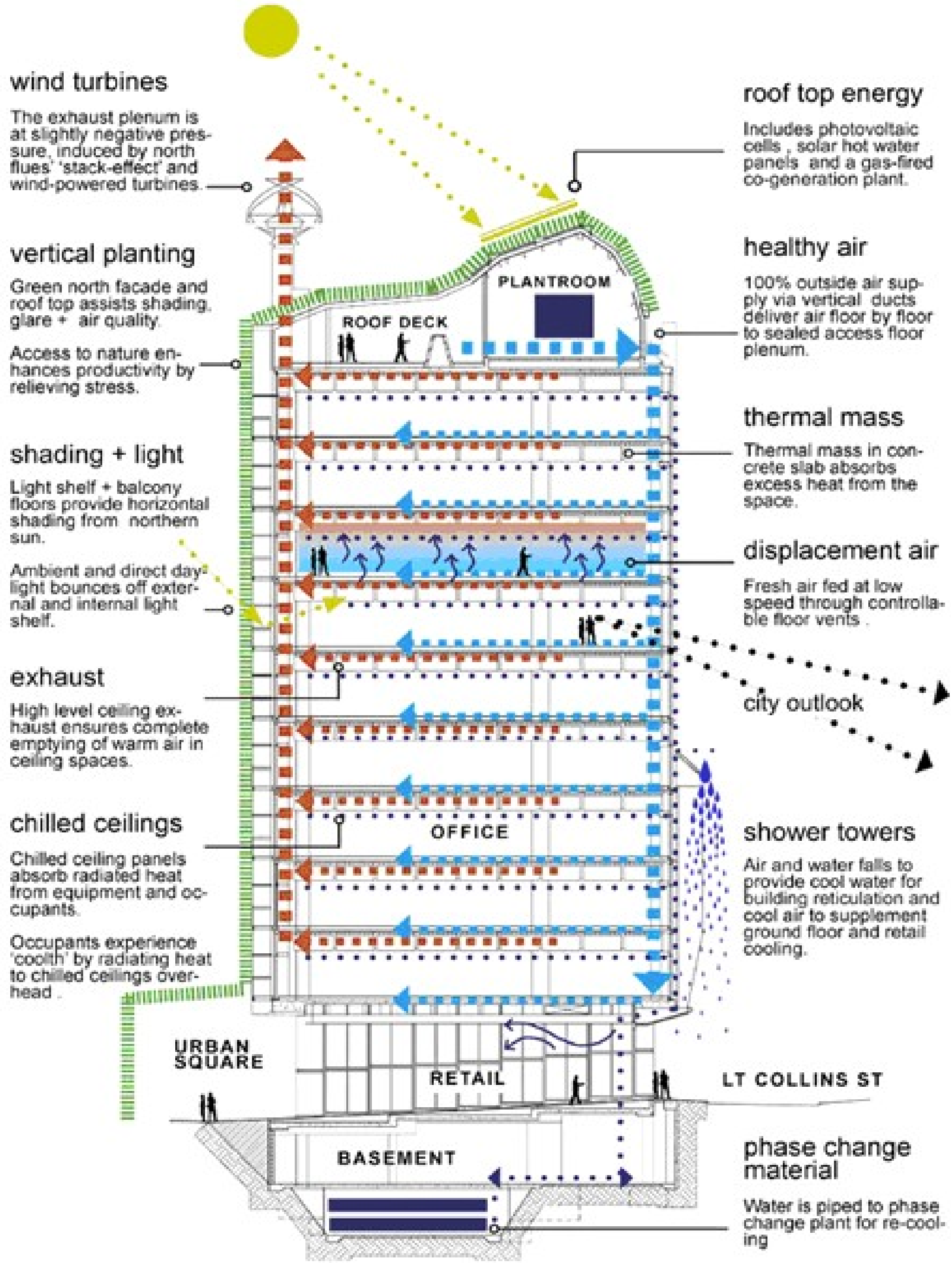
- CH_2's emissions will be 64% lower,
- Reduction of electricity consumption by 85%,
- Reduction of gas consumption by 87%,
- Reduction of water mains supply by 72% from 31 liters per day per person to just 8.4 litres per day per person[39],
- Light fittings consume 65% less energy,
- The building also houses 48 m^2 of solar panels, which provide 75% of hot water,
- Gas-fired cogeneration plant which provides 40% of the building's overall electricity[40].
- Equally important to its environmental features is that it provides 100% fresh air to all occupants with one complete air change every half hour.
- The temperature of air coming out of the bottom of the shower tower was measured and compared to the outside air temperature (and the relative humidity). The chart below is a summary of some of the recordings of the temperatures for the weekend at the 2004 are shown below. They show a reduction of temperature between 4 and 13 degrees Celsius.

Time	**Relative Humidity- air entering tower**	**Temp – In at top** °C	**Temp- out at bottom** °C	**Temp – Improvement** °C
Friday 13/2/04				
11:40am	66%	22.1	17.6	4.5
3	56%	25.8	17.6	8.2
7	61%	23.4	17.4	6.0
Saturday 14/2/04				
11	44%	31.4	23.6	7.8
3	35%	40.9	26.8	14.1
6	30%	38.9	25.1	13.8
Sunday 15/2/04				
1	45%	31.5	23.1	8.4
3	48%	31.4	23.1	8.3
4	50%	30.1	22.1	8.0

39 Ibid

40 Ibid

Table 5- Selected results for CH2 Shower Tower Performance 13/2/04 – 15/2/04[41]



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[41] **Dominique Hes**, *2004,Design snap shot 06: Shower Towers*. PDF, p3.

Figure 5- section ***shows all the passive cooling and sustainable strategies used in the CH2 building***[42]

5-4 Pearl River Tower, Guangzhou, China

Location: Guangzhou, China
Client: CNTC Guangdong Tobacco Company
Architect: Skidmore, Owings & Merrill with partner Adrian Smith and Gordon Gill
Construction year: 2006-2010
Rating and awards: 2008, Green, Carbon-Lowering & Environmental Category: Gold Award

5-4-1 Background

China consumes more than 500 millions kilowatts of electricity each year. It obviously needs to find a way to control their energy consumption, and to find a way to reduce emissions of carbon dioxide by presenting alternative technologies that are widely available.
In 2005 Skidmore, Owings & Merrill (SOM) with partner Adrian Smith and Gordon Gill presented plans for a new headquarters tower in Guangzhou that would incorporate the latest sustainable technology and attempt to create the world's most energy efficient high-rise structure), a tower that would significantly reduce its dependency on the city's infrastructure (figure 5-23). Moreover, the design of the 'zero-energy' concept Pearl River Tower reflects the principle of humankind in harmony with the environment. However, it will be a high performance building when completed and should be the most energy efficient high rise building in the world[43].

[42]Council House Two (CH2), Melbourne, VIC, accessed 2008, http://www.yourbuilding.org/display/yb/Council+House+Two+(CH2),+Melbourne,+VIC
[43] **Roger E. Frechette, Russell Gilchrist**, 2008, *Towards Zero Energy: A case study of the Pearl River Tower Guangzhou, China*, SOM, Chicago, USA, CTBUH.

Figure 5- Perspective view of Pearl River Tower, Guangzhou, China[44]

5-4-2 Overview on Climatic Conditions

Guangzhou is in southeastern China which has a hot and humid with heavy rain climate with predictable prevailing north, south and southwest winds. Summer season is long, wet, hot, and humid; it is from May through early October and has average mean temperature 28°C and can rise to 38°C with sun shine all day. Winter period lasts from November through early February and is mild, dry, and free of snow with average mean temperature 13°C[45]. Autumn and spring can be the best climates, with day temperatures in the 20°C to 25°C range. Sometimes, it can be wet and cold, with rain or drizzle. Rainfall averages 76 cm (30 inches) per year.

5-4-3 Effect of Climatic Conditions on Building Design

The 71-story Pearl River Tower, a headquarters for Guangdong Tobacco Company, is completed by October 2009. Early within the conceptual stage, local climate was analyzed for annual trends in: temperature and humidity; rainfall; available solar radiation and sun path; wind directions and speeds, establishing weighted criteria for an environmentally responsive design (figure 5-24).

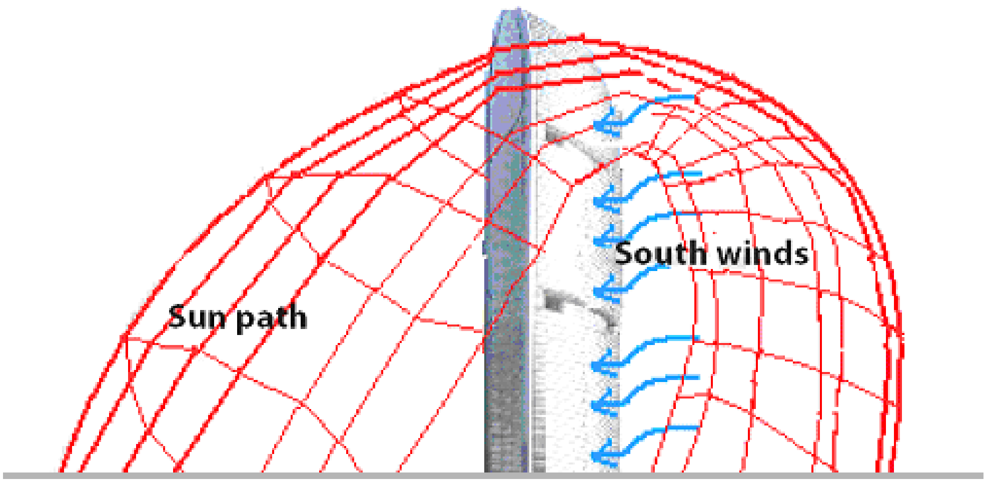


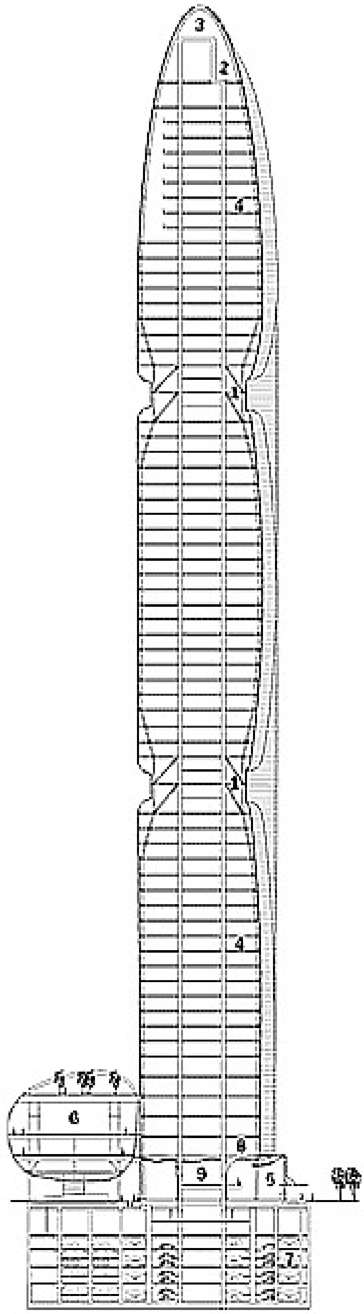
Figure 5- Sun path and wind direction analysis for Pearl River tower[46]

[44] Ibid

[45] Introduction Of Guangzhou City, Guangzhou climate, accessed 2009, http://www.cctsbeijing.com/china_guide/attraction/city_guangzhou/city_guangzhou_climate.html

[46] Net Zero Energy Design, A case study of the Pearl River tower, accessed 2009,

Some considerations including site analysis, wind direction analysis, and sun path analysis (Appendix C) create the building form and leads to presenting more complicated approaches and technologies (high performance façade on the east and south facades, radiant ceilings, photovoltaic cells, and wind turbines at the south façade facing the wind direction). Pearl River tower contains: two mechanical levels at the 22 and 50th floors contain integrated wind turbines, business club with skylight shaded by photovoltaic panels on the last floor, meeting room with an integrating shape with green roof, 6 underground floors garage, and the rest floors are offices, conferences, cafeterias, and services (figure 5-25).



1. Integrated wind turbines in mechanical floors
2. Business club
3. Operable skylight
4. Typical office floor
5. Lobby
6. Meeting room
7. Parking garage
8. Cafeteria
9. Double-decker elevator

Figure 5- CH2 building section[47]

Pearl River's sculpted body directs wind to four openings at its mechanical floors (figure 5-26) where turbines are placed. Traveling winds push turbines which generate energy for the building's heating, ventilation and air conditioning systems. Moreover, it is angled to take full advantage of natural daylight as well as, embedded photovoltaic to gather more solar energy. Even

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http://www.som.com/content.cfm/pearl_river_tower

[47] Ibid

the facade's shape has a structural purpose: its curves bend with natural wind pressures to reinforce the overall structure's stability.

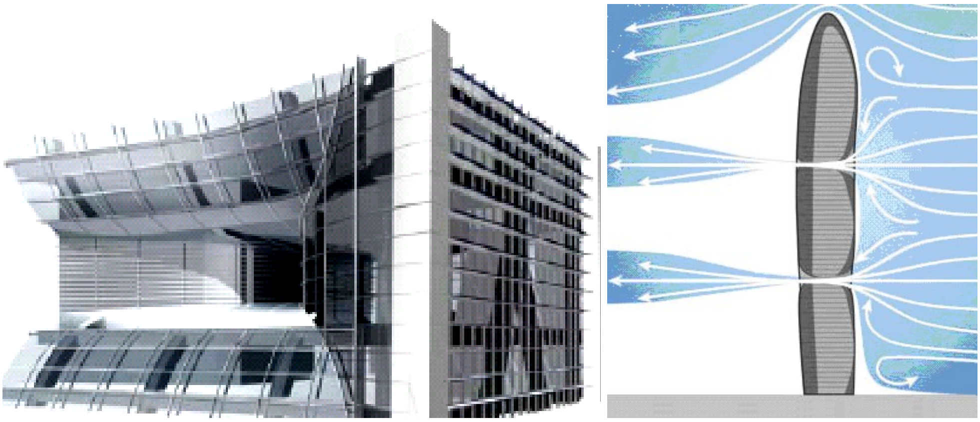


Figure 5- Façade sculpted form directs wind to mechanical floors where there are wind turbines for generating electricity [48]

5-4-4 Passive Cooling Strategies

The office tower is cooled by a combination of passive cooling and ventilation strategies, and by blocking direct solar radiation from entering the space by using high performance glass double skin façade and energy efficient building form and by presence of some passive cooling strategies include:

- Radiation: Chilled ceiling panels and Geothermal cooling
- Ventilation: Night purge, Solar stack ventilation and High performance energy efficient facades
- Shading techniques

5-3-4-1 Radiation: Chilled ceiling panels and Geothermal cooling

a) Chilled ceiling panels

Chilled ceiling panels are fixed to the curved ceiling in offices; they have been sized to overcome the internal cooling loads generated by occupants, lighting and equipment (figure 5-27). The chilled panels cover 35 % of the curved ceiling. Moreover, internal cooling loads are controlled by the presence of chilled beams located in front of the windows around the perimeter of each office zone[49].

[48] Ibid

[49] **Frank Bruno**, 2006, Supplementary Technical Research Paper, Centralised PCM Systems for Shifting Cooling Loads During Peak Demands in Buildings .pdf, University of South Australia.

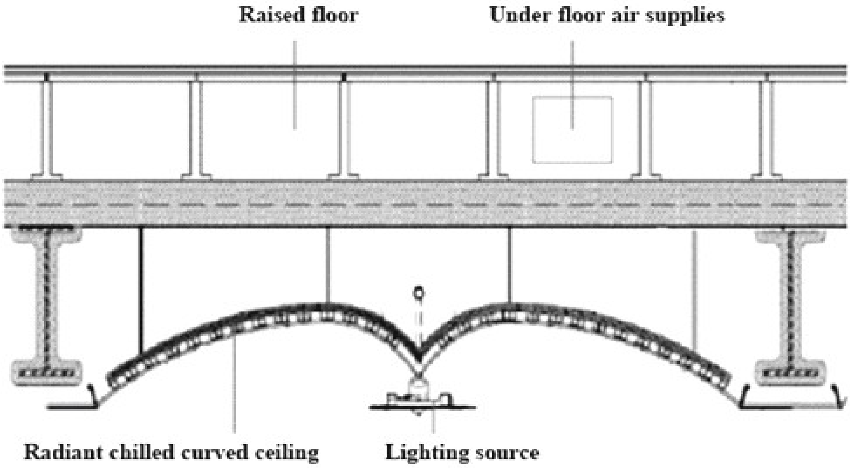
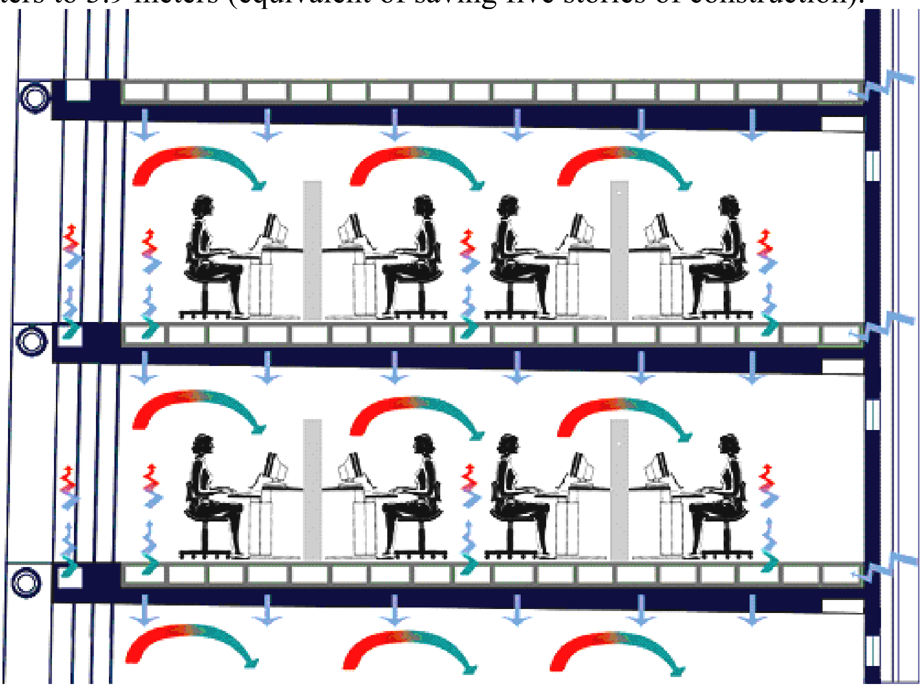


Figure 5- Radiant Chilled Ceiling Panel Detail [50]

This system is working in parallel with the under floor ventilation air delivery system. Such a cooling system eliminates the need for air ducts (figure 5-28). Therefore, it could reduce the building's "floor-to-floor" height from 4.2 meters to 3.9 meters (equivalent of saving five stories of construction).



[50] **Roger E. Frechette**, and **Russell Gilchrist**,, *2008, 'Towards Zero Energy' A Case Study of the Pearl River Tower, Guangzhou, China*. PDF, CTBUH 8th World ld Congress.

Figure 5- Office space cooling by radiant chilled ceiling panels in parallel with under floor ventilation[51]

b) Geothermal cooling

The tower has energy-efficiency geothermal system as a cooling strategy as well. A geothermal heat sink is used to provide cooling water, so 38 °C water in the mechanical system return loop cooled to 24 °C to feed the cooling power needed, reducing the size of the mechanical plant by about 30 percent[52].

5-3-4-2 Ventilation: Solar stack ventilation and High performance energy efficient facades

Pearl River tower facades design features many layers of sustainable approaches providing increase the occupant thermal comfort and air quality as well as associating with transparency, improve views to outside, permits useful daylight into the space, reduce noise transmission from outside of the building to inside.

a) Solar stack ventilation

As the sun rays hit the exterior double glazed skin some of the solar radiation enters the cavity between the outer and inner glazed layers. The intermediate blind acts as defense preventing any solar gain to enter to the inner façade in turn reducing the temperature of the inside face of the inner single glazed panel adjacent to the occupants. The cavity acts as a natural chimney using the cooler air from the occupied office areas to enter the cavity from a gap at floor level and allow more fresh air to enter the occupied areas. The trapped hot air in the cavity is then extracted through the ceiling void until it is extracted to the vertical exhaustion ducts (figure 5-29). This system is used in both north and south facades.

[51] **Michelle Wong**, 2007, *The Pearl River Tower:Skyscraping Innovations*, CaliforniaEngineer, volume 86, p 13.

[52] Ibid

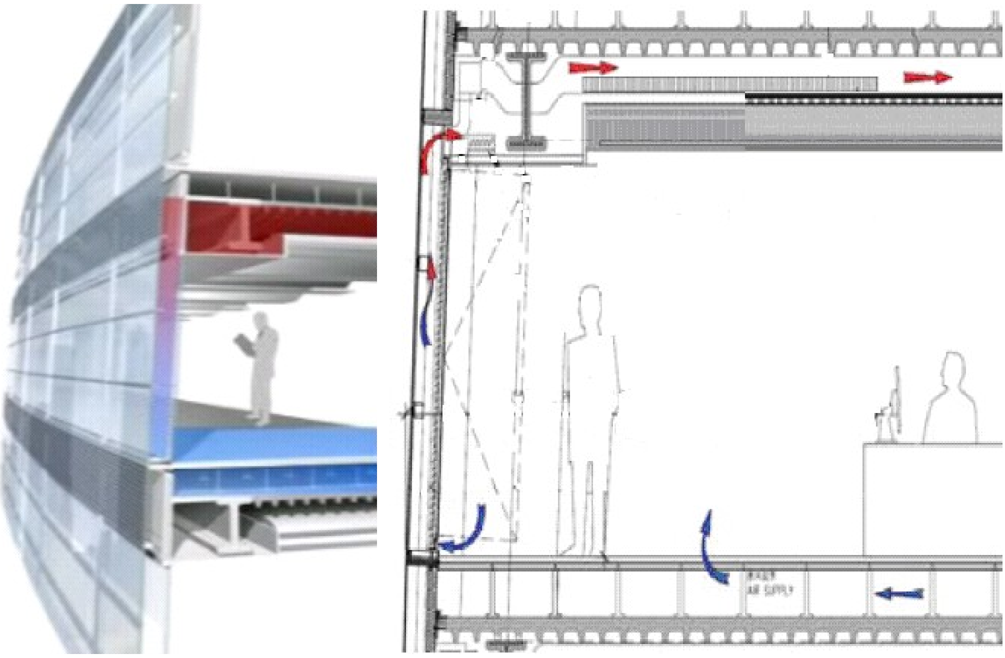


Figure 5- North and south facades: supply and exhaustion of air[53]

Cool air is supplied through under floor air supply vents and then exhausted through air cavity in the double wall façade and then through ceiling. Exhausted air rises upward to the mechanical floors, where excess heat is harvested from it. The energy from heat access is in turn used to precool incoming air. In mechanical floors, exhausted air is then channeled through a passive dehumidification system to remove moisture (figure 5-30). Fans are used to mix fresh air through dehumidifying and pre-cooling processes. Then the dehumidified air is pumped directly to vertical ducts and introduced directly to under floor ventilation ducts. Moreover, the incoming air will be treated with germicidal ultraviolet radiation to kill germs and prevent the spread of disease.

[53] Ibid

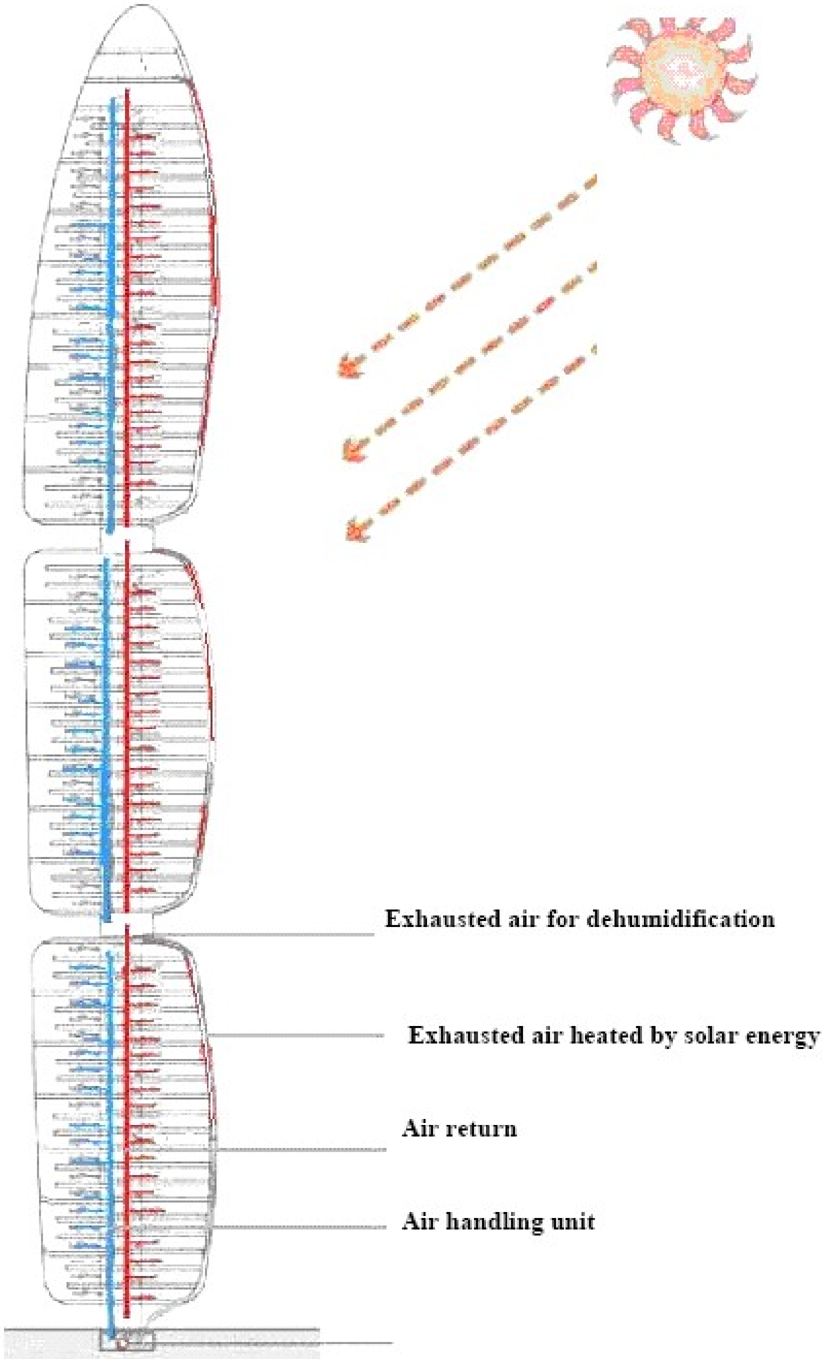


Figure 5- The tower reclaiming energy by air exhaustion and dehumidification system[54]

54 **Michelle Wong**, *The Pearl River Tower:Skyscraping Innovations*, CaliforniaEngineer, volume 86, p 13 2007.

b) High performance energy efficient facades

- Double glazed wall system: The north and south facade double-layer curtain-wall system offers insulation that reduces heat gain and leads to less demand on the HVAC systems. It consists of a double glazed insulated unit with integral spandrel panel in a 3.0 x 3.9m unitized panel with a cavity space 200mm[55] (figure 5-31).

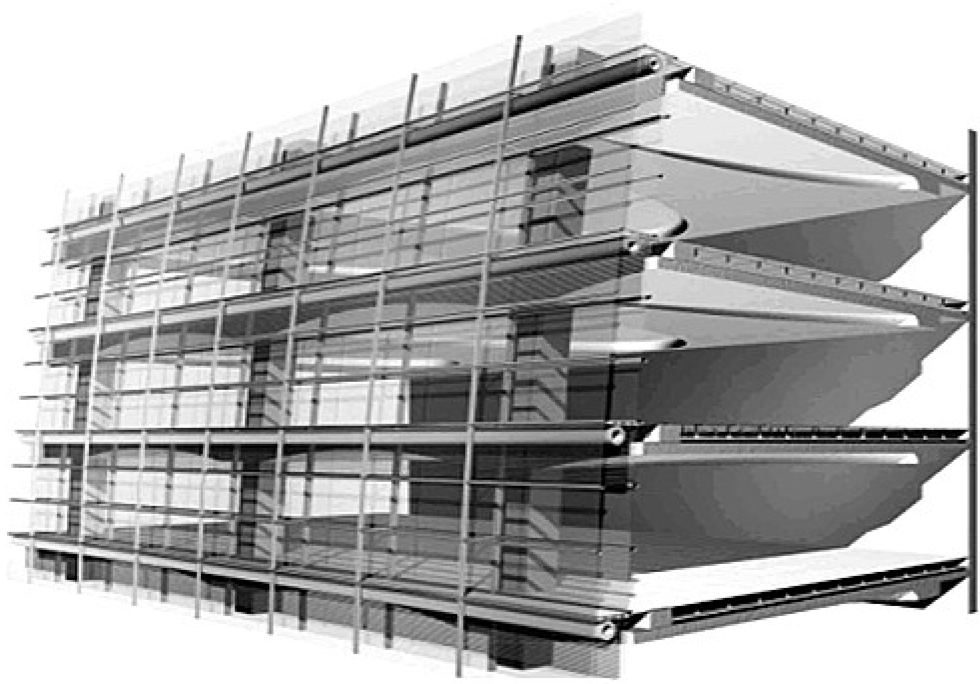


Figure 5- South façade: Double glazed wall system in high performance facade[56]

- Exterior glazing materials: Exterior glazing is insulated, tempered glass with a low-E coating; the inner layer is an operable clear glass panel on the building's south face. Low-emittance glass is coated with a microscopically thin, virtually invisible, metal or metallic oxide layer that reduces thermal conductivity. These coatings are transparent to visible light but are opaque to infrared radiation.

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[55] **Roger E. Frechette, Russell Gilchrist**, 2008, *Towards Zero Energy: A case study of the Pearl River Tower Guangzhou, China*, SOM, Chicago, USA, CTBUH.
[56] Ibid, p4.

- Triple-glazed façades: East and west elevations are associated with external shades and automated blinds within the facade's cavity. A photovoltaic system is integrated into the building's external shading system and glass outer skin.

5-4-4-3 Shading techniques

As all facades of Pearl River tower are double glazed facades, then, shading blinds are placed within their cavities. A motorized 50mm perforated silver Venetian blind is in the east and west double facades (figure 5-32). The blinds are always fully extended within the cavity, however it has 3 modes of operation; open, closed to 45 degrees or fully closed depending on angle of the sun. The blind position is determined by a photocell that tracks the sun position and is connected to the building management system which activates the blind position to ensure occupancy comfort from both solar gains and glare.

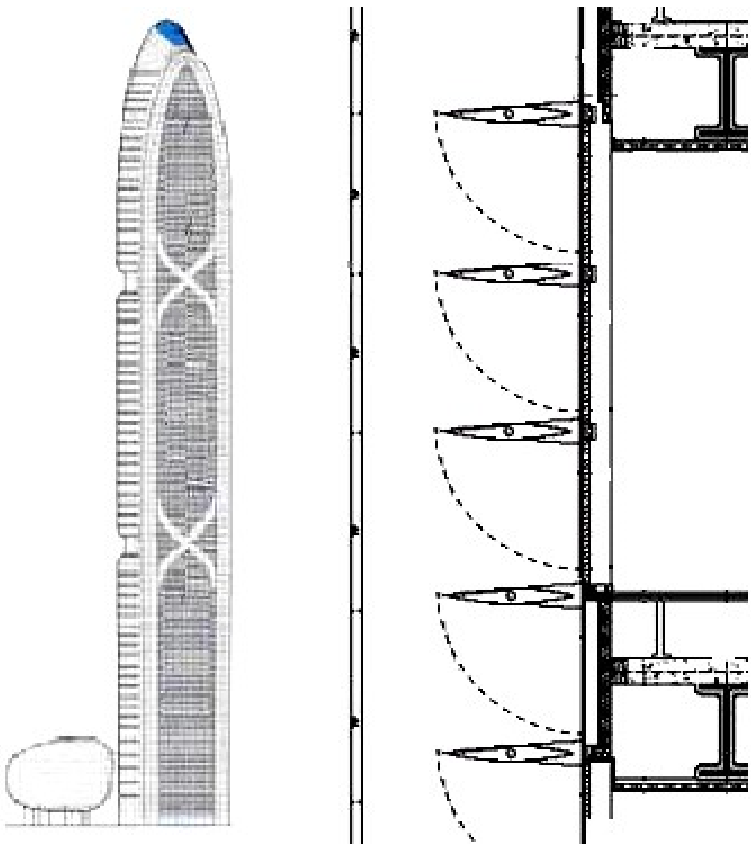

Figure 5- Perforated silver Venetian blind is in the east and west double facades[57]

[57] Ibid

5-4-5 Energy Efficient and Sustainable Features

In addition to passive cooling, Pearl River tower has integrated strategies and techniques for energy conservation that has been applied to achieve a zero energy office building. The next section will introduce energy efficient strategies that have been presented in the tower: natural lighting, water conservation, and energy generation.

- Energy conservation: Natural lighting and Energy generation.
- Water conservation

5-4-5-1 Energy conservation: Natural lighting and energy generation

a) *Natural lighting*

Pearl River tower integrated glass façade is providing high visual transmittance, enhancing daylight harvesting, and allowing for a reduction in the amount of artificial lighting required in the space in addition to its high thermal performance. Even when blinds are fully closed the perforations allow for good visual transmission. Moreover, sensitive lighting controls sensors are attached to the artificial lighting in the rooms to detect the current lighting level and adjust lighting level with natural light in order to reduce energy consumption below the initial baseline estimate.

Figure 5- 100 % Day lighting in offices and business club in the roof level through operable sky light[58]

b) *Energy generation*

[58] Net Zero Energy Design, A case study of the Pearl River tower, accessed 2009, http://www.som.com/content.cfm/pearl_river_tower

The previous passive cooling and energy conservation strategies could reduce the building's energy use by nearly 65 % over a baseline of Chinese building codes[59]. To reach the final goal of net zero energy, the building design incorporated three power-generating technologies: wind turbines, integrated photovoltaic and hydrogen fuel cell.

- Wind turbines: The most innovative of Pearl River's elements are the vertical axes integrated wind turbines that are used for catching prevailing winds from the south and the north with minimum loss. Building's east and west facades are flat while the south façade is the façade facing the south wind, so it has sweeping curves in the mechanical floors (figure 5-34). The design would increase wind velocity to 1.5 times ambient wind speeds. The power is then converted to energy and used to dehumidify the building ventilation.

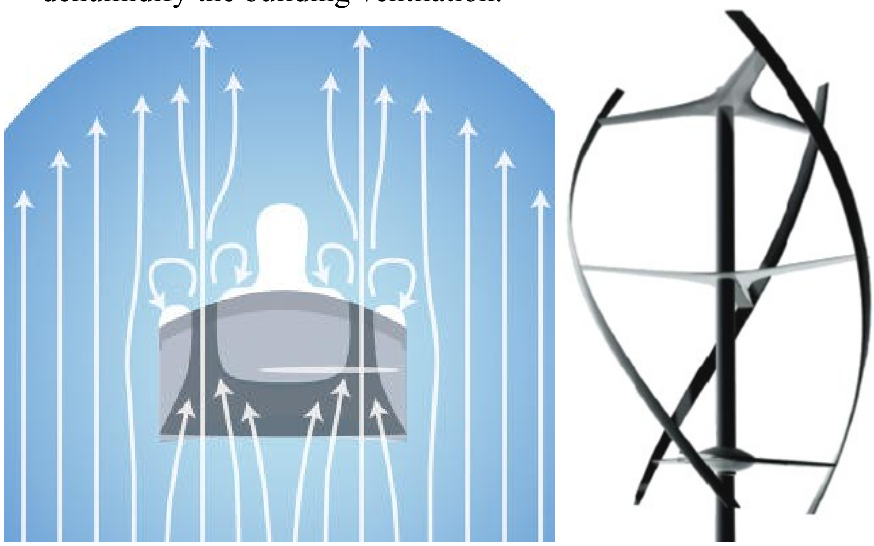

Figure 5- South façade is curved to catch all prevailing wind to the mechanical floor[60]

- Micro turbines: Micro turbines are capable of operating on a various types of fuel mediums, such as kerosene, biogas, diesel, methane, propane, and natural gas. Hot air coming from the exhausted façade could be reclaimed in micro turbines and used as an auxiliary heat source for the building functions such as

[59] Sustainable design update, Zero Energy Office Building, accessed 2009, http://sustainabledesignupdate.com/?p=113

[60] Chinagreenbuildings, Pearl River Tower, accessed 2009, http://chinagreenbuildings.blogspot.com/2008/11/peal-river-tower.html

water heating. It considered a safe, low noise, and vibration free machines, which make it an ideal solution to this project[61]. The original concept for the building was to use up to 50 micro-turbines to generate more than 3 Megawatts hour of power but some problems applied so that it will be hard in this stage to connect them. However, the current design of the basement has reserved a location for them to be retrofitted at a later date should the local Guangzhou infrastructure becomes available.

- Photovoltaic panels: Photovoltaic panels are integrated into façades to transform the sun's energy to usable AC current. It was determined that the use of PV cells could be productive if used on certain portions on building's envelope. The distribution of the PV's directly correlates with where they would optimize the solar power offered by the sun. It is located at roof level in order to achieve best performance[62]. Additional panels are located on the two mechanical levels on the southern face (figure 5-35). In addition, PV panels are mounted to the exterior sunshades on the western façade (figure 5-35).

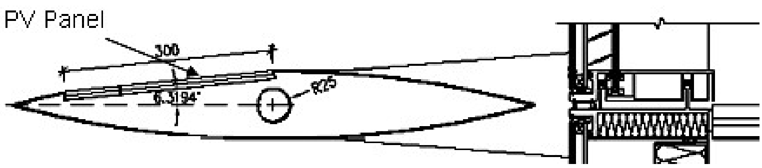

Figure 5- PV panels mounted to the exterior sunshades on the western facade[63]

- Hydrogen Fuel Cells: Pearl River Tower is planned to utilize hydrogen fuel cells to store excess generated energy and convert gas to electricity with more than 50 percent efficiency. The high-temperature waste gas produced in this process could be used as power energy for cooling and ventilation[64].

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[61] Preston Koerner, Pearl River Tower, Guangzhou, China, accessed 2009, http://jetsongreen.typepad.com/jetson_green/2006/08/pearl_river_tow.html

[62] Net Zero Energy Design, A case study of the Pearl River tower, accessed 2009, http://www.som.com/content.cfm/pearl_river_tower

[63] Ibid

[64] Ibid

- Heat exchanger tubes: Southern façade is integrated with heat exchanger tubes that approximately cover 75 % of the annual hot water demand of the building.

5-4-5-2 Water conservation

Water conservation in Pearl River tower is achieved through the presence of some issues:

- Using harvested water from chilled surfaces to control interior humidity.
- Reusing and recycling water to be used for interior plantings and toilet flushing.
- Using ultra Low Flow toilets, low flow sinks and waterless urinals[65]

5-4-6 Building Performance

Pearl River Tower is presenting a number of highly innovative technologies: wind turbines, radiant slabs, micro turbines, geothermal heat sinks, ventilated facades, integrated photovoltaic, and daylight responsive controls. These technologies work together to significantly achieve the net zero energy and ensure the highest levels of human comfort and indoor air quality. Passive cooling strategies reduce the energy consumption by 44% from the annual energy consumption.

[65] **Brendan Dillon**, 2008, *Pearl River Tower: Harvesting the wind for to make glorious building of natural energy Brendan Dillon* .pdf.

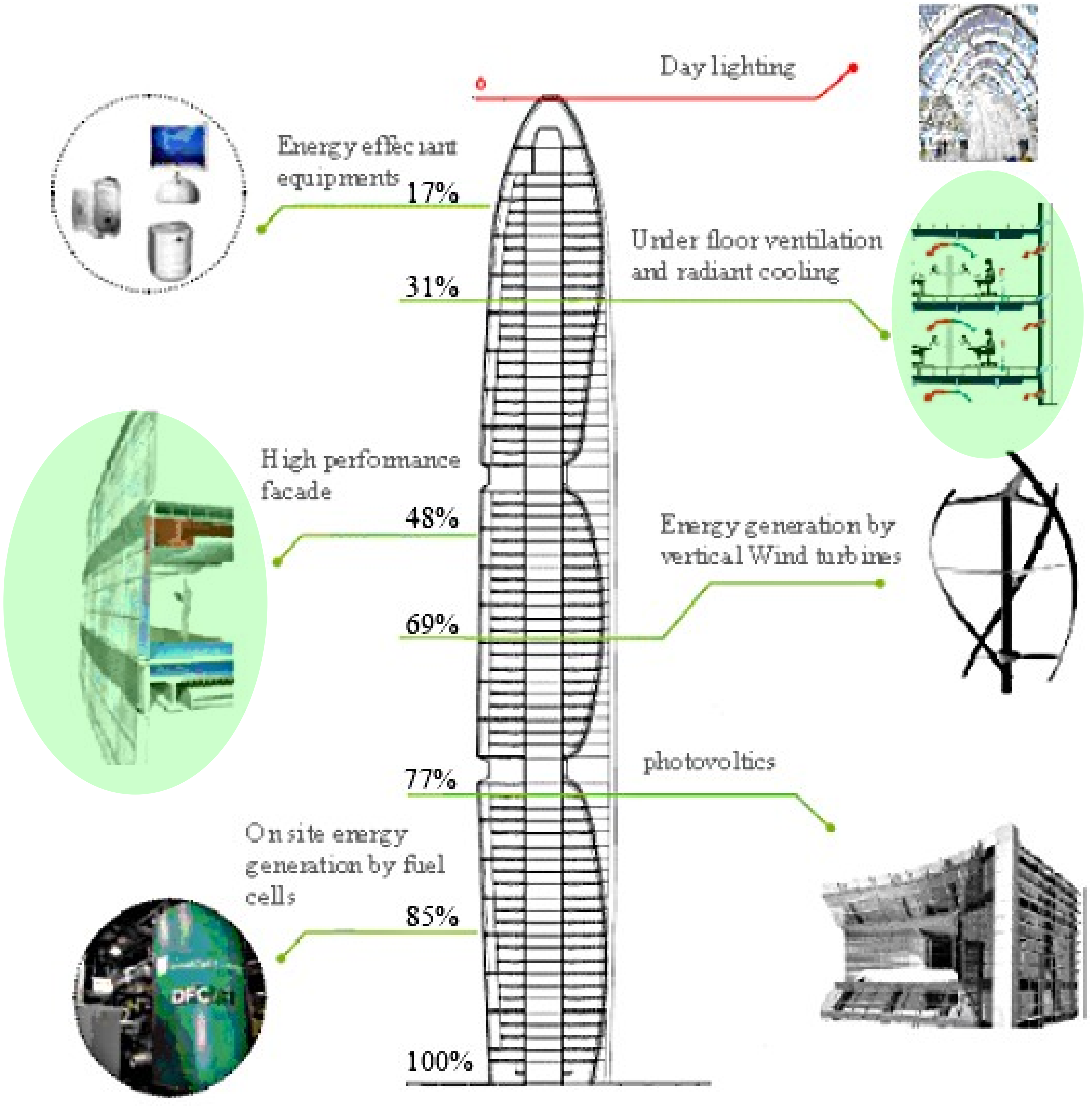

Figure 5- Section for net zero energy footprint building design[66]

Energy consumption of the Pearl River tower has been modeled and compared to a hypothetical "baseline" building of the same geometry, but without the sustainable measures included and without relying on strategy of using air to cool the building rather than a (water based) radiant ceiling system. A summary of the comparison between baseline and design cases that the expected performance associated with roughly 58% reduction of energy consumption on

[66] **Michelle Wong**, 2007, *The Pearl River Tower:Skyscraping Innovations*, CaliforniaEngineer, volume 86, p 13.

an annual basis[67] (figure 5-37). The building only 10 % extra costs than construction prices for “class A” office in China[68].

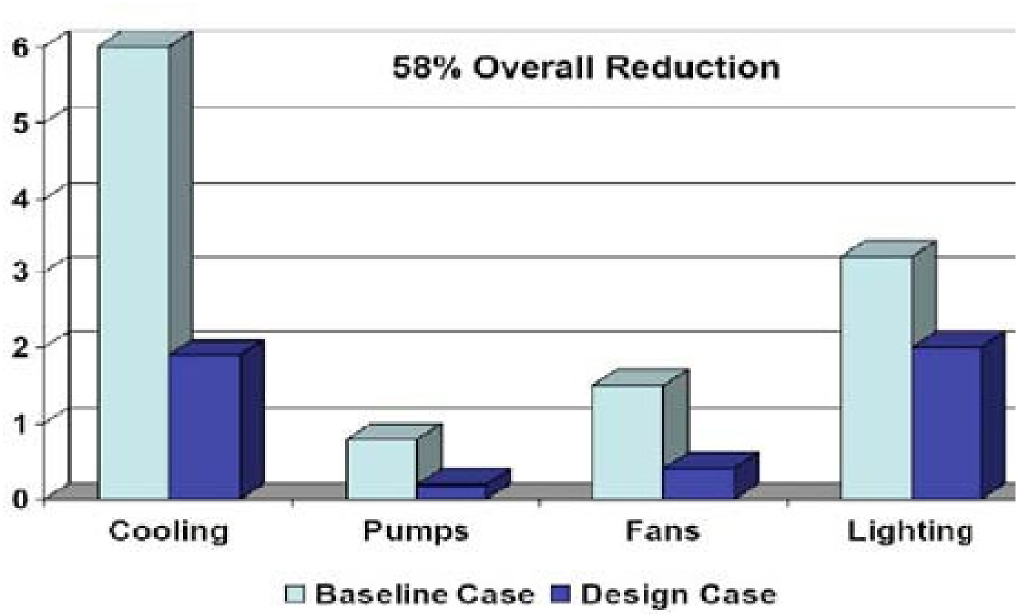

Figure 5- Pearl River Tower Annual Energy Consumption[69]

[67] **Roger E. Frechette, Russell Gilchrist**, 2008, *Towards Zero Energy: A case study of the Pearl River Tower Guangzhou, China*, SOM, Chicago, USA, CTBUH.

[68] **Roger E. Frechette, Russell Gillchrist**, 2009, *Seeking Zero Energy*, American society of civil engineering. PDF.

[69] **Roger E. Frechette, Russell Gilchrist**, 2008, *Towards Zero Energy: A case study of the Pearl River Tower Guangzhou, China*, SOM, Chicago, USA, CTBUH.

5-5 Masdar Headquarters, Abu Dhabi, United Arab Emirates

Location: Masdar City, Abu Dhabi, United Arab Emirates.
Client: The Masdar Initiative, Abu Dhabi, United Arab Emirates.
Architect: Adrian Smith and Gordon Gill Architecture
Construction year: 2008- 2010
Rating and awards: This project far exceeds LEED standards; a similar sized LEED Platinum building would still emit 6,000 metric tons of carbon dioxide a year[70].

5-5-1 Background

Abu Dhabi Future Energy Company (Masdar) plans a carbon free city, an energy, science and technology green community in Abu Dhabi, between Khalifa City and Abu Dhabi international Airport. The aim is to create the world's first car-free, zero-carbon dioxide emissions, and zero-waste city designed by Foster and Partners. The city will fully powered by renewable energy and uses just 20 percent as much power as a conventional city of similar size. The city is expected to cost a total of $22 billion[71].

Figure 5- Layout of Masdar city[72]

The city includes Masdar Institute (the first part of the city to be built in cooperation with Stanford University and MIT), apartments, laboratories, factories, movie theaters, cafés, schools, headquarters and fire station. It is generating as much electricity as it uses. Its water is recycled to save the energy costs of desalination. Vacuum tubes under the city are transporting garbage to a central location, where it is sorted, and as much as possible is recycled. The City is constructed over seven phases and is completed by 2016. Masdar's

[70] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters
[71] **Kevin Bullis** April 2009, Technology Review ***Magazine,*** from website: http://www.technologyreview.com/energy/22121/page2/
[72] Ibid

headquarters is part of phase one and is completed by the end of 2010[73]. Masdar headquarter is considered one of the most important buildings in Masdar city, it was announced that Masdar headquarters is the world's first large-scale, mixed-use "positive energy" building, producing more energy than it consumes. The massive parallelogram-shaped building is the centerpiece to Masdar City, Its complex utilizes sustainable materials, integrated wind turbines, outdoor air quality monitors, and building-integrated solar energy arrays.

Figure 5- Architectural rendering perspective of Masdar headquarters[74]

5-5-2 Overview on Climatic Conditions

Abu Dhabi's climate is considered to be subtropical climate, with temperatures that vary from warm in winter months to hot in summer with sunny blue skies prevail throughout the year and rainfall is infrequent. In winter it has average temperature 22°C, while in summer its temperature could reach 40°C. Meanwhile, January is the wettest month of the year, with minimum monthly rainfall of 22mm, followed by the month of March, which registers an average of 17.7mm of rainfall. The months of May through October see very little

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[73] Stunning Solar Building Will Generate More Power Than It Needs, accessed 2009, http://www.metaefficient.com/architecture-and-building/stunning-solar-building-will-generate-more-power-than-it-needs.html

[74] Masdar headquarters to generate more energy then it uses. Accessed 2009, http://isiria.wordpress.com/2008/02/26/masdar-headquarters-to-generate-more-energy-then-it-uses/

rainfall[75]. Wind is blowing from north and North West direction with average 26 km/h which could be suitable source for power generation.

5-5-3 Effect of Climatic Conditions on Architectural Design

Masdar Headquarters main design idea is based on the usage of steel and glass, the building is described as a flat parallelogram roof sits on top of a curving support structure fused to 11 glass-and-steel sculpted wind-tower cones that run through the full height of the building and extended from the top of it. To aid pedestrian movement, the cones are placed at strategic locations connecting with paths penetrating the site.

Some cones serve as entries or gardens on the grand plaza to the west. Others are cut into the building, forming negative space on the east façade. Interior courtyards vary, some are landscaped, some have water features, others have suspended artwork or pedestrian bridges overhead[76]. Landscaped courtyards at the base of these cones refer back to traditional Islamic architecture, and landscaping spreads over the top-level roof garden. Offices, researches, and residential spaces are located in the building's bottom seven floors. The building also house retail space contains: a prayer hall, cafeteria, and health club (figure 5-40).

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[75] welcome to Abu Dhabi, climate, accessed 2009, http://www.visitabudhabi.ae/en/uae.facts.and.figures/climate.aspx

[76] **Vernon Mays**, *ARCHITECT Magazine*, Publication date: 2008-06-01, from website: http://www.architectmagazine.com/industry-news-print.asp?sectionID=1006&articleID=721074

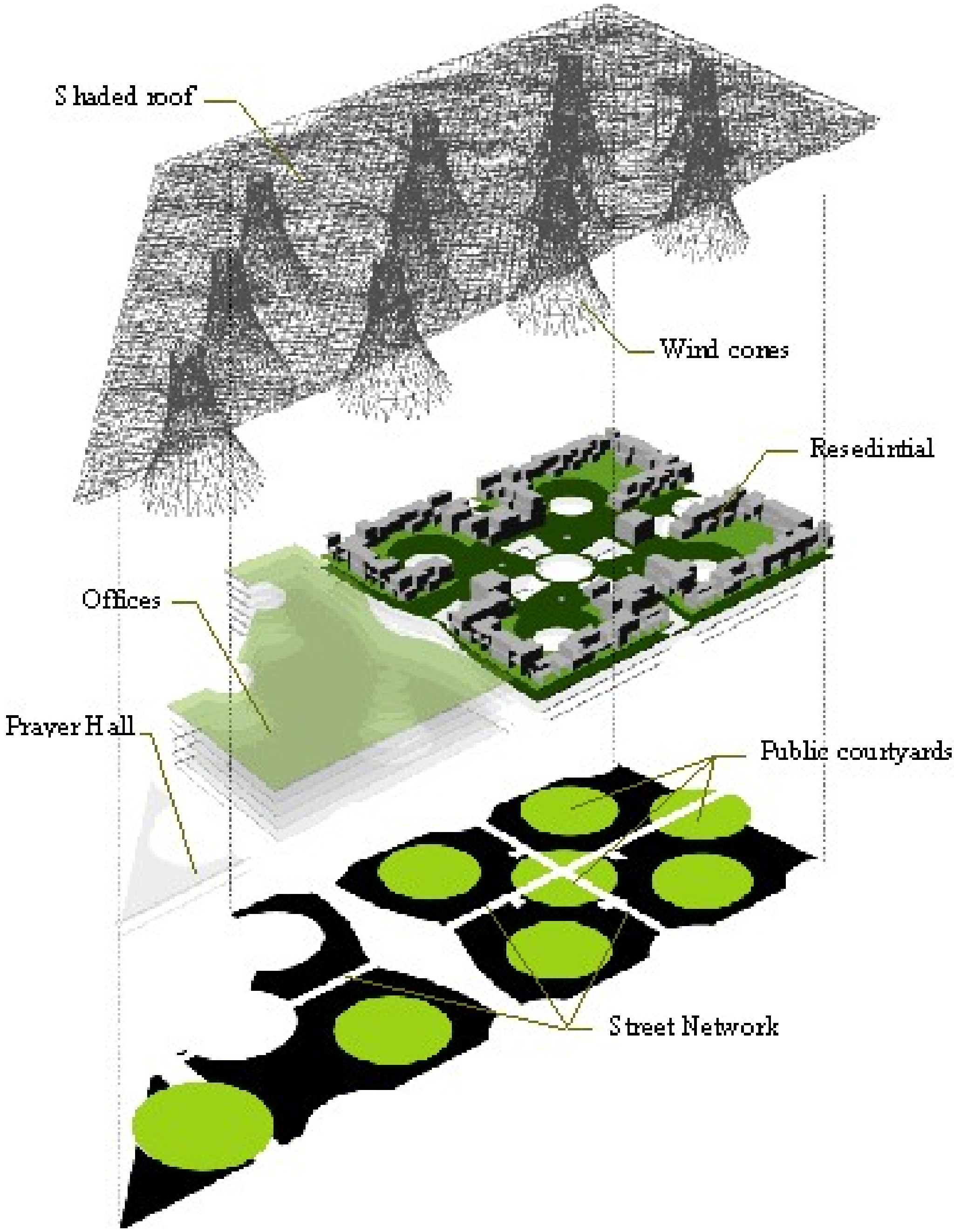


Figure 5- Architecture design description for Masdar headquarters[77]

[77] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

5-5-4 Passive Cooling Strategies

Masdar headquarter is overcoming the desert climate by the presence of some passive cooling strategies that limit the external heat gains and making use of natural cooling potentials as ground, sky and outside air. These strategies include:

- Radiation: Solar thermal driven cooling and dehumidification system
- Ventilation: Solar stack ventilation, solar thermal driven cooling and dehumidification, earth ducts, and High performance energy efficient facades.
- Shading techniques

5-5-4-1 Radiation: Solar thermal driven cooling and dehumidification system

The building's solar air conditioning system (Appendix B) works by collecting ambient heat in vacuum tube collectors and transfers it to a hot-water circulation system, this energy is used to drive an absorption chiller or a desiccant dehumidification system. This chilled water is then sent to beams to cool the exhausted air coming from the building. The cool air is then sent to an under floor air distribution system[78] (figure 5-41). Structural foundations piles coupled with a water pipes system to re-cool the chillers to the 20°C of soil temperature (200m deep) (figure 5-43).

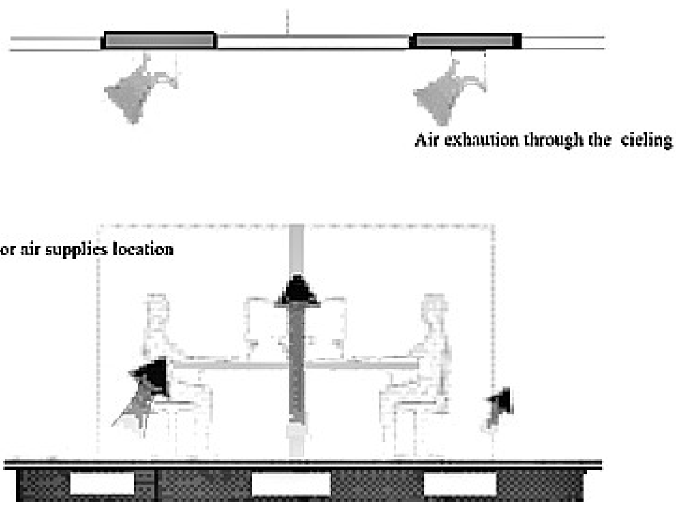


Figure 5- placement of under floor air distribution and exhaustion in offices[79]

[78] http://info.aia.org/aiarchitect/thisweek08/0404/0404d_masdar.cfm

[79] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

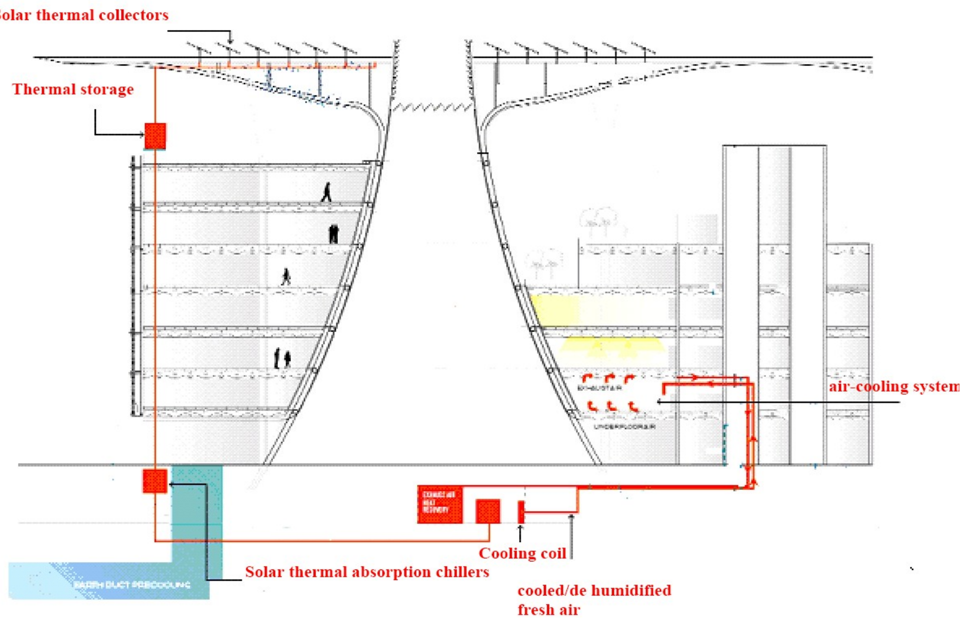


Figure 5- Schematic of solar thermal air conditioning system[80]

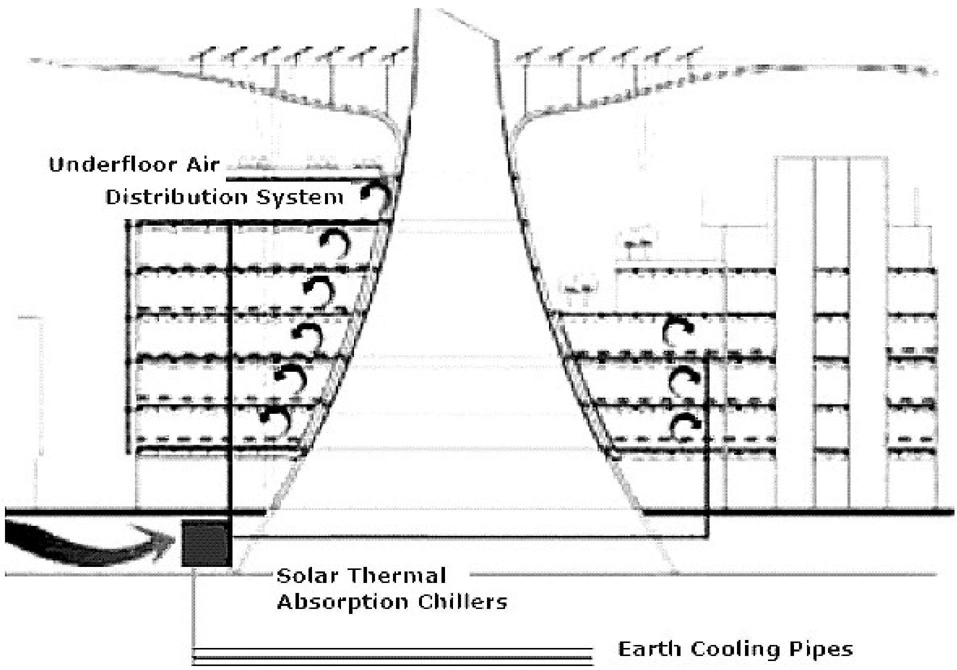


Figure 5- Earth cooling pipes system is being used to recool the chiller that supply cooled air to offices[81]

[80] **Adrian Smith + Gordon Gill Architecture**, *Feature Story. PDF*, p61
From website: www.technologyreview.com
[81] Ibid

5-5-4-2 Ventilation: Solar stack ventilation and High performance energy efficient facades

a) Solar stack ventilation

The central feature of this building design is a staggered arrangement of 11 wind towers (figure 5-44) that perform many critical functions. At the top they provide the structural support for the building's curvilinear roof. At the ground plane they delineate courtyards that serve as entrances, orientation points, and huge intakes to bring ground-source cool air into the building (figure 5-45). It ventilates the building by exhausting warm air from the top and bringing cool air up from its lower levels. They also work as solar shafts, providing natural light throughout the complex's interior.

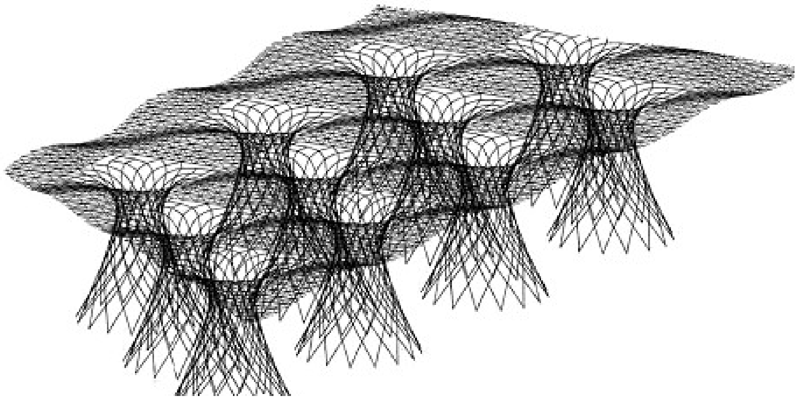


*Figure 5- **11 Wind cones used as** structural support for the building's curvilinear roof and for passive cooling*[82]

Figure 5- A rendering shows a cross section of the Masdar Headquarters, A series of bellshaped wind towers ventilates the building[83]

[82] Ibid

[83] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

Engineers tested different orientations and forms for the tops of the cones, settling on a chamfered top with the high point facing is toward the prevailing wind. This shape of cones results in presenting of most negative pressure at the top of the cone, promoting the greatest heat extraction[84].
The towers are of bell-shaped to maximize their cooling function, when winds enter at ground level, it will spiral up the cone, drawing cool air from ground. Warm air is exhausted through the open tops of the towers, which are chamfered to limit direct sunlight and minimize hot desert winds (figure 5-46). Wind cones improve thermal chimney effect supported by the temperature difference between inside and outside temperature and supported by the thermal mass of the chimney which stores solar energy and uses this heat capacity to increase the exhaust air temperature. Moreover, wind cones can improve the night-time cross ventilation by forcing the cool night wind and exhaust the hot air presented[85].

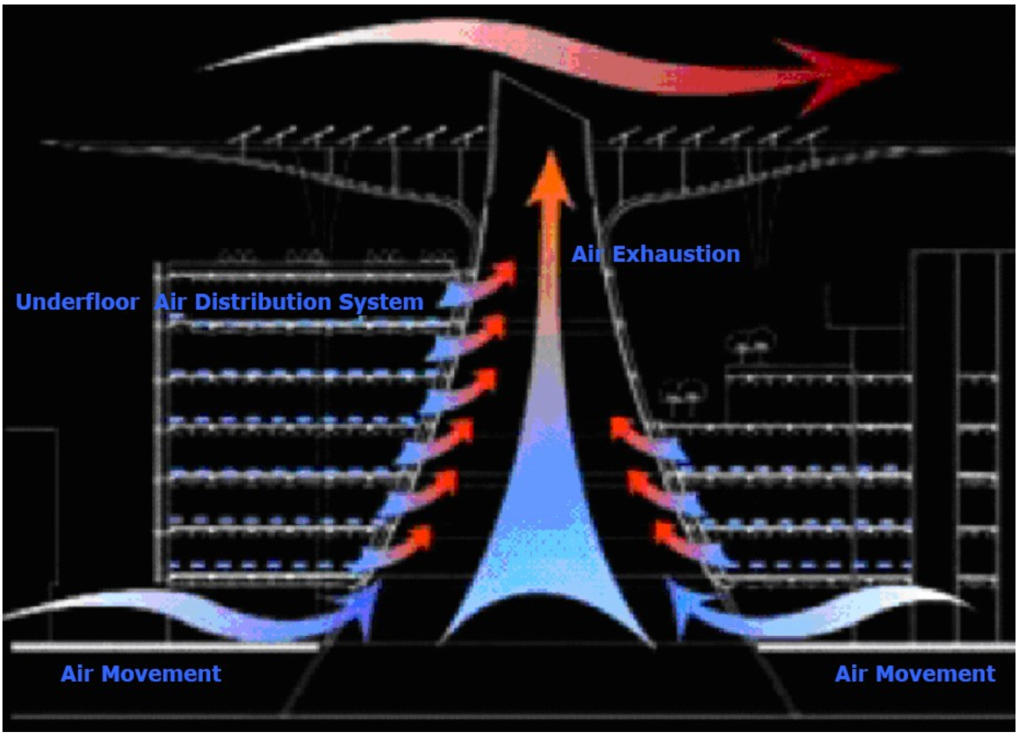


Figure 5- Passive cooling idea: as solar chimney; cool air enters belowground warm air exhausts through the open tops of the towers[86]

[84]**Michael Willoughby,** Masdar HQ to generate its own power during construction, accessed 2009, http://www.building.co.uk/story.asp?storycode=3108441

[85] **Bellerophon** 2008, Publications, *Innovation from the Innovators*. PDF, p3.

[86] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

The top of the cone is caped by operable louvers to close off the neck during dust storms. It could also help in balancing horizontal air movement through the office space. One cone could be closed off and the next one opened to shift the pattern of air flow.

b) Earth ducts

Cooling strategies technology in this project extends also to the presence of earth ducts which reduce temperature of outside air and provide underground pedestrian passages that connect public space with the proposed mass transit system.

c) High performance energy efficient facades

High-thermal-mass exterior glass cladding blocks direct solar radiations and decreases the internal cooling loads, while remains transparent to allow natural light into the building (figure 5-47).

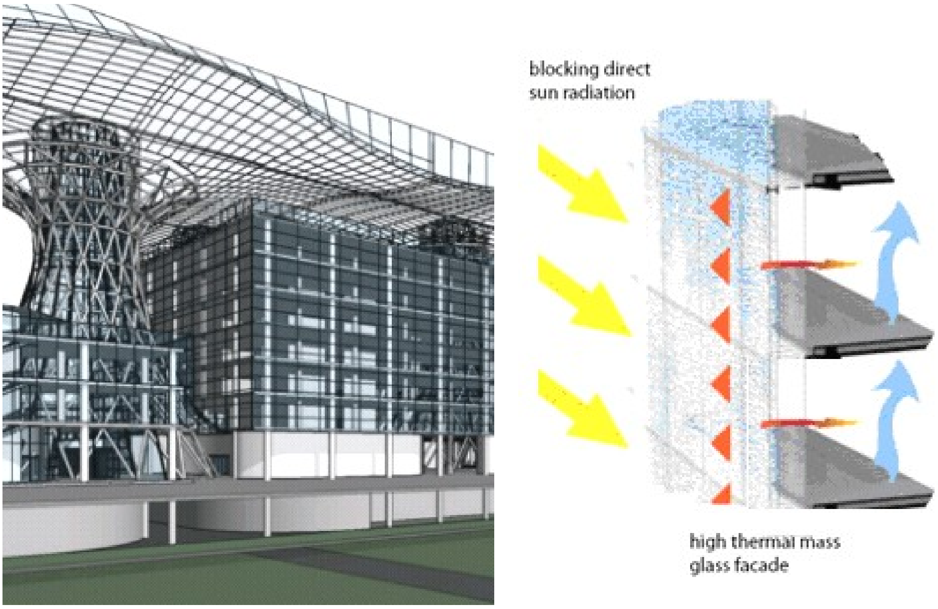


Figure 5- High thermal mass glass façade will help blocking direct solar radiation while permitting natural lighting[87]

5-5-4-3 Shading techniques

The building is protected from direct sun radiation by s lightweight roof with PV cells on the external side in order to reduce the solar gain (figure 5-48). It creates a cool environment beneath and reduces the demand for air conditioning.

[87] Ibid.

Figure 5- Solar panels on the roofs provide sun protection in public spaces between buildings[88]

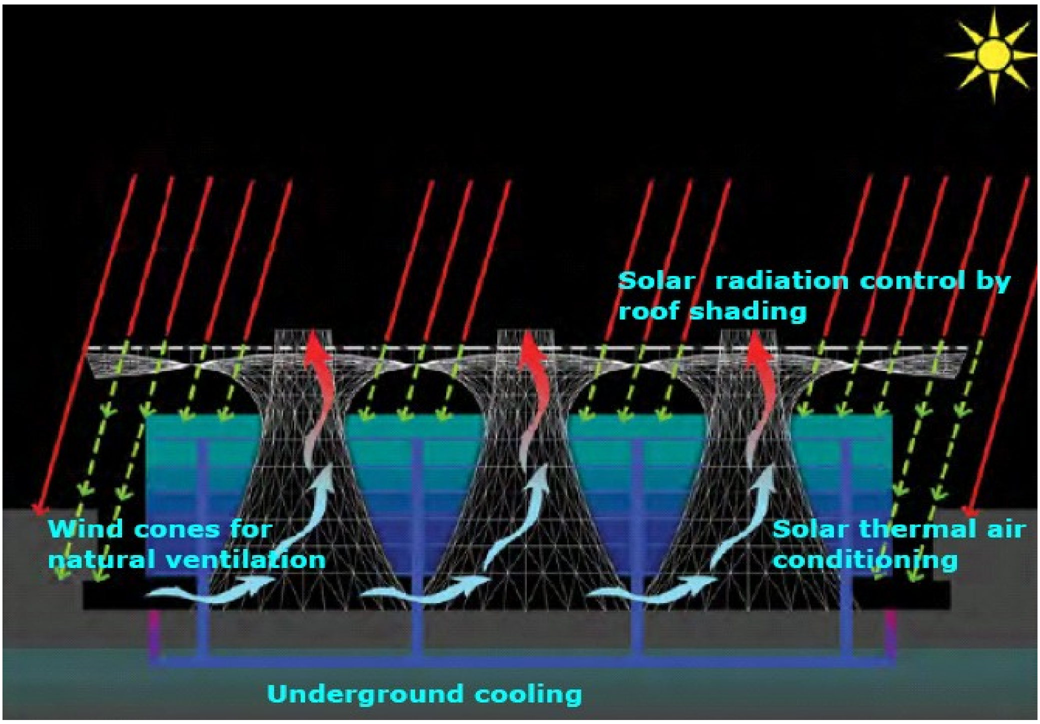


Figure 5- Schematic for passive cooling and ventilation strategies (wind cones ventilation, solar thermal air conditioning, earth cooling, and solar shading)[89]

88 Ibid

89 Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

5-5-5 Energy Efficient and Sustainable Features

Masdar headquarters aims to be the world's first zero-carbon, zero-waste headquarter in Abu Dhabi. Energy needed for cooling and lighting will be reduced by controlling the building orientation and design, and presence of green spaces to find a balance between shade and sun, to control glare, and to promote natural-air circulation. The building design includes numerous sustainable systems:

- Energy conservation: Natural lighting, sustainable transportation, and Energy generation.
- Water conservation
- Materials conservation

These systems will not only save but generate more than the needed energy for the building, eliminate carbon emissions and reduce liquid and solid wastes.

5-5-5-1 Energy conservation: Natural lighting, sustainable transportation, and Energy generation.

a) *Natural lighting*

The main idea of the building at the architect mined is based on glass-and-steel design that depends on allowing enough light into the complex while still keeping heat out, so as to avoid costly air conditioning and keep electricity bills low. This could be done by presence of a new wind cones system that in addition to providing structural support to the roof and ventilation the staggered cones bring daylight deep inside the 1.5-million-square-foot complex. They are made from glass angled at 15-22 degrees that reflect between 15-20% of the light, reducing thermal gain while letting sufficient light in from beneath the shaded roof to keep the place bright (figure 5-50).

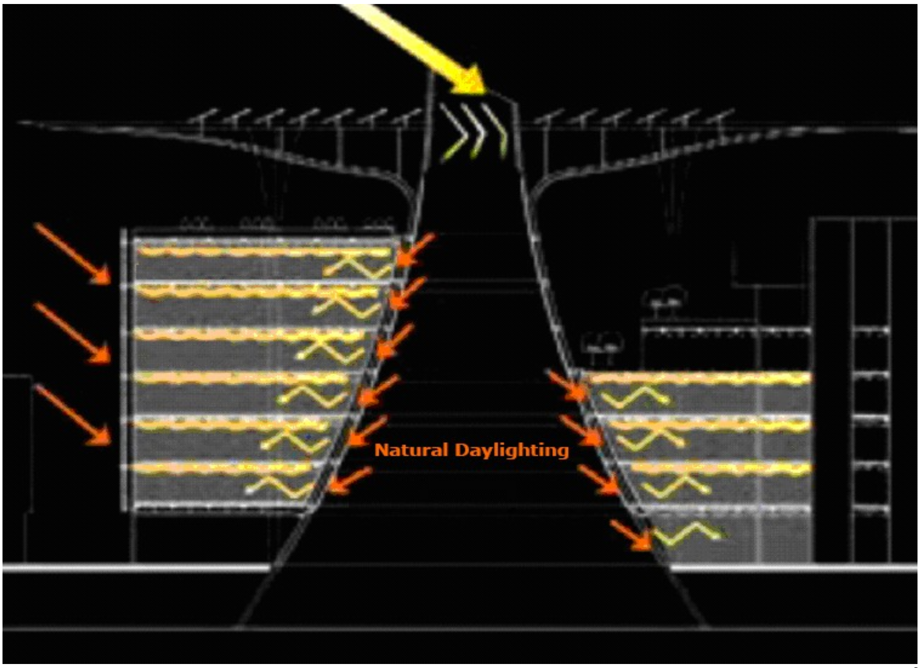
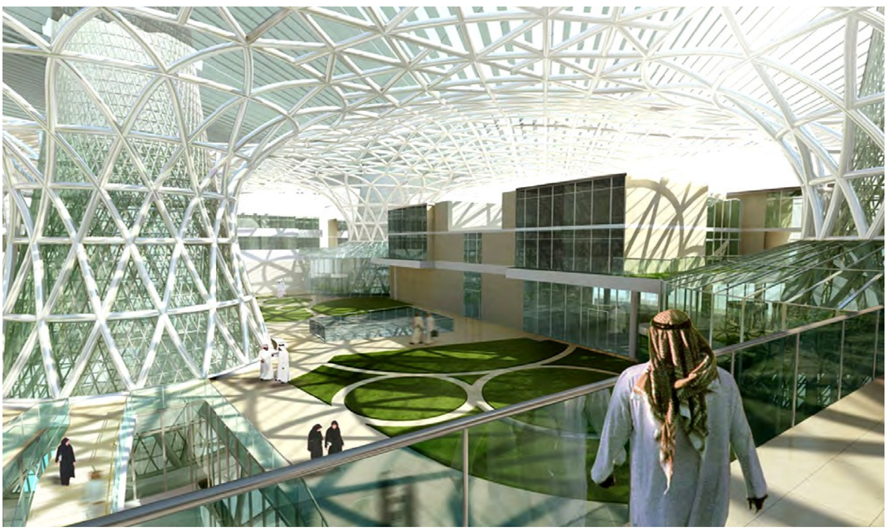


Figure 5- schematic section showing natural lighting and shading by the glass cones[90]

The cones are at an optimum nine meters apart from each other for diffusing sunlight to reach the whole building. Moreover, light sensors are being used to automatically switch bulbs off when enough light comes in from outside.



[90] Ibid

Figure 5- Sufficient natural lighting and shading by the glass cones[91]

b) Sustainable transportation

Energy for transportation will also be reduced inside Masdar city by using efficient electric personal rapid transit automotives. It will provide door-to-door service (just to type in the headquarter destination and the transport will take the employees automatically to it).

Figure 5- personal rapid transit automotives[92]

The power will be generated by renewable energy and stored onboard in batteries. Personal Rapid Transit automotives will be the only means of transport in the planned zero-carbon and zero-waste Masdar city as it is environment friendly, clean and less noisy way of transport[93].

c) Energy generation

Design plans for the headquarters include various sustainable systems that will produce more power than it needs by using renewable sources of energy generation (solar and wind energy). It will feature the largest photovoltaic power generation system and the largest solar thermal driven cooling and dehumidification system. The building will also have integrated wind turbines.

- Solar and PV panels: The 72,000 sq m roof contains one of the world's largest building integrated PV displays, it provides energy during building construction and during the building usage. Solar panel on the building’s roof was supposed to produce as much electricity over the course of a year as the building consumes[94].

[91] Ibid

[92] Car-free Masdar City will run on green PRTs , accessed 2009 http://www.business24-7.ae/Articles/2009/1/

[93] Ibid

[94] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

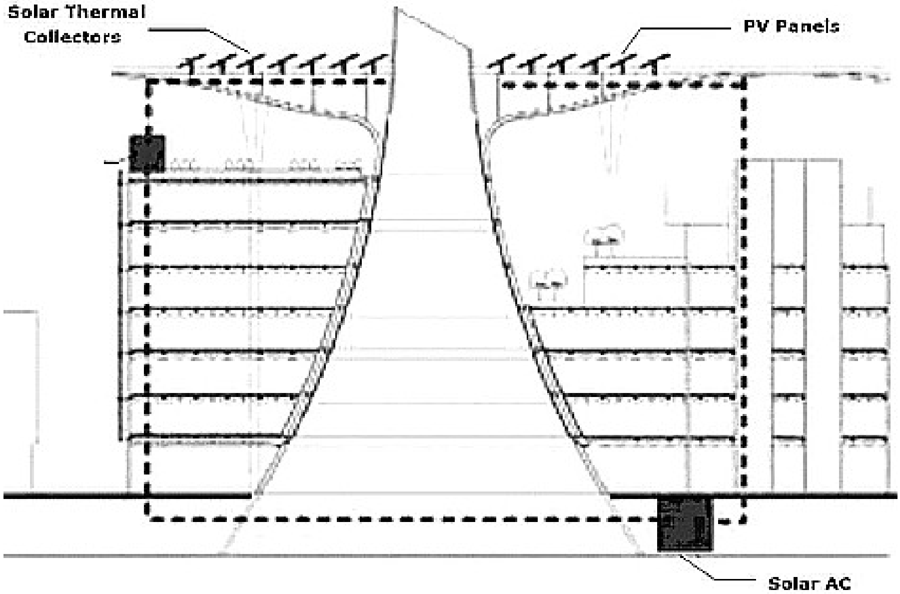


Figure 5- Power generation from PV panels and solar thermal collectors[95]

Dust from the desert quickly coats the panels and this could affect on dimming the light that reaches them, just four months of dust reduces the output of the solar arrays by more than 20 percent[96]. Therefore, these solar thermal collectors and photovoltaic cells should be cleaned gradually, but balancing power loss against water consumption for cleaning should be taken into account[97].

- Integrated wind turbines: Masdar headquarters also feature integrated wind turbines catching the prevailing winds and generate power energy. They are placed under the roof and connected to the central battery to be stored in it and used afterwards in the building.

[95] Ibid

[96] **Kevin Bullis**, Technology Review ***Magazine,*** April 2009, from website: http://beta.technologyreview.com/energy/22121/

[97] **Michael Willoughby,** Masdar HQ to generate its own power during construction, accessed 2009, http://www.building.co.uk/story.asp?storycode=3108441

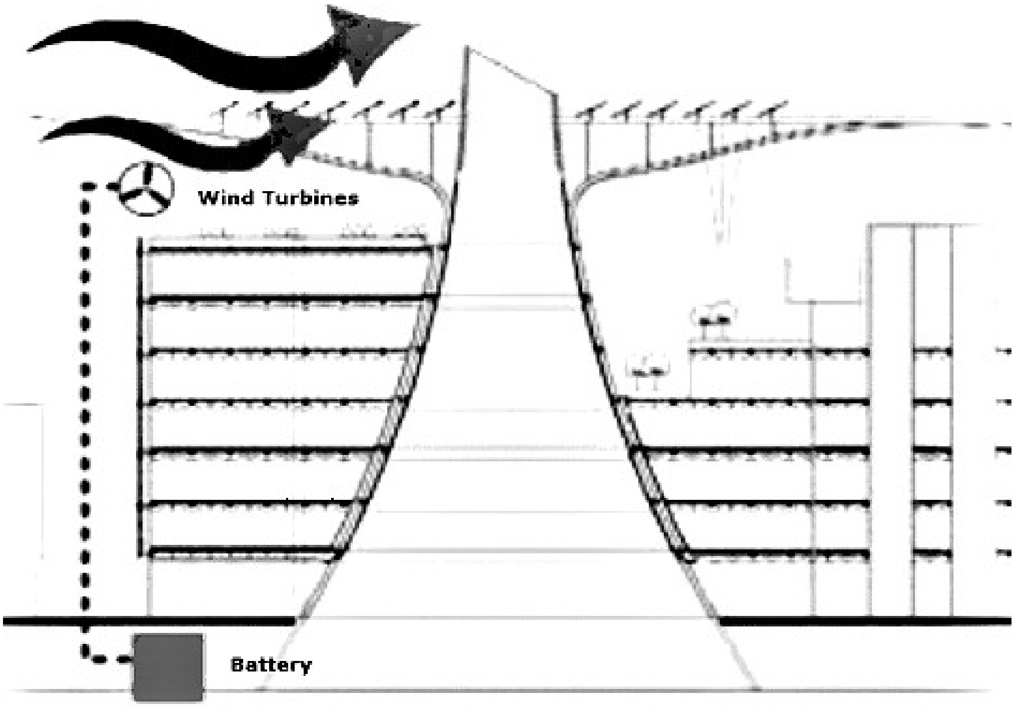


Figure 5- Power is generated from wind turbines and then stored in Batteries[98]

5-5-5-2 Water conservation

Water conservation and recycling is an obvious priority in this desert building. Graywater will be treated and stored for landscaping (figure 5-55), blackwater is treated so that its contaminants couldbe used for biofuel, and rainwater is collected and stored as well (figure 5-56). Overall, Masdar headquarter is expected to be 70% less water consumption than a typical mixed-use building of its size[99].

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[98] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

[99] **Zach Mortice**, Beyond Zero: Adrian Smith + Gordon Gill Architecture's Desert Experiment, accessed 2009, http://info.aia.org/aiarchitect/thisweek08/0404/0404d_masdar.cfm

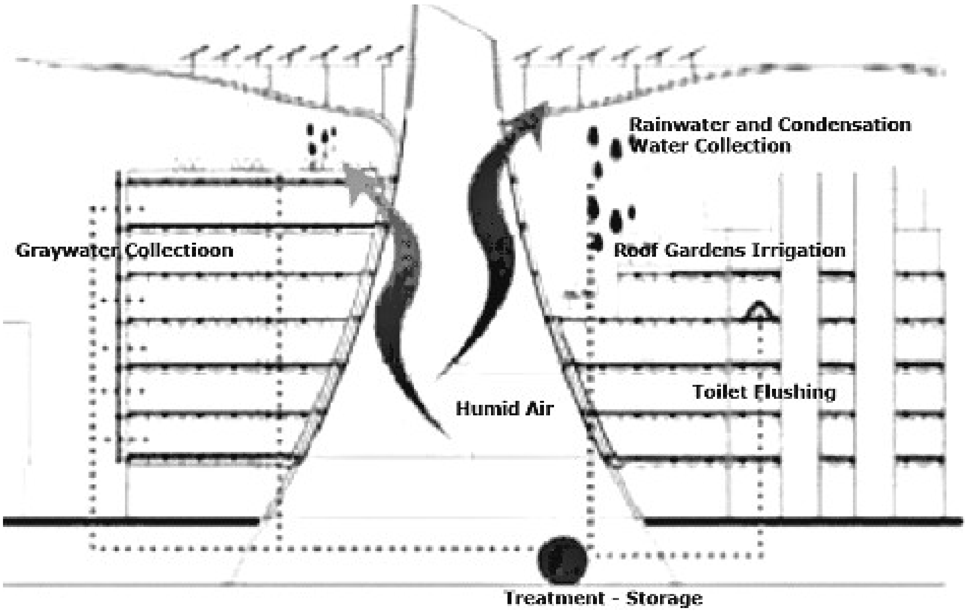

Figure 5- schematic section shows graywater treatment in Masdar headquarter[100]

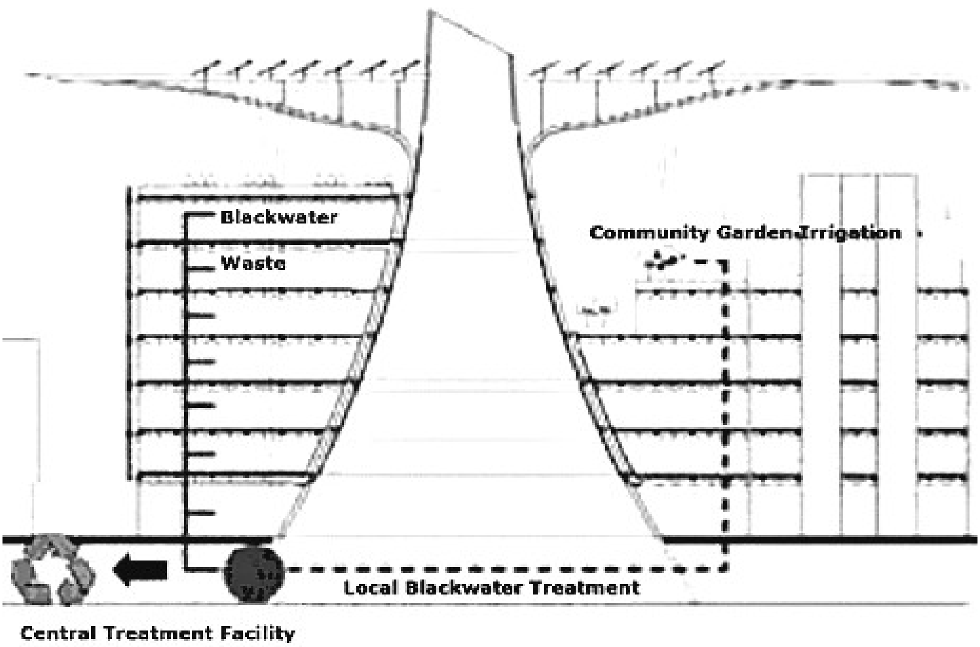

Figure 5- schematic section shows backwater treatment in Masdar headquarter[101]

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[100] Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters
[101] Ibid

5-5-5-3Materials conservation

The building construction has a global environmental situation[102], the building relates to its local environmental context while respecting its global context in terms of developing the available technologies. The building is constructed from high recycled materials content such as the use of recycled steel rather than concrete. These structures could encourage the reduction of embodied energy throughout the construction process and decreasing the environmental impact.

For enhancing the building sustainability, the construction is based on a PV roof that was constructed first before constructing the building to generate the power for the construction of the rest of the building, which leads to creating a net-zero energy construction sites. Moreover, the construction of the cones, roof, and PV panels are independent of the concrete floor slabs for offices creating flexibility in the construction. Rather than reduction of 99 % diversion of waste from landfill includes waste reduction measures and re-using of construction wastes wherever possible.

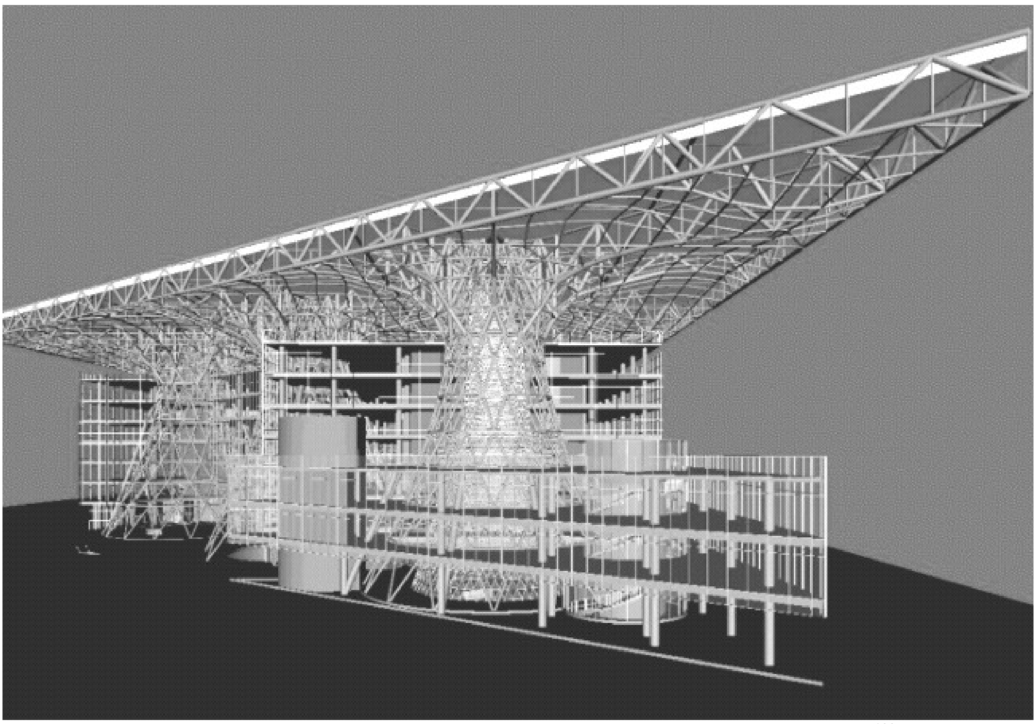

Figure 5- Model for building sustainable construction and materials[103]

[102] Ibid

[103] **Kevin Bullis**, Technology Review ***Magazine,*** April 2009, from website: http://beta.technologyreview.com/energy/22121/

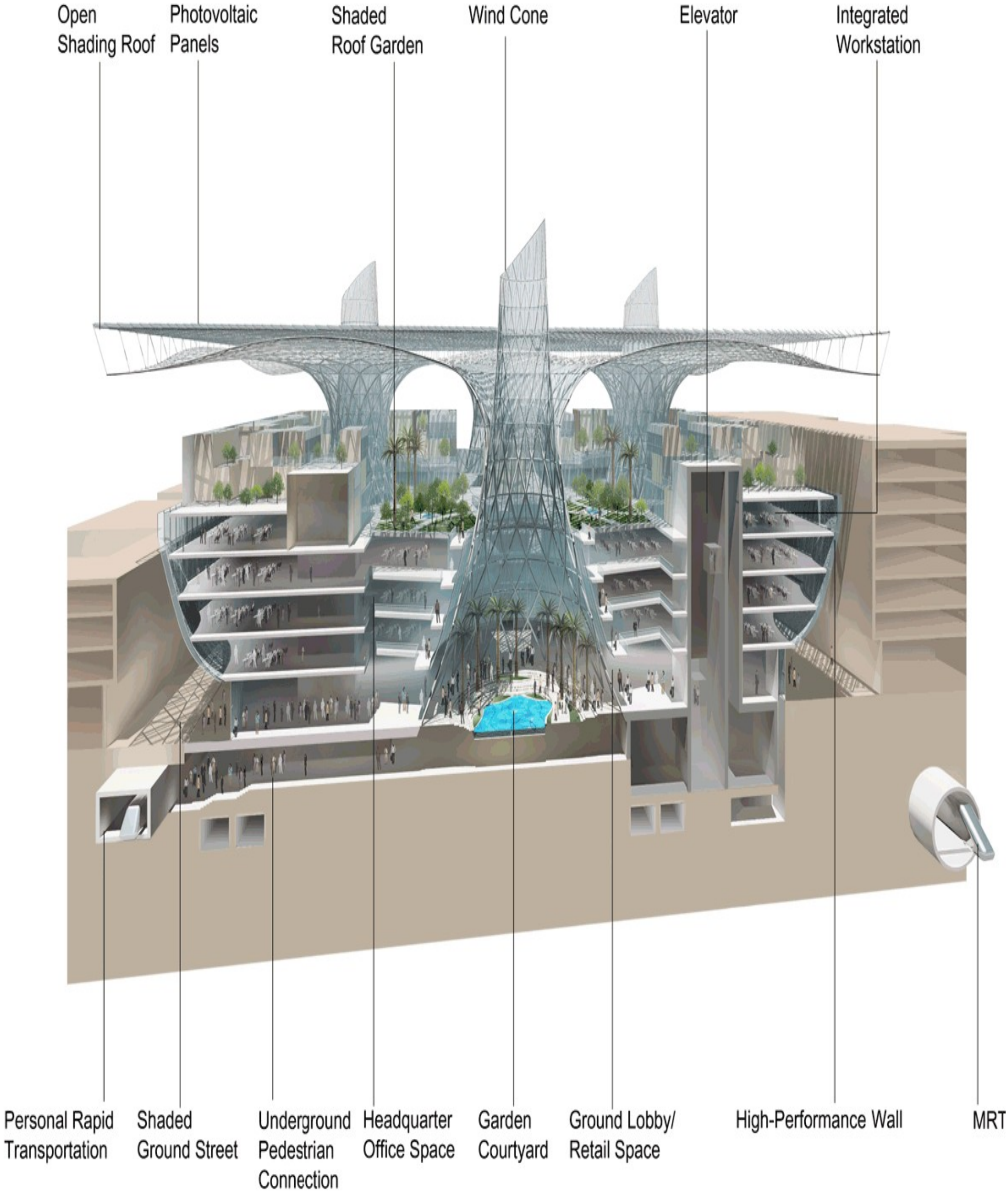

Figure 5- Cross-section shows the building different zones in connection with passive cooling and energy generation strategies[104]

104 Adrian Smith + Gordon Gill Architecture, accessed 2009, http://www.smithgill.com/#/work/by_name/masdar_headquarters

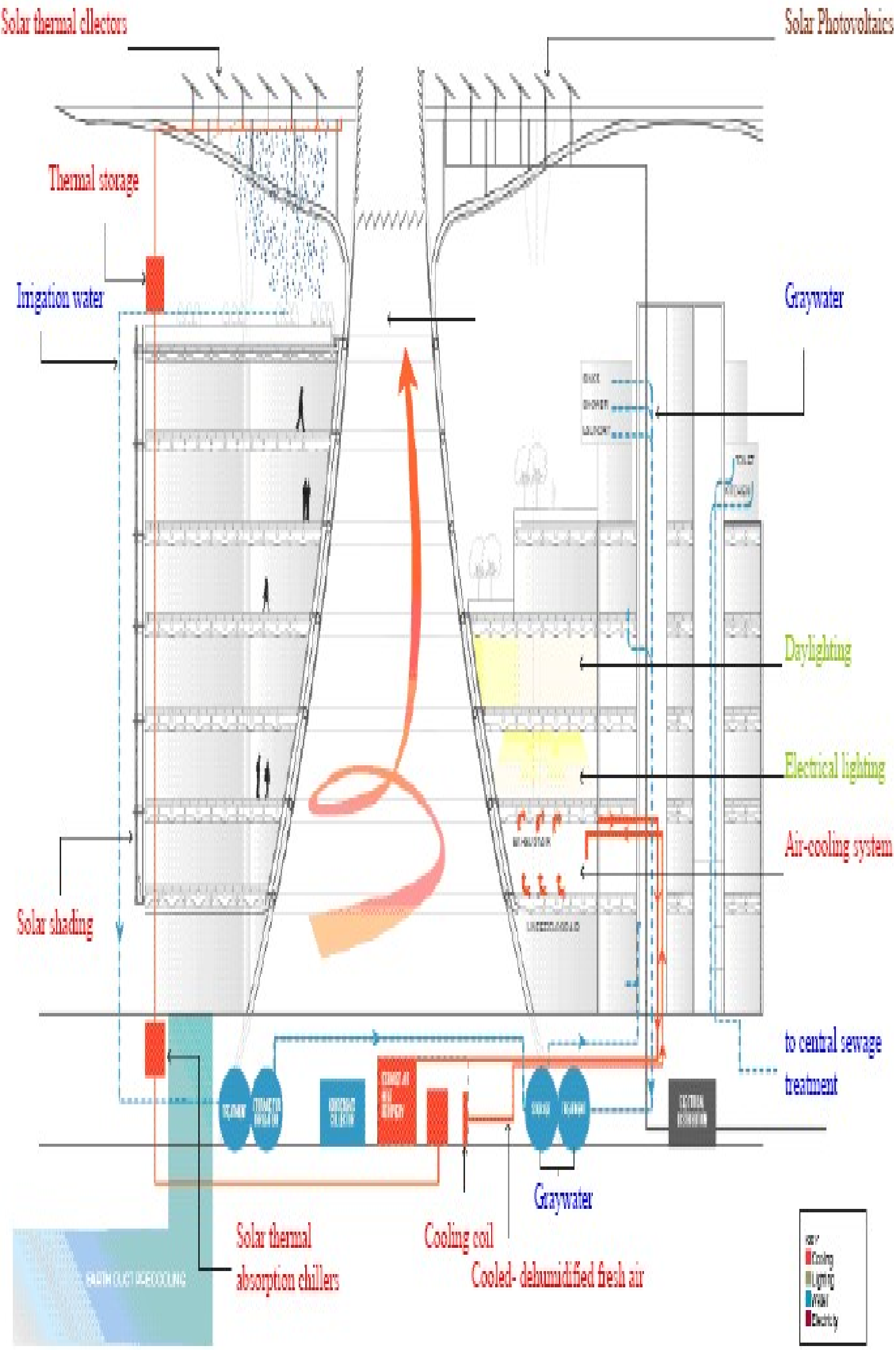

Figure 5- Schematic cross section through wind cone showing the energy efficient and sustainable strategies in Masdar headquarters[105]

[105] Ibid

5-5-6 Building Performance

This project far exceeds LEED standards[106]; a similar sized LEED Platinum building would still emit 6,000 metric tons of carbon dioxide a year[107]. In addition to being the first mixed-use net positive energy building in the world, Masdar headquarters will:

- Be the lowest energy consumer per square meter for a modern class A office building in an extremely hot and humid climate
- Feature one of the world's largest building-integrated photovoltaic arrays
- Employ the largest solar thermal driven cooling and dehumidification system
- Be the first building in history to generate power for its own assembly, through development of its solar roof pier before the underlying complex
- Consume 70 percent less water compared with typical mixed-use buildings of the same size.
- Passive cooling strategies reduce the building energy consumption by 61.5 % from the annual energy consumption (figure 5-61).

The architects used CFD or computational fluid dynamic models to analyze the effect and performance of the wind cones to cool the interiors by drawing warm air up and out of the building through their tips. Computational fluid dynamics (CFD) utilizes numerical methods to ensure that the flow of air through these cones produces the greatest cooling effect. To validate their assumptions, the team used FloVENT, a program that predicts 3D airflow, heat transfer, and distribution in and around buildings. By doing a simple model of the cones, including the courtyards created at their base to analyze the effects of repositioning the intake from the base of the cone to the side. The team found that by putting it to this side, the air could easily directs around the cone and provides more uniform ventilation[108] (figure 5-60).

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[106] Adrian Smith and Gordon Gill confirm

[107] **Zach Mortice**, Beyond Zero: Adrian Smith + Gordon Gill Architecture's Desert Experiment, accessed 2009,
http://info.aia.org/aiarchitect/thisweek08/0404/0404d_masdar.cfm

[108] **Josephine Minutillo**, *Model Behavior: Anticipating Great Design,* Architectural Record magazine, published in the December 2008.

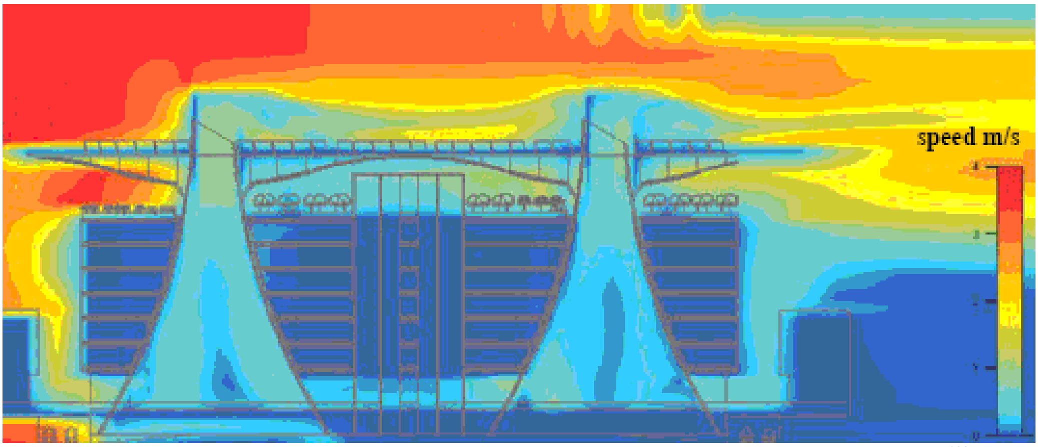

Figure 5- CFD model the building geometry and surrounding wind patterns speed[109]

From the previous model for the building geometry and surrounding wind patterns speed: Hot winds traveling at high velocities around and over the cone openings create low pressure areas providing inducing airflow out of the cones. The cone's shape captures cool air moving in the opposite direction.

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[109] Ibid

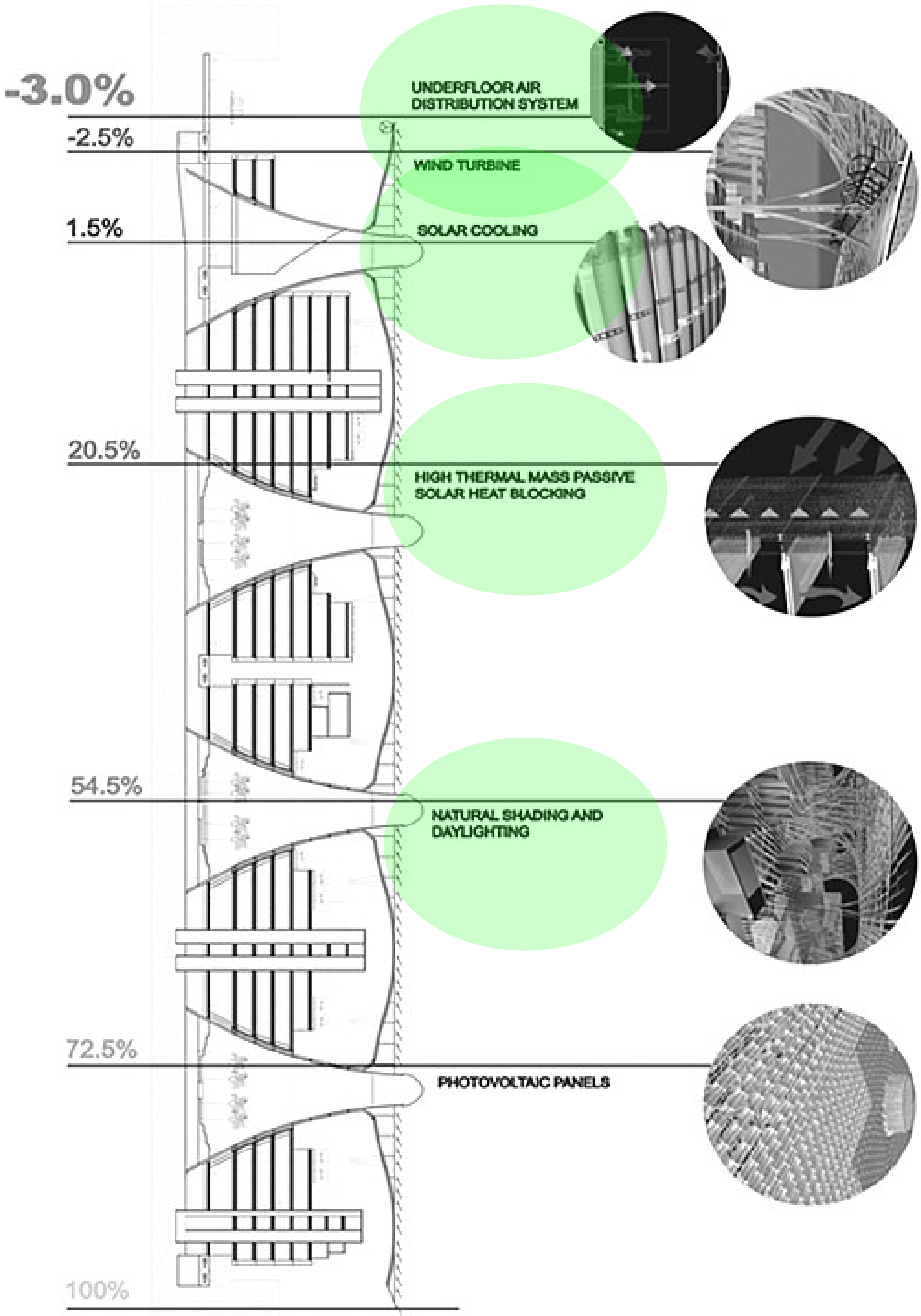

Figure 5- Energy conservation analysis in Masdar Headquarters providing an estimated 103% of energy compared with similar headquarter with no sustainable strategies from construction leveluntil building usage[110]

[110] Ibid

5-6 Conclusions

Sustainable office building main goal is to build what is most comfort and economic to maintain an efficient productive environment. This chapter has focused on the effectiveness of applying the sustainability strategies on three office buildings as case studies. It has proved that the most important features that can help improving the internal workplaces quality, cost efficiency, and employees' productivity are the internal space sustainability. It has been found that from 5–15% improvements in productivity results of a building green design[111].

The case studies in this chapter has performed that the challenges of zero energy buildings can take place not only on the residential scale or on small scale commercial buildings but also on large scale and high rise commercial buildings. The case studies were taken in different regions with different climates (hot, humidity, tropical climates) to encourage the main idea that it could be possible for large scale and high raise commercial buildings to be totally naturally cooled and ventilated even in tough climates. Some technologies were used to take the most advantages of passive cooling includes radiant cooling, geothermal cooling, solar thermal air conditioning, wind cones, thermal massing, evaporative cooling, and solar control shading devices. Moreover, natural lighting, water conservation, and energy generation strategies have been clarified in each case study to achieve significant decrease in carbon emission, increase productivity, better environmental quality, and a net zero energy office building.

[111] Greening Federal Facilities: An Energy, Environmental, and Economic Resource Guide for Federal Facility Managers - 2nd Edition (05-01-2001)

6-1 Introduction

This research has studied the main objectives for an efficient sustainable building taking into account the environmental, economic, and social sustainability. It has introduced the main principals forming the sustainable building which includes: energy conservation, water conservation, material conservation, efficient site selection, efficient indoor environmental quality, and waste management. It has focused on the passive cooling strategies as an approach to the sustainability development. This chapter will introduce some of conclusions to the study and appliance of passive cooling and sustainability considerations. It will present also some recommendations for the appliance of the passive cooling strategies in Egyptian buildings. Finally, it will study also some of responsibilities of architects and government for enhancing the appliance of sustainability principals on the Egyptian building.

6-2 Conclusions

This research has focused on the principals of passive design as an energy efficient feature for achieving a sustainable design. It has studied the principals for enhancing the internal passive cooling as an important approach for efficient passive design which include: blocking direct sun light, decreasing transmittance of external high temperature, and decreasing the internal sources emitting heat. The research has analyzed some passive cooling techniques for enhancing the internal cooling, conclusions drawn are as follows:

1. Efficient internal cooling design is drawn from efficient architectural design and should be considered from the first stage of the design.
2. Passive cooling concepts represent alternative cooling possibilities which require much less primary energy. It is possible to use natural heat sinks with these systems by employing some very simple measures (cool earth area, cold night air, cold water) by leading off heat or energy and making use of storage effects.
3. The previous studied passive cooling techniques in this research are aiming at bettering the urban environment and corresponding thermal conditions, and improving buildings' thermal characteristics by using passive and hybrid cooling systems and techniques.
4. Passive cooling methods can significantly contribute the reduction of overheating in buildings during the summer. In particular the combination of cooling, ventilation with shading has proved to be very efficient. Theoretical studies have shown that the application of all these techniques in buildings may decrease their cooling load up to 70%.

5. According to the case studies conducted in this research, the passive cooling strategies needs very low electricity consumption in usage. Some of the results of the appliance of each system are:
    - Radiant cooling is considered the most effective passive cooling system in many international case studies. It could be efficient also in hot and dry countries. Especially when using the phase change materials in the cooling process. The system could be connected with evaporative cooling tower to enhance its efficiency. From the case studies, it could decrease the building energy consumption by about 30 % of the energy used in cooling process before.
    - Geothermal cooling tubes are not efficient for small projects as it could be expensive to put the underground tubes to a great depth. Moreover, for different land characteristics in different sites, the ground should have a percent of humidity to help in cooling the underground air tubes in some regions. While in other cases the ground might not have the suitable humidity for cooling.
    - Wind catchers is a traditional ventilation system has been used in Egypt, it was efficient solution for Egyptian climate. Innovative wind catchers is now more efficient in usage as it could be automatically controlled, but its problem is that it could be not efficient in buildings more than two floors.
    - Double skin facades is the more widely used in commercial buildings to permit natural light over the working hours, it is considered also an efficient innovative ventilation system (if properly designed) for office buildings.
    - The most advantageous shading schemes have proved to be external shading devices and movable overhangs, considering also the other benefits of external shading as it could be suggested as a very effective design solution against overheating. Only the application of external shades reduces the overheating up to 20%.
    - Solar control glazing is considered very important issues for decreasing the internal cooling loads for sites which enjoy sun shines all over the year. For passive cooling in summer the sun radiations should be blocked from entering the space. The most effective shading system is the adjustable exterior shading louvers, it is considered to be the most effective shading devices as it has verity in color and materials.
6. This research has identified the parameters and requirements for passive cooling strategies in order to provide sustainable comfort interior spaces (table 6-1).

Enhancing the internal space cooling			Parameters and requirements
Architectural Considerations for Passive Cooling	**Decreasing Transmittance of External High Temperatures**		• Appropriate site layout, building location, and orientation • Building envelope materials • Using Airtight Construction • Using Non-porous materials • Minimizing fenestration
	Decreasing Internal Sources Emitting Heat Energy		• Maximizing daylighting, • Using energy efficient lighting installations
Passive Cooling Strategies	**Radiation**	**Radiant cooling pipes**	• It needs chilled water source • To ensure better indoor air quality and avoid condensation, radiant cooling systems need to be used in conjunction with a low-volume, low-velocity ventilation systems. • Air supply vents could be as fixation of fans connected to the outside fresh air in the false ceiling or under the raised floor.
		Geothermal cooling tubes	• Underground geothermal tubes should be buried underground at depth more than 5 meters in order to be efficient. • The Earth tubes should be installed at a 2-3 degree grade[1] to ensure the constant removal of condensed water from the tubes. • Soil surface should be protected from direct solar radiations
			• Evaporative coolers require a constant supply of water to operate, and where there

[1] Wikipedia, Ground-coupled heat exchanger, accessed 2007, http://en.wikipedia.org/wiki/Ground-coupled_heat_exchanger

	Evaporative cooling towers		is a water shortage, they may not be as practical. • It requires presence of high wind availability of fan supply air. • It requires a source of water in a tank. • It requires a small pump to circulate water and it is located outside the tank.
	Ventilation	**Wind catchers**	• Openings, wind catchers, or cones should be oriented opposite to the wind direction
		Double skin facades	• For efficient ventilation, a vertical displacement should be presented between inlet and outlet openings • Cavity should not be less than 30 cm depending on the function.
	Shading devices		• Designing an efficient shading system varies with variation of many factors like: building location, orientation, site, and building usage. • Shading devices affects natural light, but some solar control devices can make use of both natural light and shading like: the insulated glazing and solar control coated glazing.
	Insulated glazing		• Efficient glazing materials could control the amount of radiation • Coatings for the glazing could minimize the conductive energy transmission. • Filling the spaces between the glazing layers with an inert low-conductivity gas.

Table 6- summery of parameters and requirements affecting the interior space cooling

6-3 Recommendations

Some recommendations about the appliance of the passive cooling strategies in Egypt will be interviewed in this section taking into account the environmental, economic, and climatic conditions. Egypt lies within the North African desert, this geographical location give the Egyptian climate some characteristics which affects on designing any building. Egyptian climate is semi-desert characterized by hot dry summers, moderate winters and very little rainfall and sunshine throughout the year. Egyptian solar and wind characteristics encourage the designers to design a passive design building depends mainly on the passive cooling strategies, and especially when it needs less costs and energy efficient than conventional buildings. Following some recommendations for the architects and Governments in order to enhance the appliance of passive cooling strategies on sustainable office buildings

6-3-1 Responsibilities of Architects

Designers should consider two important issues for efficient passive cooling building; 1st applying the Design guidelines for minimizing the cooling loads for a building, 2nd selecting the efficient naturally passive cooling strategy that could be appropriate for the building requirements. To take maximum advantage of the opportunities for designing a passive cooled building and therefore energy savings, designers should:

- Properly select site for building, as the design features changes with site climatic characteristics.
- Be aware of any significant change in climatic conditions in the site.
- Properly decide the passive design that serves the target of passive cooling.
- Choose the appropriate cooling and ventilation strategies that are suitable for the building usage.
- Analyze the planning, site, and design studies before beginning the construction.
- Be updated to all computer modeling that can lead the designer to exact performance of the chosen the perfect cooling or ventilation strategies.

6-3-2 Responsibilities of Governments

Governments own and maintain a wide range of buildings and facilities, including administrative and office buildings, park facilities, health clinics and hospitals, fire and police stations, convention centers, and airports. There are a variety of tools that could help the governments to develop and operate building resources for applying efficient passive cooling strategies in a sustainable manner, following some of these tools:

- Government should restrict on the appliance building codes and policies for the construction process, contract specifications, and building performance.
- It should permit training and education programs that focus attention on sustainable development.

- It could create community boards and commissions to study local sustainable issues and provide economic motivations for sustainable development.
- The government building projects can incorporate energy efficient cooling systems, indoor-air-quality guidelines, and water-efficiency measures that harmonize with the Egyptian climate.

Reference Books

American National Standards Institute, American Society of Heating ASHRAE, 1990. *Ventilation for Acceptable Indoor Air Quality*, *The ASHRAE Standard 62.1*, Published by American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc,

Alison G. Kwok, Walter T. Grondzik, 2007, *The Green Studio Handbook: Environmental Strategies for Schematic Design*, Published by Architectural Press.

Albert Thumann, William J. Younger, 2003, *Handbook of Energy Audits: Sixth Edition*, Published by Marcel Dekker, p148-170.

Baruch Givoni, 1994, *Passive and Low Energy Cooling of Buildings*, Published by John Wiley and Sons.

Baruch Givoni, 1998, *Climate Considerations in Building and Urban Design*, published by John Wiley and Sons.

Berhard Oesterle, Rolf-Dieter Lieb, 2001, *Double-skin Facades: Integrated Planning*, Published by Prestel.

Brian Edwards, 2003, *Green Buildings Pay*, second edition, Published Taylor & Francis

Brown, G. Z. and Mark Dekay, 2001, *Sun Wind and Light.* 2nd ed., published by John Wiley & Sons Inc..

Brad Hardin, 2009, *BIM and Construction Management*, Published by John Wiley and Sons.

Cristian Ghiaus, Francis Allard, 2005, *Natural Ventilation in the Urban Environment: Assessment and Design*, Published by Earthscan.

C. Ní Riain , J. Fisher, F. MacKenzie, J. Littler1 MA, 2001, *BRE's Environmental Building: Energy Performance in Use*.

Charlotte Baden-Powell, Jonathan Hetreed, Ann Ross, 2008, *Architect's Pocket Book*, Published by Architectural Press.

Daniel D. Chiras, 2002*, The Solar House*, Published by Chelsea Green Publishing.

Deo Prasad and Mark Snow, 1994, Designing with solar power – A source book for Building Integrated Photovoltaic's (BiPV), Guiding Principles of Sustainable Design, Denver, Colorado.

Francis Allard, 1999, *Natural Ventilation in Buildings: A Design Handbook*, Earthscan.

George Baird, 2001, *The Architectural Expression of Environmental Control Systems*, Published by Taylor & Francis.

Geoff McDonell, 2007, *Selecting radiant ceiling cooling and heating systems (part 2)*, OMICRON, Vancouver, British Columbia. --Consulting-Specifying Engineer.

Girja Sharan, Ratan Jadhav, Ahmedabad, 2002, *Performance of Single Pass earth-Tube Heat Exchanger: An Experimental Study*.

Graham Farmer and Simon Guy, 2003, Department of Architecture**,** *Visions of Ventilation: Pathways to Sustainable Architecture.* University of Newcastle upon Tyne (UK) Newcastle upon Tyne, NE1 7RU. UK.

Hazim B. Awbi, 2003, *Ventilation of Buildings*, Published by Taylor & Francis.

James Parker, Arnold Teekaram, Teekaram, 2005, Building Services Research and Information Association,, *Wind-driven Natural Ventilation Systems*, Published by BSRIA.

John Twidell, Anthony D. Weir, 2006, *Renewable Energy Resources*, Taylor & Francis.

John D. Spengler, Jonathan M. Samet, John F. McCarthy, 2001, *Indoor Air Quality Handbook*, Published by McGraw-Hill Professional.

Jong-Jin Kim, 1998, *Sustainable Architecture Module: Introduction to Sustainable Design,* College of Architecture and Urban Planning, The University of Michigan, Published by National Pollution Prevention Center for Higher Education.

Kibert, Charles J., 2005, *Sustainable Construction: Green Building Design and Delivery*, published by John Wiley and sons, Hoboken, New Jersey.

Koen Steemers, Simos Yannas, 2000, *Architecture City Environment*, Published by Earthscan.

Lynne Elizabeth and Cassandra Adams, 2005, *Alternative Construction: Contemporary Natural Building Methods*,published by John Willy.

Leslie Starr Hart, 1994, *Guiding Principles of Sustainable Design,* Published by Gordon Press Publishers, Denver, Colorado.

M. Santamouris, D. Asimakopoulos, 1996, *Passive Cooling of Buildings*, published by Earth scan..

Martin W Liddament*,* 1996, *A Guide to Energy Efficient Ventilation*, *1996.*

Michael Wigginton, Jude Harris, 2002, *Intelligent Skins*, Published by Architectural Press.

Matheos Santamouris, 2003, Solar Thermal Technologies for Buildings: The State of the Art, Published by Earthscan.

Peter Frederick Smith, 2005, *Architecture in a Climate of Change*, published by Elsevier.

Public Technology inc, 1996, *Sustainable Building Technical Manual Green Building Design, Construction, and Operations*.

Rodger Edwards, 2005, *Handbook of Domestic Ventilation*, Elsevier.

Randall Thomas, 2006, *Environmental Design*, Published by Taylor & Francis.

Slessor, Catherine, 1997, *Eco-Tech: Sustainable Architecture and High Technology*, published by New York: Thames and Hudson.

Simon Burton and Marco Sala, 2001, *Energy efficient office refurbishment*, Published by Earthscan.

Conferences, Documents and publications

Berhard Oesterle, Rolf-Dieter Lieb, 2001, *Double-skin Facades: Integrated Planning*, Published by Prestel.

Brager, G.S., G. Paliaga, and R. de Dear, 2004, *Operable Windows, Personal Control and Occupant Comfort*. *ASHRAE Transactions*, 110 (2), June.

BINE Themeninfo1, 2007, A compact guide to energy research, Thermo-active building systems.

Brendan Dillon, 2008, *Pearl River Tower: Harvesting the wind for to make glorious building of natural energy Brendan Dillon* .pdf.

Catherine Slessor, November, 1997, *ECO-TECH: Sustainable Architecture and High Technology.* New York, N.Y.: Thames and Hudson, dist. by W. W. Norton &Company.

C.Y. Shaw, Jan. 1997, *Construction Technology Updates, Maintaining Acceptable Air Quality in Office Buildings through Ventilation*, National Research, Council of Canada, No. 3.

C.K. Cheung, 2005, *CH_2 Energy Harvesting Systems: Economic Use and Efficiency*, Built Environment Research Group (BERG) School of Architecture and Building, Deakin University, Geelong, Victoria, Australia.

Donald L. Basham, James W. Wright, Kathleen I. Ferguson, Get W. Moy, Unified Facilities Criteria (UFC), 16 January 2004, *Cooling Buildings By Natural Ventilation, Department of defense,* United States of America.

Dominique Hes, 2004, *Design snap shot 15: Shower Towers. PDF*.

Earth Tech Canada, 2002, *New Approaches to Economical Energy Efficient Buildings*.

E.M. Okba, May 2005, *Building envelope design as a passive cooling technique*, International Conference “Passive and Low Energy Cooling for the Built Environment”, Santorini, Greece.

Fachhochschule koln, university of applied science, 2007, *Ventilation and solar protection in hot and dry climate zone*, infrastructure and housing in an innovative oasis system for Aswan.

Frank Bruno, 2006, *Supplementary Technical Research Paper, Centralised PCM Systems for Shifting Cooling Loads During Peak Demands in Buildings* .pdf, University of South Australia.

Fang Li, James Antell, and **Martin Reiss**, 2008, *Pearl River Tower, Guangzhou:Fire Protection Strategies for an Energy Efficient High-Rise Building*, CTBUH 8th World Congress.

Girja Sharan, Ratan Jadhav, Ahmedabad, 2002, *Performance of Single Pass earth-Tube Heat Exchanger: An Experimental Study*.

Roger E. Frechette, Russell Gillchrist, Jan. 2009, *Seeking Zero Energy*, American society of civil engineering. PDF.

Harris Poirazis, 2004, *Double Skin Façades for Office Buildings,* A literature review, report. PDF, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology ,Lund University.

Heerwagen, Judith H., et al., 1996*, Tale of Two Buildings: Biophilia and the Benefits of Green Design*," paper presented at the U.S. Green Building Council's Third Annual Conference.

Hong kong university architecture department, 17 Aug 2001, Lecture: *Air Movement and Natural Ventilation.,*

Jae-Weon Jeong, **Stan Mumma**, 2006, *Designing a Dedicated Outdoor Air System*

with Ceiling Radiant Cooling Panels ●

Jim Gorman, March 2007, *Sunlight Direct's Hybrid Solar Lighting: Fiberoptic Brilliance*.

J.R. García Chávez, K. Tsikaloudaki, May 2005, *Potential of innovative day lighting and passive cooling systems for achieving luminous and thermal comfort in commercial buildings*, International Conference "Passive and Low Energy Cooling for the Built Environment", Santorin, Greece.

Johnson, Timothy E. Boston*,1991, Low-E Glazing Design Guide*, Butterworth Architecture.

Jeffrey Boyer, Arvinder Dang, 2007, *Designing for performance: A case study in the applied science of an environmentally responsive high-rise design*, Skidmore, Owings and Merrill, Chicago, USA, Proceedings: Building Simulation.

Kimmo Kuismanen, 2007*, Climate and Ventilation*, project by ECONO.PDF.

Lars H. Ringvold, September 22-24, 2004, *Innovative Façade Concepts*, ALUMINUM 2004, World Trade Fair and Conference for the Aluminum Industry. PDF, Essen.

Marsh, A.J., 1996, *Performance Modeling and Conceptual Design*, International IBPSA for Conference, The University of New South of Wales, Sydney, Australia.

Mertens S., 2006, *Wind Energy in the Built Environment*, Ph.D. Thesis, Delft University of Technology (The Netherlands).

Public Technology inc, 1996, *Sustainable Building Technical Manual Green Building Design, Construction, and Operations. PDF*.

Partnership for Achieving Construction Excellence, June 2004, *Field Guide for Sustainable Construction.* The Pennsylvania State University, University Park, PA, Pentagon Renovation and, Construction Program Office, Arlington, VA.

Paul Roelofsen, 2002, *Ventilated Facades Climate Facade versus Double-Skin Façade*, EUROPEAN CONSULTING ENGINEERING NETWORK report.PDF.

Ropert Hsin*,* 1996, *Guidelines and Principles for Sustainable Community Design*, *A study of sustainable design and planning strategies in North America from an urban design perspective*, a thesis submitted to the faculty of the School of Architecture at Florida Agricultural and Mechanical University.

Roger E. Frechette, Russell Gilchrist, *2008, Towards Zero Energy: A case study of the Pearl River Tower Guangzhou, China*, SOM, Chicago, USA, CTBUH.

Roger E. Frechette, Russell Gillchrist, January 2009, *Seeking Zero Energy*, American society of civil engineering. PDF.

Steven J. Emmerich, W. Stuart Dols, James W. Axley,august 2001, *Natural Ventilation Review and Plan for Design and Analysis Tools. PDF*.

Smith, Peter F., 2001, *Architecture in a Climate of Change: a Guide to Sustainable Design* Boston: Architectural Press.

S. General services administration (GSA), 2002, office of Government wide Policy, *Office of Real Property, Real property sustainable development guide*.

Steven J. Emmerich, W. Stuart Dols, James W. Axley, August 2001, *Natural Ventilation Review and Plan for Design and Analysis Tools*.

Sam C M Hui , August 2001, *Air Movement and Natural Ventilation*, HKU Arch Lecture.

Terry Egnor, MicroGrid, 2004, Inc., developed by: Paladino & Company, Inc., *Natural Ventilation in Buildings,* Sponsored by: Better Bricks, an initiative of the Northwest Energy Efficiency Alliance.

Timothy Moore, Fred Bauman, and Charlie Huizenga, April 2006, *Radiant Cooling Research Scoping Study*, Internal Center for the Built Environment (CBE), University of California, Berkeley, REPORT.

Tim Weber, **Dietrich Schmidt, Gudni Jóhannesson**, 2002, *Concrete Core Cooling and Heating -a Case Study about Energy Analysis on Building Components*.

UNEP collaborating center on energy and environment, 2001, *implementation of renewable energy technologies- opportunities and barriers, Egypt country study*, 2001.

US environmental protection agency, 1997, *An Office Building Occupant's Guide to Indoor Air Quality*, Washington.

Vijaya Yellamraju, 2004, *Evaluation and Design of Double Skin Facades for Office Buildings in Hot Climates*, Master thesis. PDF.

Wolfgang Streicher, 2005, *BESTFAÇADE, Best Practice for Double Skin Façades*, report. PDF.

Wong N.H, Song J, Tan G.H, Komari B.T, Cheong D.K.W., 2003, *Building and Environment*, Volume 38, Number 11, published by Elsevier.

Josephine Minutillo, *Model Behavior: Anticipating Great Design,* Architectural Record magazine, published in the December 2008.

Journals, Lectures, Technical catalogues and Magazines

Vernon Mays, *ARCHITECT Magazine*, Publication date: 2008-06-01, from website: http://www.architectmagazine.com/industry-news-print.asp?sectionID=1006&articleID=721074

Kevin Bullis, April 2009, Technology Review Magazine,
from website: http://www.technologyreview.com/energy/22121/page2/

Official journal of Airah, February 2003, *Cooling Rural Australia Passive Downdraught Evaporative Cooling*, Dubbo Campus harles Sturt University,

American Society of Heating, Refrigerating and Air-Conditioning Engineers, April 2009, Inc. ASHRAE Journal.

Futurarc: New Architecture magazine, 3rd Quarter 2008

Mark Piepkorn, August 06, 2007, *Colt's Facade Shading with Passive Control*, green source magazine, .

Dominique Hes, 2004, *Design snap shot 15: Shower Towers. PDF*.

European green building forum, April 2001, C*atalogue of best practice examples, Produced* by W/E Consultants Sustainable Building, The Netherlands.

The official journal of Airah, February 2003, *Cooling Rural Australia Passive Downdraught Evaporative Cooling*, Dubbo Campus, Charles Sturt University.

Brager, G.S., R. deDear, 2000, *"A Standard for Natural Ventilation."* ASHRAE Journal 42,
Passivent, July 2005, AIRSCOOP VENTILATORS technical catalogue. PDF.

Window Master INC., 2007, Natural Ventilation Fresh Air- simple and efficient, Solutions for Natural Ventilation cataloge.

Monodrought wind catcher natural ventilation system, September 2006, technical catalogue.PDF.

Colt International Limited, 2005, New Lane Havant, *Architectural solutions, solar shading systems,* Leaflet,.

European green building forum, April 2001, *Catalogue of best practice examples*, by W/E Consultants Sustainable Building, The Netherlands.

Bomin solar GmbH, Data sheet 2002*Innovative Systems made by BOMIN SOLAR, Movable or fixed Glass Scale Louvers,* BOMIN GSL for inside and outdoor purposes, Aeration and sunshading system.

Michelle Wong, 2007, *The Pearl River Tower:Skyscraping Innovations*, CaliforniaEngineer, volume 86.

BRE research and development group*, The Environmental Building, The Building Research Establishment (BRE) Office Building*, project. PDF, 2006.
From website: http://www.caa.uidaho.edu/arch504ukgreenarch/CaseStudies/bre2.pdf

Zehnder ZBN, Ceiling Heating and Cooling System, Technical catalogue,2007
http://www.zehnder.co.uk/pdf/zip_technical_brochure.pdf

Monodrought *wind catcher natural ventilation system*, September 2006
Evaporative Cooling catalogue
From website: http://www.arch.mcgill.ca/prof/bourke/arch672/fall2002/evapor.htm

Websites

Rural serve company, Solar Thermal Energy, (accessed 2006)
http://www.ruralserv.com/Solar-thermal-energy.php

BEER, Sustainable Architecture, (accessed 2006)
http://www.arch.hku.hk/research/BEER/sustain.htm#1.3

digitallibrary, Hassan Fathy,(accessed 2006)
http://archnet.org/library/images/thumbnails.jsp?location_id=5161

The Vital Signs project, architecture department, Berkeley University, ,(accessed 2008)
http://arch.ced.berkeley.edu/vitalsigns/workup/two_houses/two_bkgd.html.

Daylight, sportscotland, (accessed 2008)
http://daylight.sportscotland.net

The Encyclopaedia of Alternative Energy and Sustainable Living, Earth cooling tube, (accessed 2007)
http://www.daviddarling.info/encyclopedia/E/AE_earth_cooling_tube.html

Wikipedia, Ground-coupled heat exchanger,(accessed 2007)
http://en.wikipedia.org/wiki/Ground-coupled_heat_exchanger

US Department of Energy, Energy Efficiency and Renewable Energy, Earth Cooling Tubes, (accessed 2007)
http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12460

LBNL, High- Performance Commercial Building Facades, Technological Solutions, Double skin Facades and Natural Ventilation, (accessed 2007)
http://gaia.lbl.gov/hpbf/perfor_c.htm

Double Skin Façades for Office Buildings, (accessed 2008)
http://www2.ebd.lth.se/ebdhome/avd_ebd/main/personal/Project_home_page/main/DoubleSkinFacades.htm

San Joaquin, energy effeciancy saving energy, Insulation & Windows, (accessed 2008) http://www.intergycorp.com/sanjoaquin_energy_efficiency/insulation.html

Environmental Building, Building Research Establishment, accessed 2008, http://www.maxfordham.com/projects-item.php?id=58&cat=9

Northwest construction, best of 2008 green smart awards, (accessed 2008) http://northwest.construction.com/features/archive/2009/01_feature1.asp

Geoff McDonell, PEng, Selecting radiant ceiling cooling and heating systems (part3), (accessed 2007)
http://www.csemag.com/article/CA6499931.html

WBDG Sustainable Committee, Optimize Energy Use, (accessed 2008) http://www.wbdg.org/design/minimize_consumption.php

nwcommunityenergy.org, Conservation and Efficiency, (accessed 2008) http://www.nwcommunityenergy.org/biogeo/efficiency

The authority on sustainable building, Passive Design: Introduction, (accessed 2008) http://www.level.org.nz/passive-design/

Gregg D. Ander, FAIA, Daylighting, (accessed 2007)
http://www.wbdg.org/resources/daylighting.php

wikipedia, Thermal conductivity, (accessed 2008)
http://en.wikipedia.org/wiki/Thermal_conductivity

Comfortable Low Energy Architecture, Thermal Resistance, (accessed October 2008) http://www.learn.londonmet.ac.uk/packages/clear/thermal/buildings/building_fabric/properties/resistance.html

Glossary, Influence of thermal mass on the periodic heat flow,(accessed 2007) http://www.learn.londonmet.ac.uk/packages/euleb/en/glossary/index6.html

Wikipedia, Windcatcher, (accessed 2007)
http://en.wikipedia.org/wiki/Windcatcher

Wekalah in Islamic Architecture in Egypt, Wekalate Bazar'a, (accessed 2008) http://www.egyptarch.com/historicalcairo/islamicmonements/bazaraa/bazara2.htm

University of Michigan, Natural Resources and Environment, (accessed 2007) http://www.snre.umich.edu/greendana/conservation/radiant_cooling.php

Rudek, Construction Services Inc. Radiant Heating & Radiant Cooling, A New Concept of Air Conditioning, (accessed 2008)
http://www.rudekinc.com/radiant-cooling.htm

KaRo company, Radiant Cooling Corporation, Capillary Tubes, (accessed October 2008)
http://www.radiantcooling.org/capillary.htm

Passive Air Conditioning company, (accessed 2009)
http://www.thefarm.org/charities/i4at/lib2/aircool.htm

Solar Air Conditioning, (accessed 2009)
http://hubpages.com/hub/Solar_Air_Conditioning

Sunairco Company, (accessed 2009)
http://www.sunairco.com/

Sustainable design update, Zero Energy Office Building, (accessed 2009)
http://sustainabledesignupdate.com/?p=113

Zach Mortice, Beyond Zero: Adrian Smith + Gordon Gill Architecture's Desert Experiment, accessed 2009,
http://info.aia.org/aiarchitect/thisweek08/0404/0404d_masdar.cfm

Adrian Smith + Gordon Gill Architecture, (accessed 2009)
http://www.smithgill.com/#/work/by_name/masdar_headquarters

Michael Willoughby, Masdar HQ to generate its own power during construction, (accessed 2009)
http://www.building.co.uk/story.asp?storycode=3108441

Car-free Masdar City will run on green PRTs (accessed 2009)
http://www.business24-7.ae/Articles/2009/1/

Stunning Solar Building will generate more power than it needs, (accessed 2009)
http://www.metaefficient.com/architecture-and-building/stunning-solar-building-will-generate-more-power-than-it-needs.html

welcome to Abu Dhabi, climate, (accessed 2009)
http://www.visitabudhabi.ae/en/uae.facts.and.figures/climate.aspx

Chinagreenbuildings, Pearl River Tower, (accessed 2009)
http://chinagreenbuildings.blogspot.com/2008/11/peal-river-tower.html

Guangzhou City, Guangzhou climate, (accessed 2009)
ttp://www.cctsbeijing.com/china_guide/attraction/city_guangzhou/city_guangzhou_climate.html

Theses and Researches

Sayed, Zeyad Fikry, Mohamed Anwar, 1997, *Energy efficient housing***,** faculty of Engineering. Alexandria.

M.Tarek M, 2008, *Intelligent Buildings*, fuculty of Engineering. Alexandria.

Badr , Amani Mostafa Aldossouky , 2004, *Sustainable Multi store Buildings*, faculty of fine Arts, Alexandria.

El-Deeb , Khaled Mohamed Farid Mohamed Mohamed , 2005, *The design of building envelope as a tool for achieving environmental design goals*, , faculty of fine Arts, Alexandria.

Youssef ,Tamer Mohamed, 2006, *Virtual Environmental Immersive*, Ain Shams University - Faculty of Engineering, cairo

El Shawarby,Mahmoud M. Abd El Razik, 2005, *The Future Of Smart Architecture In Egypt Away Design Environmental Buildings*, Ain Shams University-Faculty Of Engineering, Cairo.

Algohary, Sherif Abd El-Monem Ibrahim, 2002, *Importance of Energy and Environment Aspects in the Design of Solar Passive Building Aoase Study Inshas Science City Project*, Ain Shams University-Faculty Of Engineering, Cairo.

Abd EL-Aziz, Mazen ATTIA, 2003, *Conserving Energy in Buildings by Passive Design Means*, faculty of Engineering, Alexandria.

El Sayad, Zeyad Tarek, 2000, *The Ecological footprint*, faculty of Engineering, Alexandria.

Mansour, Alaa Adel, 2005, *Integrating the principles of sustainability into architectural design*, faculty of Engineering, Alexandria.

Shaaban, Sameh Mahmoud, 1997, *Environmental studies in Architecture*, faculty of Engineering, Alexandria.

Gala, Kareem Saad Ahmed Mohamed, 2005, *The ventilation of open spaces of cities*, faculty of Engineering, Alexandria.

Mahmoud, Hebat-Allah Hamdy, 2006, *A design process for energy efficient buildings/* faculty of Engineering, Alexandria.
Abu El Dahab, Enas El Sayed Ebrahim.,2006, *An approach for sustainable building in Egypt*, faculty of Engineering, Alexandria.

سرور, ياسر حسن محمود سرور, 2008, الغلاف الخارجى للمبنى كمنظومة بيئية متكاملة :نحو عمارة مستدامة جامعة الأسكندرية. كلية الهندسة.قسم الهندسة المعمارية.

Mohammad Refaat Mohammad, 2002, *Renewable energy, Sustainable communities, Solar energy, Renewable energy institutional framework*, Cairo .University

Ahmed Ahmed Allabbad, May, 2002, *External spaces, Thermal environment, Microclimate*, Cairo University.

Nihal Mohamed Maarouf Mohamed, 2002, *Housing, New communities, Communal parks, Social design, Human needs, 10th of Ramadan city*, Cairo University.

Ahmed Fathy Ahmed Ibrahimm, 2002, *Environmental efficiency, Housing complexes planning, Climatic region*, Cairo University.

اشرف منصور حبيب منصور , *2001*,التنمية السكنية المتوافقة – الاعتبارات البيئية فى تصميم الإسكان منخفض التكاليف, كلية الهندسة.قسم الهندسة المعمارية, جامعة القاهرة.

غادة ممدوح محمد فهمى,2000, استخدام تقنيات المعلومات في صياغة أسس العمارة الخضراء, كلية الهندسة.قسم الهندسة المعمارية, جامعة القاهرة.

عباس محمد الزفارنى, 2000,التصميم المناخى للمنشآت المعماريةمدخل كمى لتقييم الأداء المناخى للغلاف الخارجى للمبنى وتفاعله مع محيطه العمرانى_, كلية الهندسة.قسم الهندسة المعمارية, جامعة القاهرة.

احمد عبد الوهاب احمد رزق, 2000, تكامل الأنظمة البيئية فى مبانى القرى السياحية, كلية الهندسة.قسم الهندسة المعمارية, جامعة القاهرة.

إيمان مختار عمر مختار , 1999, نحو عمارة خضراء : مفاهيم وركائز, كلية الهندسة.قسم الهندسة المعمارية, جامعة القاهرة.

Appendix A: Evaluation of the Required Ventilation Rate for Building Interior Spaces

The methodology of proper ventilation system is based on the evaluation of the required ventilation rate. Airflow rate for human comfort is defined as the minimum airflow rates that enhance the indoor air quality and requirements for health.

A-1 Considerations before Evaluation the Ventilation Rates

In order to determine the required level of ventilation rate, it is important to identify conditions of the surrounding, kind of activity being carried out, and the level of occupancy in interior space. However, there are some factors that influence the design of the ventilation rate for efficient cooling the interior; these factors are mentioned as follows:

a) *External Air Quality*
External air quality is an important aspect which should be considered for calculating the required ventilation rate when designing a ventilation system. as well as, percentage of pollution from dust and smoke is important aspects that determine if natural ventilation would be possible.

b) *Occupancy Levels*
The occupancy level should be known to evaluate the amount of air flow rate required for the space. As, for working spaces, every person should have his minimum airflow rate for feeling comfort. Moreover, airflow rate for crowded spaces is much more than that in less occupant spaces.

c) *Occupancy Activity*
Knowing the types of activity of the people in the space will determine the required air change rates and ventilation system required. For example, people whom working are stationary on desk in front of computers differs from those whom are moving all the time.

d) *Relative Humidity Level*
The space relative humidity level is an important aspect should be known by the designer before designing the ventilation system. The relative humidity level specifies the required rate of ventilation to control it in order to achieve more interior comfort.

e) controlling pollutants level

Continuous recirculation of interior air can help people to avoid the concentrated levels of bacteria and chemicals within the building. Moreover, natural ventilation is considered a healthier cooling strategy as it supplies the building by 100% fresh air and increases the oxygen level which will leads for more productive environment. The long-term exposure to these pollutants could have a detrimental effect on the occupants' health. In order to ensure good indoor air quality, internal pollutants sources should first be avoided, and then the outdoor air flow rate should be designed or adjusted to keep the concentration of the pollutants below an acceptable level. This strategy is very clear in the next graph (figure A-1), the pollution level decreases with increasing the airflow rate. It is important to identify the dominant pollutant sources, to calculate the minimum air flow needed to control the pollutants level.

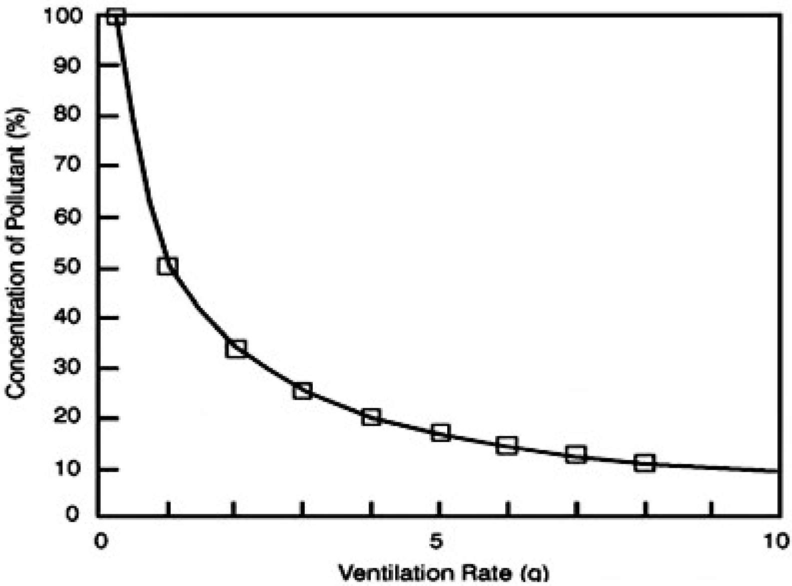

Figure A-1 Natural ventilation rate for comfort indoor air quality[1]

f) Controlling oxygen and carbon dioxide levels

Oxygen concentration in outdoor fresh air is about 21% and CO_2 is about 0.03 %[2], these percentages are considered the perfect for human comfort. Any variation in these extents can be insufficient for human usage, the

[1] Rationale and Background to Ventilation, accessed 2007, http://www.aivc.org/

[2] CBD-110, Ventilation and Air Quality, November accessed 2008, http://irc.nrc-cnrc.gc.ca/pubs/cbd/cbd110_e.html

minimum accepted percent exposure of the concentration of O_2 is 16 percent and a maximum accepted concentration of CO_2 is 0.5 percent for human comfort standards[3]. For achieving these percentages in any occupied space, the minimum rate of supply of outdoor fresh air should be approximately 3 L/s per person[4]. This rate is required to control the concentration levels of CO_2 and O_2 level in the indoor air. Moreover, as the interior activity increases the consumption of O_2 and production of CO_2 increases which leads to increase the requirement of fresh airflow rates correspondingly.

A-2 Required Ventilation Rates for Working Spaces

During the day working hours for normal occupancy, the minimum required fresh air is 5 l/s per person, while the recommended rate is 8 l/s per person. This rate satisfies substantial majority of adapted occupants during office hours. while the adaptive temperature standard for naturally ventilated office buildings for indoor air comfort varies from the range of 17 ºC to 22 ºC in winter and of 26 ºC to 31 ºC in summer when outdoor air temperatures reach 34 ºC or higher. Moreover, this ventilation rate should be sufficient to limit carbon dioxide. The number of occupancy inside the office determines the amount of production of CO_2. Thus, for efficient ventilation rate, the CO_2 should be controlled automatically by adjusting the outdoor air supplies rate, according to the number of occupants in the building and the percentage of CO_2 emitted into the space[5].

The following mathematical simulation systems can calculate the required airflow rate for the wind pressure difference ventilation (cross ventilation) and thermal forces ventilation (stack ventilation) systems for the interior space depending on the area of the opening, wind speed, air density, and pressure difference.

A-2-1 Calculating the Airflow rates caused by wind pressure (cross ventilation)

By using the following equation could calculate the air flow rate through ventilation inlet opening forced by wind[6]:

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[3] Ibid

[4] Ibid

[5] Ibid

[6] **Sam C M Hui** , 2001, HKU Arch Lecture, Air Movement and Natural Ventilation.

$$Q = C_v \cdot A \cdot v$$

Where
Q = air flow rate (m^3/s)
A = free area of inlet openings (m^2) *v = wind velocity (m/s)*
C_v = effectiveness of openings (Cv is assumed to be 0.5–0.6 for perpendicular winds and 0.25 to 0.35 for diagonal winds).

From the previous equation, if the ventilation rate *Q* of special space is known and the wind velocity v is given, then the architect can easily know the surface area of the inlet openings *A*. This could help in the designing process for achieving efficient naturally ventilated building. And also if the inlet areas *A* are known, then the architect can know easily the airflow rate *Q* in the given space. This could help him for evaluating the efficiency of the ventilation system and if it needs an additionally system.

A-2-2 Calculating the airflow rate caused by thermal forces (stack ventilation)

The internal airflow rate caused by stack effect may be estimated by:

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_o - T_i}{T_o}} \quad \text{if } T_o > T_i$$

Where
Q = air flow rate (m^3/s)
K = discharge coefficient for the opening (usually assumed to be 0.65)
A = free area of inlet openings (m^2)
Δh = height from lower opening (mid-point) to neutral pressure level (m)
g = gravitational acceleration, 32.17 ft/s^2
T_i = indoor air temperature (K)
T_o = outdoor air temperature (K)

From the previous equations, for a given building design, the inlet opening areas *A* and their difference in height Δh are known, then the airflow rate *Q* can easily known for evaluating the system efficiency and if it needs any additional system. While if the building is still in the design stage and needs to achieve a given airflow rate *Q* and achieve a given indoor air temperature T_i, then from

the previous equation, the architect can know the area of the inlet openings *A* which will help in proper design a naturally ventilated building.
The average recommended nominal airflow rates for some special spaces according to ***ASHRAE Ventilation Requirements***[7] are presented in the following table:

Space	**Recommended airflow rate** (cfm/person)
Offices	17
Heavy industrial spaces	30
Residential buildings	22
Conference room	6
Theater auditorium	5
Educational classroom	15

Table A- Recommended nominal airflow rates for spaces with various functions

Where the minimum ventilation rate in cubic feet per minute (cfm) per person is equal to 2119 m^3/s.

A-3 General Methodology for designing an efficient Natural Ventilated Building

The general design methodologies for designing a building that relies on natural ventilation systems while conserving nonrenewable energy are as follows:

a) Develop the building design requirements
This step is the first step of the natural ventilation design methodology, in this step the designer should establish the building design requirements for natural ventilation. It should also establish whether or not the natural ventilation system is efficient for the building purpose. Moreover, for efficient design, the designer should take into consideration the indoor environmental requirements, air quality and humidity, space requirements, the natural ventilation system construction and its operating costs.

b) Identify building usages and features that might require special attention
In this step the designer should consider the issues that might affects the ventilation behavior and effectiveness. It includes internal heat gain

[7] American National Standards Institute, American Society of Heating ASHRAE, *Ventilation for Acceptable Indoor Air Quality*, *The ASHRAE Standard 62.1*, Published by American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, 1990.

sources, direction of solar radiations, and space usage. Actually, these issues should be considered before deciding the natural ventilation system as they will have a great effect on the evaluation of required ventilation rates.

c) Plan airflow paths

This step requires the establishment of the airflow paths into the interior space and then out through drawing plans for the exhausted spaces. Consideration must be given to the orientation of the building to the prevailing winds and the external pollutant sources. The architect should consider also implementing mechanically assisted and mixed-mode ventilation strategies into the plans as well as the use of night cooling of the building thermal mass[8].

d) Determine the required ventilation rates for each space

This step requires the designer to determine the airflow rates required to satisfy the previously determined design requirements. Ventilation for better indoor air quality establishes minimum ventilation rates based on existing ventilation standards and building codes[9]. Weather data and internal loads are used to determine required flow rates during the different seasons.

e) Estimate external driving pressures

The designer in this step determine the driving forces to which the building is likely to be subjected including wind pressure and stack-induced, and to determine the design conditions to be used in selecting and sizing the ventilation devices.

f) Select the efficient ventilation system

In this step the designer should identify the efficient natural ventilation system (cross ventilation, stack ventilation or single sided ventilation system) that should be used in this building. The designer also should identify the locations of the inlets and the outlets of this ventilation system through the building envelope. Moreover, he should decide the location at which the ventilation devices will be placed according to the previously planned airflow paths. Ventilation devices include windows, wind catchers, chimneys, exhaust stacks, louvers, and mechanical assist fans. Beside, the characteristics of these devices should be identified to recognize the

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[8] **Steven J. Emmerich, W. Stuart Dols, James W. Axley**, August 2002, *Natural Ventilation Review and Plan for Design and Analysis Tools*, P43.

[9] Ibid

relationships between airflow rate through the device and the pressure difference across it, the general description for ventilation systems which is mentioned in the section 3-6.

g) *Size of the ventilation devices*

The designer in this step determines the size of the selected ventilation devices. Sizing can be performed using computational methods and tools relaying on driving forces and airflow characteristics. The use of sizing methods and tools can be very helpful in designing a natural ventilation system to increase the effectiveness of the system.

h) *Use CFD modeling for control systems*

The architect can make use of CFD modeling programs in order to accurately analyze the effects of wind pressure on a building, it creates 3D computer simulations of the building structure and its surrounding area, which includes objects such as trees, other buildings and hills which will affect wind flow to the building. This makes it possible to predict the effect of wind on precise areas of the building to a high level of accuracy. Then engineering designers could make use of this modeling for creating the efficient control strategy (manual or automatic controls)[10].

i) *Analyze the design*

It is the last step for designing efficient natural ventilated space. The designer in this step analyzes the ventilation system and evaluates its effectiveness to the building and whether or not this system meets the design requirements. This includes evaluating the design under various weather conditions and heat loads, and evaluating the potential mistreatment of occupant-controlled ventilation devices. The use of analysis tools can be very useful in this step to provide detailed simulations of the behavior of the building design including airflow rates, pressure relationships between zones, temperatures, and energy use. Nevertheless, there are several multi-zone modeling software tools now available that provide very flexible handling of airflow and pollutant transport such as E-Quest, Fluent, ECOTECT, CONTAM, COMIS, and BREEZE. This software can analysis the enable simulations up to a year, including the use of design or measured weather data.

A-4 Critical barriers for applying natural ventilation strategy on buildings

[10] Natural ventilation by design, Modern building services, journal published October 2007, http://www.modbs.co.uk/news/fullstory.php/aid/3936/Natural_ventilation_by_design.html

Successful application of natural ventilation strategies is only possible when there are no problems in any area at various levels from the building design stage until the building operation stage. Following section are some general barriers that architect should have to take into account before designing any naturally ventilated building:

a) *Fire regulations*
Fire regulations and cods may prevent the free flow of air to control smoke or odors propagation. There are technical solutions to meet the fire resistance requirements, both on the design stage and by adding some automatic controls to space to prevent the flow of the smoke through the whole building levels. Moreover, it is necessary to apply special techniques for fire safety in atrium buildings. For example the architect can design an open boundary between the atrium and the adjacent floors and place an effective smoke control system. The smoke control system should be adopted to prevent smoke in the offices from entering the atrium and to prevent smoke in the atrium from entering the adjacent floors[11].

b) *Exterior pollutants*
Opening windows for admitting air into the building can also admit exterior pollutants to the interior. Because it is too difficult to filter pollutants from the air that enters the spaces, the building should be upwind of the pollution sources. It is desired in the design stage to position the building as far as possible from upwind pollution sources, such as major roads, so that the pollution has space to disperse in the atmosphere before reaching the building[12]. Moreover, there are special filters that can be placed inside the wind catcher or ventilation source to overcome this problem but in much polluted areas it may be significant problem. Thus, in these cases mechanical and chemical filtering may be required and natural ventilation might be difficult.

c) *Lake of suitable and reliable design tools*
Simulation tools are needed to study some factors to achieve an appropriate natural ventilated design. By knowing some factors including: wind direction, outdoor temperature, site location, indoor and outdoor difference, these factors should be known. Simulation tools software will guide the designer to choose a proper: natural ventilation system, envelope design,

[11] **Simon Burton and Marco Sala**, *Energy efficient office refurbishment*, Published Earthscan, 2001, p36.

[12] **Donald L. Basham, James W. Wright, Kathleen I. Ferguson, Get W. Moy**, 16 January 2004Unified Facilities Criteria (UFC)*, Cooling Buildings By Natural Ventilation, Department of defense,* United States of America, p12.

external materials, and perfect building plan. But unfortunately, there were no friendly design tools to cover all this conditions. Recently, there is a wide development of software serving this purpose but it requires a reasonable degree of user training.

d) Back-up Mechanical Systems

It may be necessary or desirable for office and commercial buildings to include a backup ventilation system to ensure comfort when wind-driven ventilation is insufficient. Moreover, ceiling fans are required in all major occupied spaces of naturally ventilated buildings when comfort cannot be achieved by natural ventilation alone[13] .

e) Safety concerns

Safety means preventing illegal entry of other people, of animals including bugs and insects or preventing rain from damaging the furniture[14]. Special screens can be placed on the openings to solve these problems, with providing visual contact with the outside and also has no effect on the natural ventilation process. Moreover, there are special sensors to open, partially close, or close the openings if needed; these sensors can be placed on the openings to solve this problem.

f) Noise

Preventing noise of outdoors from entering the space through the ventilation openings is an important issue should be taken into account. As, the noise may interfere with many activities especially in working spaces, this means that it need special design to protect the space from noise. Sound-reducing baffles can be placed on the building openings to overcome this problem. However, the noise reducing mechanisms can involve a significant resistant to air flow, but it can't be compared to its efficient solutions. Moreover, Perfect design for the air chimneys and ducts can minimize the noise coming from outside, by covering its internal walls by an appropriate sound insulation materials[15].

These designing barriers that have presented are the ultimate responsibilities of the architect. These barriers should be solved by him the fact that could load on

[13] ibid

[14] **Francis Allard, Mat Santamouris,** 1999, *Natural Ventilation in Buildings: A Design Handbook*, published by Earthscan, , P174.

[15] **Simon Burton, Marco Sala**, *Energy Efficient Office Refurbishment*, Published by Earthscan, 2001, p37.

the architect more limits on the designing procedure. These barriers create the need of back-up mechanical systems in case of the very hot regions.

Appendix B: Solar Thermal Driven Cooling and Dehumidification System, Case Study: Masdar Headquarters, Abu Dhabi, United Arab Emirates

Solar thermal air conditioners are not new; they have been commercially used in the U.S. since the early 20th century and are a very widely deployed technology. They are also very popular in Asian countries like Japan, where the high cost of electricity make them very desirable and they constitute up to 40% of all installed commercial air conditioning. The fact is that the times that air conditioning is needed are the times when the sun also produces the most power. A new technology is to make use of these sun radiations as a power to run an air air-conditioning system and uses water and liquid salt as refrigerant. It has no mechanical parts and consumes very small amount of electricity. An absorption machine can be powered by any heat source available at the site including solar energy.

B-1 Working Idea

Its idea is that air conditioners will use absorption chillers that run on heat from the sun in place of conventional compressors. The system is consists of a vacuum tube heat collector which heats water to drive an absorption chiller.

Solar cooling is the use of solar thermal energy (heat via hot water) instead of electricity as the energy source to power a cooling appliance. For solar thermal air-conditioning, single effect water fired absorption chillers are most commonly used because they require relatively low temperature heat input.

Figure B- Vacuum tube heat collector for heating water[16]

[16] **Marye Audet**, Solar Air Conditioning, accessed 2009. http://hubpages.com/hub/Solar_Air_Conditioning

In principle, it works like a normal electrical driven appliance, however, instead of electricity; water fired absorption chiller systems use hot water from solar thermal collectors as a source of energy to start the cooling process. The chiller provide cold water at temperatures between 7°C and 9°C, therefore they can be used for either central cooling or decentralized cooling via fan coils. Additionally, the thermal heat source can be used as a source of hot water during the year.

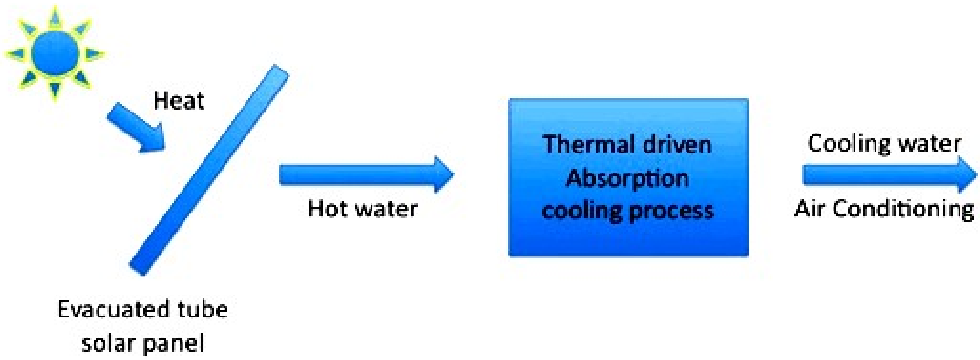

Figure B- Diagram of a solar thermal driven cooling system[17]

The unit do not have compressor and refrigerant, it is full solar energy but also its water pump and cooling power need some electricity. The system paths through three stages to cool the space: heat supply stage, chilled water supply stage, and air supply stage

[17] Sunairco, accessed 2009.
http://www.sunairco.com/

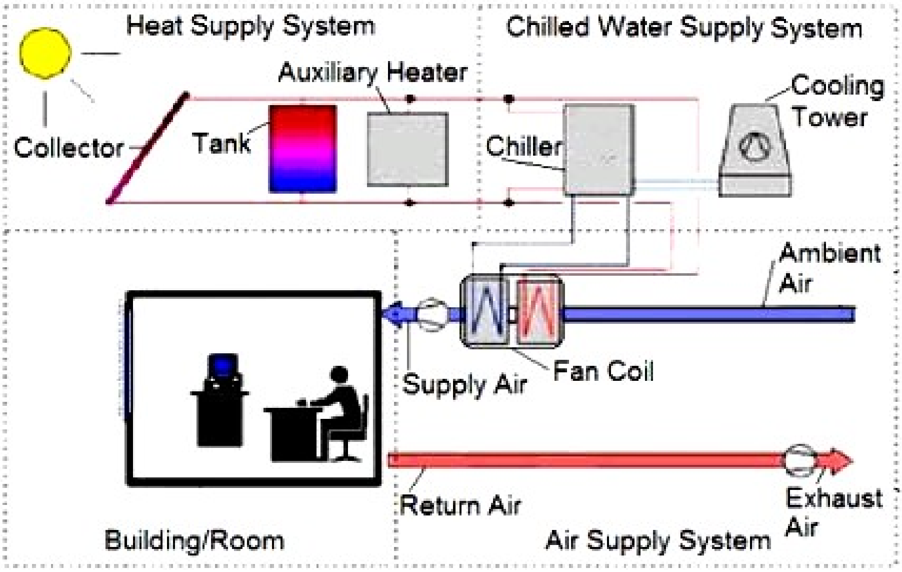

Figure B- Three stages forming the solar thermal driven cooling system[18]

B-2 Advantage of Solar Cooling

- Uses almost no electricity: Solar thermal cooling system uses only about 10,060 watts total for all components (Chiller, pumps, heaters, etc), whereas most conventional, high efficiency electrical driven 30 ton chiller systems will consume approximately 33,400 watts. It has no moving parts and requires no electrical input.
- Very quiet operation: Since there are very few mechanical parts (the solution pump being the only moving part on the chiller), the chiller has a very small noise footprint.
- Extremely high reliability and reduced maintenance costs: With proper maintenance, the major components of the system are rated for a life expectancy of approximately 20 years. The chiller requires very little maintenance. The maintenance is in the form of three evacuations per year to remove hydrogen buildup in the system. The evacuated tube solar panels are manufactured from glass and high-grade metals. The solar panels are modular in design, thus the evacuated tubes can be individually added or replaced as required.
- Environmentally friendly: Absorption chillers use environmentally friendly non-toxic refrigerants that have no global warming or ozone destruction potential. The chiller uses non-toxic Lithium Bromide as the

[18] **Marye Audet**, Solar Air Conditioning, accessed 2009. http://hubpages.com/hub/Solar_Air_Conditioning

absorbent and water as the refrigerant. This system completely eliminates dangerous compounds from CO_2 and other air conditioning by products being released into the atmosphere[19].

Appendix C: CFD Simulation Tools for Analyzing and Designing a Passive Cooled Building, Case Study: Pearl River Tower, Guangzhou, China

The present work studies the simulation tools analyzing the environmental conditions around Pearl River tower. CFD tools allow for the efficient visualization of climatic conditions such as diurnal temperatures, prevailing wind directions, available direct and diffuse solar radiation and sun path. The tools also feature internal analysis functions for rapid feedback on parameters such as sun penetration, potential solar gains, thermal performance, internal light levels, reverberation times and fabric costs. Moreover, they utilize ambient energy generation from the onsite wind and sun power, while minimizing its external environmental loadings though massing and a high performance fenestration system, a multitude of analytical tools were required such as: E-Quest, Fluent, and ECOTECT.

C-1 Pearl River Tower Form Analysis

Site geometries, building planning and structure, surrounding environmental conditions were imported into the software, their performance were compared

[19] Sunairco, accessed 2009.
http://www.sunairco.com/

by mapping the annual average incident solar radiation and prevailing windward onto the building envelopes. Through a rapid and efficient means of visually cross-correlating these environmental boundary conditions, a tower form was able to be developed in response to solar loading by minimizing east and west exposures, which in turn exposed the broad faces to the prevailing wind directions.

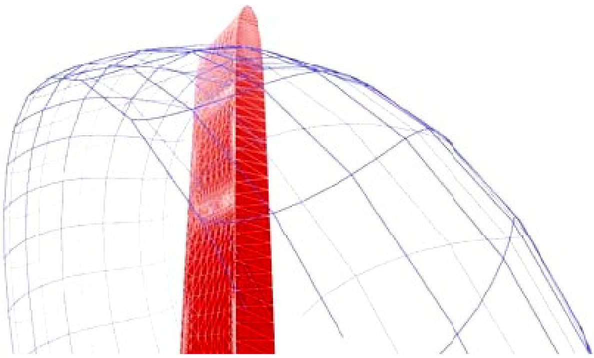

Figure C- Sun path informed the design for the tower (minimizing east and west exposures)[20]

Taking advantage of the pressure difference across the windward and leeward facades, wind turbines would be located in orifices formed through the tower. This form allows for planning a very shallow floor plate design, this allows for easier cooling and especially keeps all workspaces as close to the perimeter windows as possible in addition to maximizing daylight penetration.

C-2 Double Skin Facade Simulation and Design

The tower's fenestration system was designed as a Double skin facade to reduce the buildings cooling demand and to allow for the coupling with an efficient radiant space conditioning system. After analyzing a number of potential construction techniques and with consideration to the associated costs, the final design would include a 300mm internally ventilated cavity wall on the southern facade, the East and West facades would feature a triple glazed unit with integral blinds and 750mm fixed external shading, the design of which was informed by sun path information and shading masks generated within ECOTECT.
The following section presents a performance data for one of the analyzed configurations of the south-facing DSF of the Pearl River tower showing a collection of different types of assessment measures. The analysis presented in the figures corresponds to a DSF using a double-glazed low-e panel as the outer

[20] **Jeffrey Boyer, Arvinder Dang**, *Designing for performance: A case study in the applied science of an environmentally responsive high-rise design*, Skidmore, Owings and Merrill, Chicago, USA, Proceedings: Building Simulation 2007.

skin and clear monolithic glass as the inner skin. Glass properties are listed in (Table C-1)[21].

	Thickness (mm)	Solar Heat Gain Coefficient	U-Value (W/m^2-K)	Solar Transmissivity	Solar Reflectivity
Inner Skin	10	0.79	5.6	0.73	0.07
Outer Skin	25	0.33	1.7	0.29	0.38

Table C- Glazing properties for Pearl River Tower[22]

The following analysis (figure C-2) provides a comparison of the DSF performance with and without blinds. In both cases, the cavity airflow rate is the same. However, the without blinds case results in more than twice the interior energy gain. It also shows that the amount of energy that is captured in the DSF cavity is reduced without the blinds. It is recognized that the type of blind can significantly influence the penetration of solar energy into the room. Where: solar energy exists at short wavelengths while heat transfer between room surfaces (i.e., floor, walls, and windows) occurs at long-wavelength bands. Solar radiation must be considered in its direct and diffuse components.

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[21] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE Journal, p22 April 2009.

[22] Ibid

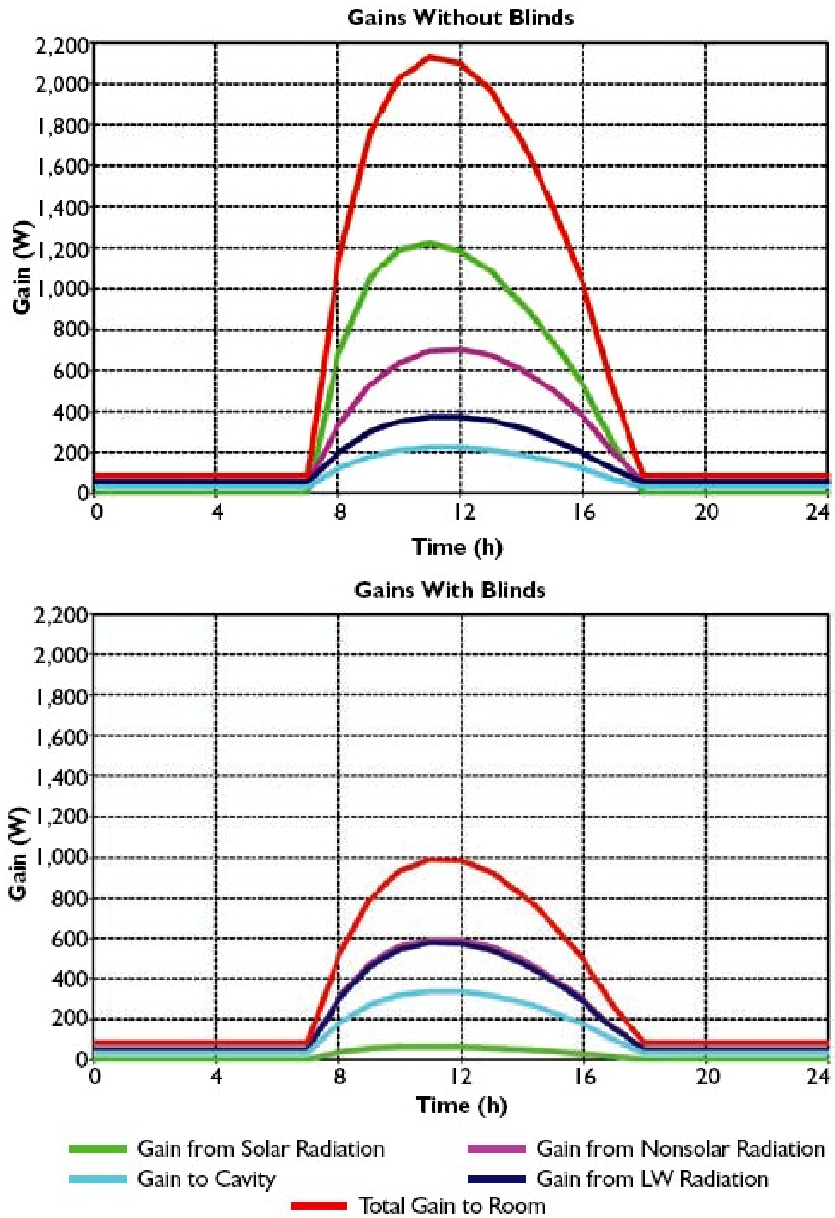

Figure C- Comparison of the heat gains in DSF performance with and without blinds [23]

Next analysis (figure C-3) shows the diurnal variation of average air and surfaces temperatures in the DSF without shading. The figure shows how the temperature on the various glazing surfaces, as well as the temperature of the cavity air, changes during the day. This leads to the observation that the cavity ventilation airflow rate need not be constant during the day. In fact, there is a

[23] Ibid

parallel relation of higher energy efficiency if the cavity has varying flow rates throughout the day. The flow rates for a cavity on the north and south facades of the building will also be different if energy efficiency is to be optimized[24].

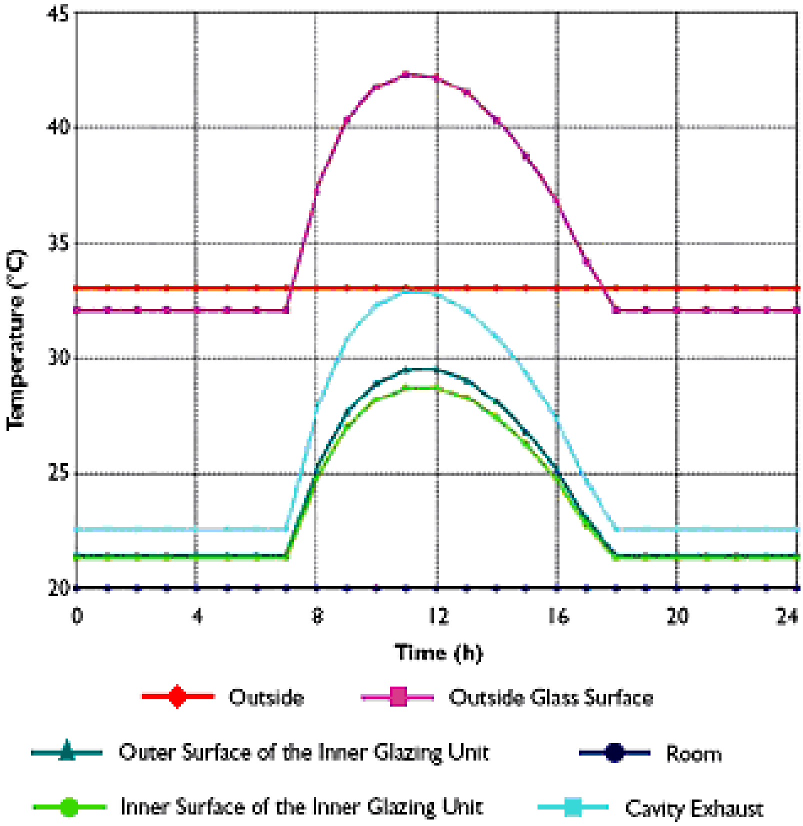

Figure C- Diurnal variation of average air and surface temperatures in Pearl River Tower DSF south-facing façade without shading devices[25]

Next analysis highlights how the performance of the DSF can be significantly influenced by the flow rate within the cavity. The figure presents predictions of energy gain and cooling load to the room, through the DSF, at noon in December for different flow rates. These results are for the DSF operating without shading devices. The plot shows that gain and load to the room are decreased as the flow rate in the cavity is increased. The cost associated with this is the increased energy picked up in the cavity air. This data can be input into a cost-benefit analysis to determine at which point the reduction in gain entering the room is offset by the additional fan energy driving the air through

[24] Ibid,p24.

[25] Ibid

the cavity and the increased energy within the cavity air. A holistic approach to building design is required.

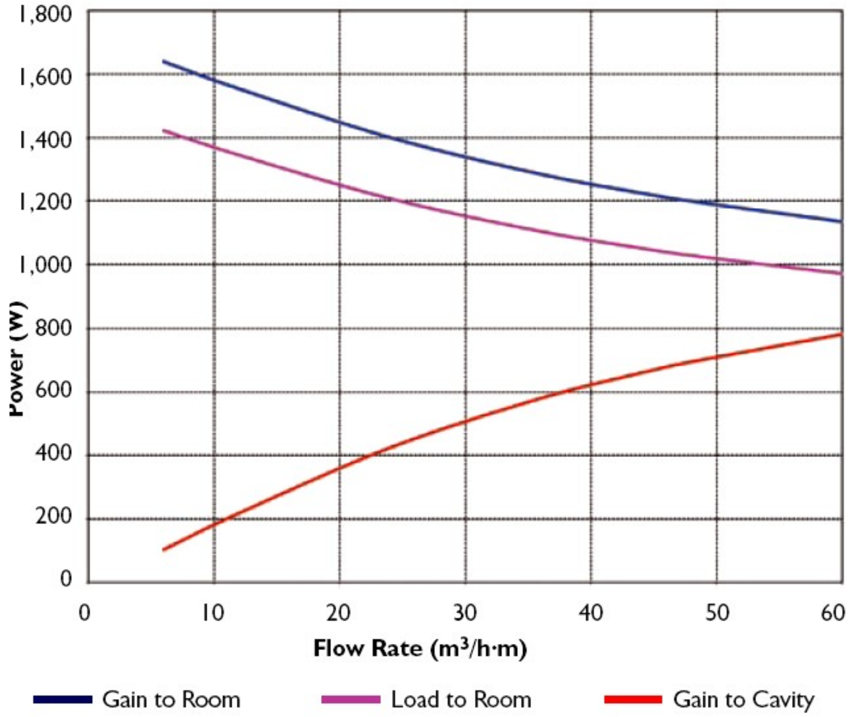

Figure C- *Predicted effects of cavity airflow rate on energy flows of the south-facing façade for Pearl River without shading devices*[26]

Next analysis shows a sample prediction from a CFD simulation of short-wave radiation, air speed, and air temperature distributions in a Pearl River Tower DSF cavity with the presence of the blinds in the modeling for solar control. To verify the final design for the ventilated façade, the Computation Fluid Dynamic (CFD) software package Fluent was implemented. Through analysis it was discovered that thermal buoyancy in the cavity was great enough to induce a stack-effect between the cavity and internal space, resulting in warmed return air reentering the space from the top of the façade. To decrease this effect, an additional modification was to incorporate a mesh filter into the lower intake slot, a small pressure drop would serve to improve flow uniformity and thus the heat transfer from the façade to the exhaust air.

[26] Ibid

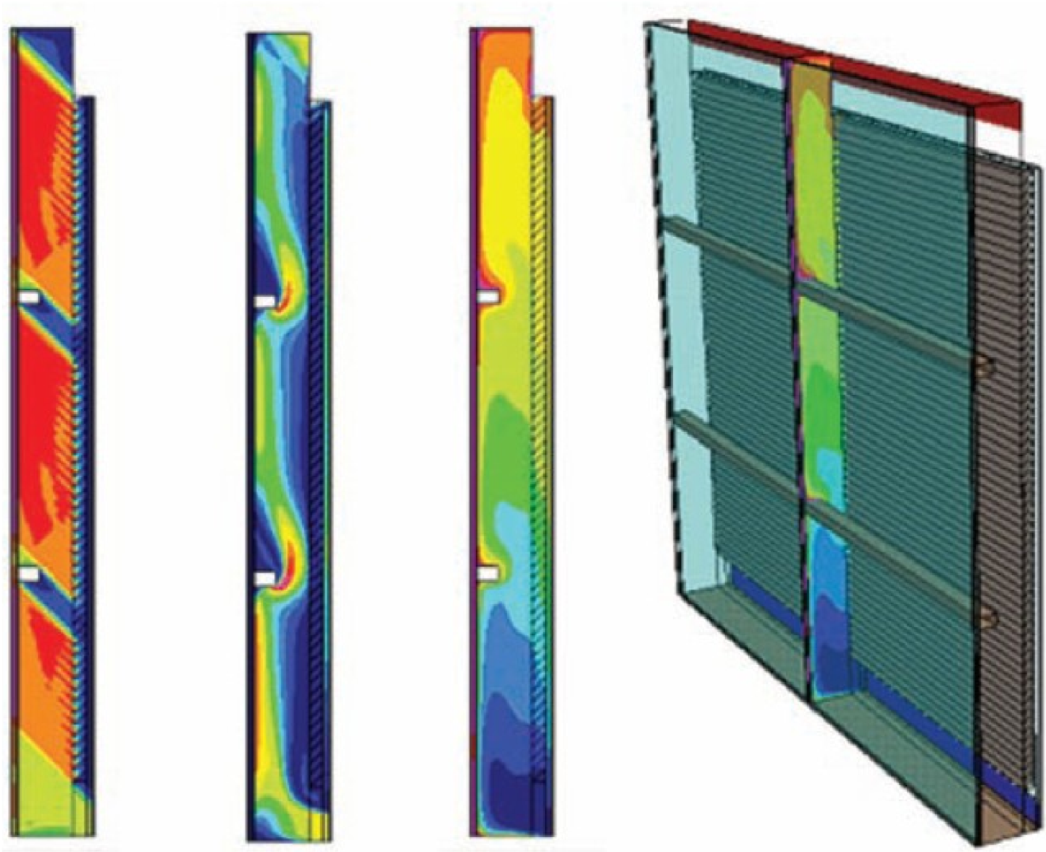

Figure C- *Example of CFD computer model prediction of airflow and temperature distribution in a DSF*[27]

From left to right the images are: (1) predicted solar radiation flux in the cavity; (2) predicted air speed distribution; (3) predicted air temperature distribution; and (4) configuration of mechanically ventilated DSF for Pearl River Tower building with outflow from top of cavity, which draws air from the room into the base of the single-story cavity[28]

The final performance of the façade, coupled with the radiant cooling and hybrid displacement ventilation system was then verified by a multi-physics simulation carried out within Fluent to ascertain operative temperatures and air change effectiveness for the internal space.

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[27] Ibid,p26.

[28] Ibid

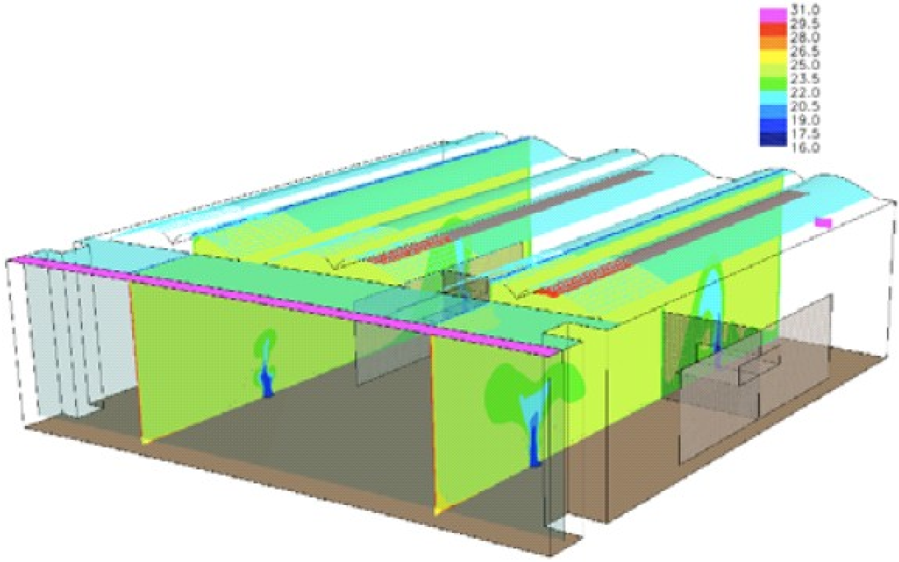

Figure C- Dimensional verification of final design performance: Air Temperature (C)[29]

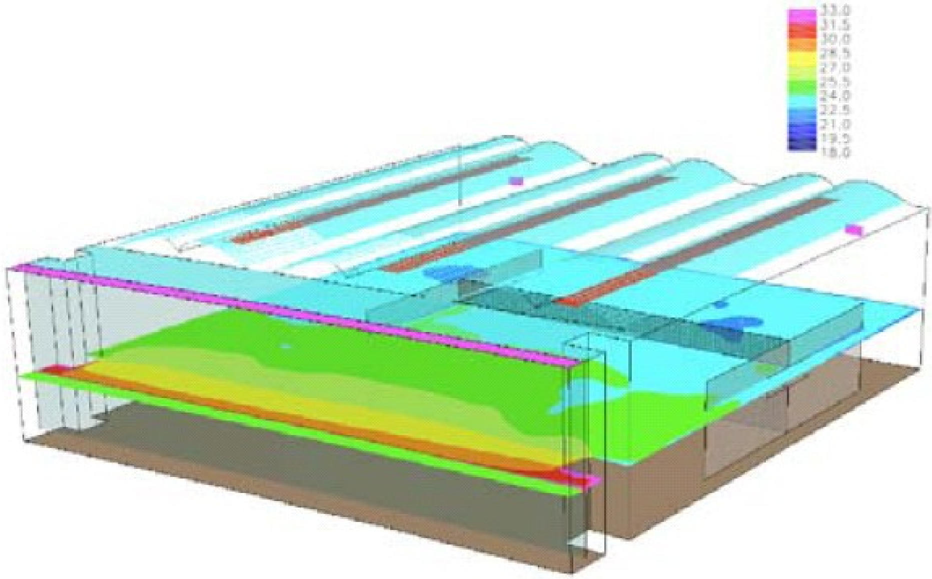

Figure C- Dimensional verification of final design performance: Operative Temperature (C)[30]

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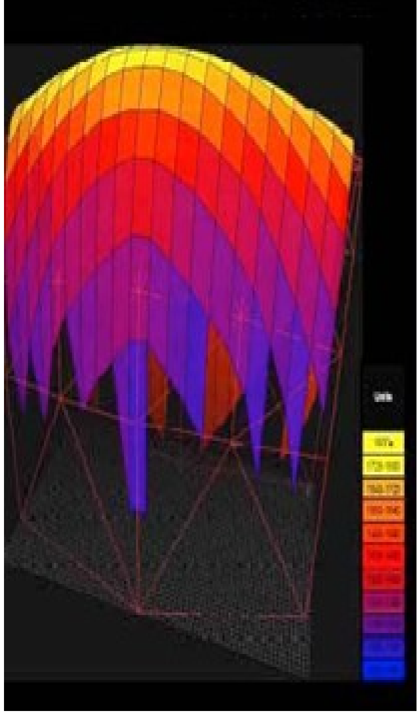
[29] **Jeffrey Boyer, Arvinder Dang**, 2007*Designing for performance: A case study in the applied science of an environmentally responsive high-rise design*, Skidmore, Owings and Merrill, Chicago, USA, Proceedings: Building Simulation, p1723.
[30] Ibid

C-3 Integrated Photovoltaic System



Using the incident solar radiation map generated in ECOTECT, integration of a photovoltaic system could be applied to generate power for the automated sun tracking blind system. The facades are designed to maximize photovoltaic cell coverage. Additionally, photovoltaic cells were integrated into the glass roof of the upper level which additionally served to minimize heat gain to the space. A total active area of 3000 m2 will produce in excess of 300,000 KWh annually.

Figure C- Incident Solar Stress Model of Pearl Tower for placement of PV cells

C-4 Wind Analysis

Wind direction and velocity was carefully analyzed with contact with the building direction, openings locations, and building shape to maximize power generation. The tower form was able to be developed in response to solar loading by minimizing east and west exposures, which in turn exposed the broad faces to the prevailing wind directions. The sweeping curves capture the wind and guide it up from street level and down from the top of the building, into the turbine openings.

A scaled model of Pearl River tower was assembled and tested. Effect of the wind traveling through these openings was carefully studied in a wind tunnel testing. Airflow measurements were taken of wind speeds as they approached the building along with the corresponding air velocities within the building's openings. The building was then rotated within the tunnel to simulate wind approaching from all possible directions. As the air passes through the openings, acceleration takes place and increases its velocity.

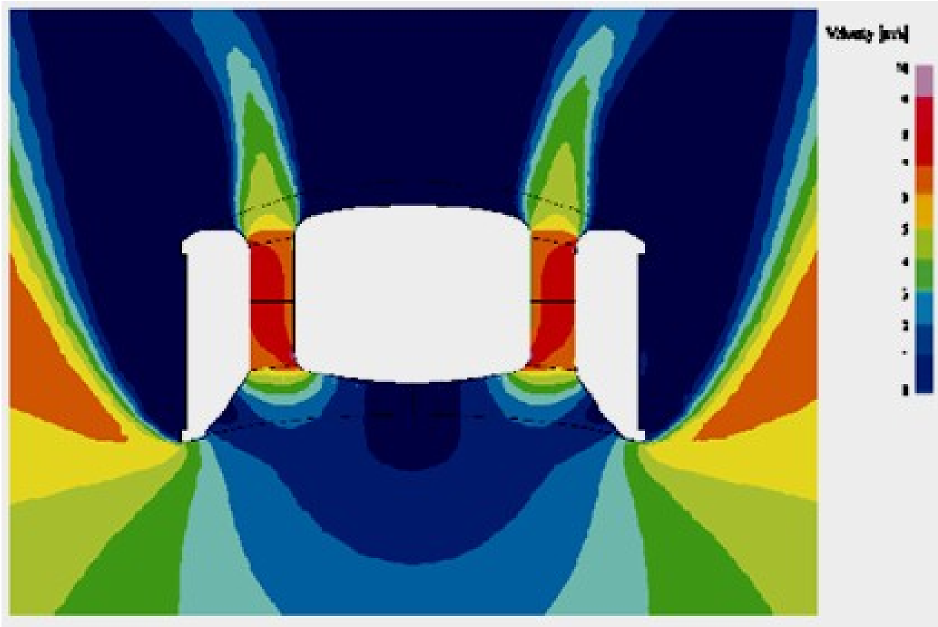


Figure C- Contours of velocity at mechanical floors in mid-elevation: the wind velocity increase than the ambient wind speeds[31]

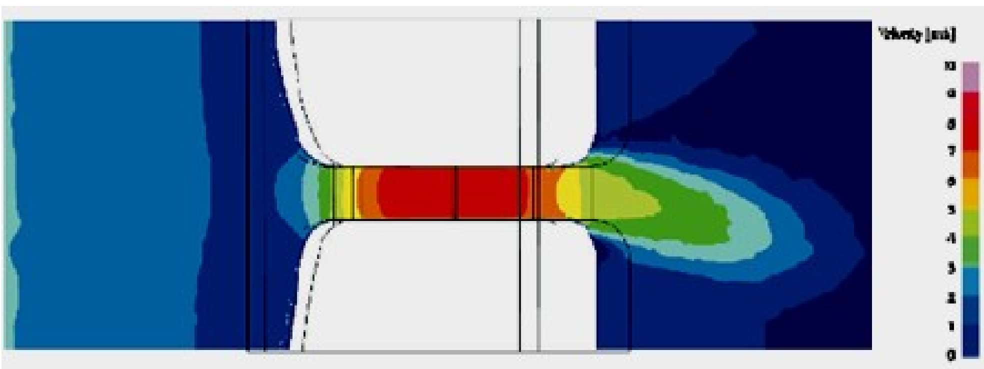


Figure C- Contours of wind velocity at mechanical floor section[32]

The results of this preliminary analysis were then compared with the results from a small scale wind tunnel test. In the absence of the turbines, winds would be accelerated by a magnitude of 2-3 from what would typically be encountered. The placement of the wind turbines inside these ducts in this building form will improve the power efficiency by about 34% than that

[31] Ibid

[32] Ibid

without building form modification[33]. These wind turbines could provide power year round.

C-5 Performance results

A detailed energy simulation of the final design for the Pearl River Tower project was performed using the eQUEST building energy simulation program. As eQUEST was intended for evaluating the energy performance of traditional commercial and residential buildings several modeling approaches were required to quantify the performance of the systems incorporated in the design for the Pearl River Tower. In order to accurately account for the double skin facade performance, the gains and losses for the perimeter zone as well as the cavity zone were calculated for 8760 hours on an hourly time step using the model developed for the initial comparison of facade typologies in order to model the whole building energy performance[34].

From the eQuest model a total energy savings of 31% is estimated with a 46% energy reduction associated with HVAC and lighting for the office floors of the tower as compared with the minimum requirements of the “Design Standard for Energy Efficiency of Public Building in China”. The model has the same gross square footage and space area distribution as the actual Pearl River Tower design case[35].

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[33] Ibid

[34] Ibid

[35] Ibid

Appendix D: Phase Change Material (PCM) Based Cooling Technology, Case Study: Council House 2 (CH2), Melbourne, Australia

D-1 Concept of PCM Based Cooling

Phase change materials are best thought of as a very efficient thermal storage device. They work on the fact that whilst a material is undergoing a phase change (solid to liquid or liquid to gas (and vice versa)) it absorbs/releases a lot of heat energy for no change in temperature until the phase change is complete, similar to the energy required to convert ice to water. This heat is called the latent heat of the material, and varies for different matter. It is proposed that a Phase Change Material is used as based-cooling due to its low melting point. Thus the ideal temperature for this Phase Change Material is about 13 degrees[36]. The phase change materials proposed for cooling development comprise both mixtures of non-toxic salts and organic compounds. These solutions are known as Eutectic Salts and the freezing/melting points can be modified by adjusting the percentages of the mixing compounds.

D-2 PCM Options

a) *PCM-Filled Spheres*

The idea is a sphere with two halves filled with the salt blend will sit in a tank surrounded by passing water. A 500m3 tank will be required, based on a 50/50 ratio of spheres to reservoir water and a requirement of 250m3 of Phase Change Material. Spheres are made of stainless steel, so they are corrosion resistant and have greater thermal efficiency.

Figure D- PCM-Filled Spheres[37]

[36] **Advanced Environmental Concepts Pty Ltd**, *PCM-Based Cooling.PDF*, April 2008.

[37] **Dominique Hes**, *Design snap shot 15: Shower Towers. PDF*, 2004, p3.

Daily Cooling Load	DCL + 25%	Qty reqd (kg)	Unit Cost £	Start-up Cost	Total £
3631	4538.75	116710.7143	$ 3	$ 80,000	$430,132

Table D- Economic analysis for PCM-Filled Spheres[38]

b) PCM cylindrical tubes

In this option, the fluid is pumped through a series of pipes. These pipes are surrounded cylindrically by a cavity containing the appropriate Phase Change Material. The cylinder geometry offers a more efficient heat transfer compared to the spherical balls. It consists of a 0.0127m (½") inner metal tube surrounded by a 0.1m outer tubes housing the PCM.The beams are available in meter lengths with the maximum length being 6m. The self stacking modules are made up to 2.3m x 2.3m x 6.5m, which are designed to fit into a 20' shipping container. Total weight of a 20' module is estimated at 34.5 tones with each single beam weighing 14.7kg/m.

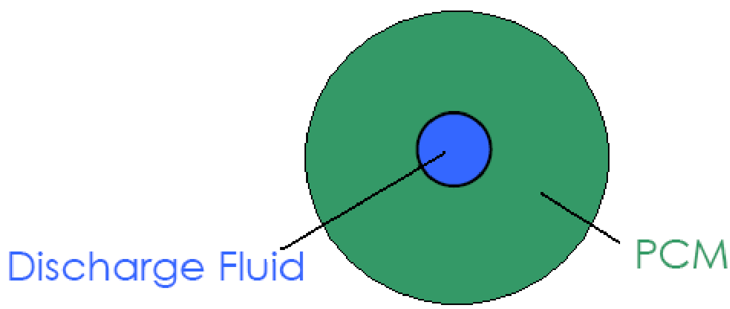

Figure D- working idea of PCM cylindrical tubes[39]

c) Two Flow Beam

In this option, the same fluid is used for charging and discharging. Consequently to maintain a closed loop to the chilled panel/beams, it would be necessary to install a heat exchanger. A direct supply of water from the cooling tower to within the building (chilled beams/panels) is not desired. It is composed of a metal tube being surrounded cylindrically by a Polypropylene outer cavity containing the appropriate Phase Change Material. The cylinder geometry offers a more efficient heat transfer, due to surface area exposure, than compared to other PCM options available, such as the spherical balls.

Water or refrigerant is circulated within the inner metal tube. During charging mode the excess capacity (heat transfer from a temperature differential) from this fluid is stored in the form of latent heat by the

[38] **Advanced Environmental Concepts Pty Ltd**, *PCM Operational Report. PDF,* p6, 2003.

[39] Ibid, p8

(PCM). The operation is reversed during discharge mode. Charging for the PCM will occur during the night time. The lower ambient temperatures at night will enable "free cooling" during certain times of the year. "Free cooling" refers to heat rejection without operating a chiller, i.e. by utilizing cooling towers or shower towers.

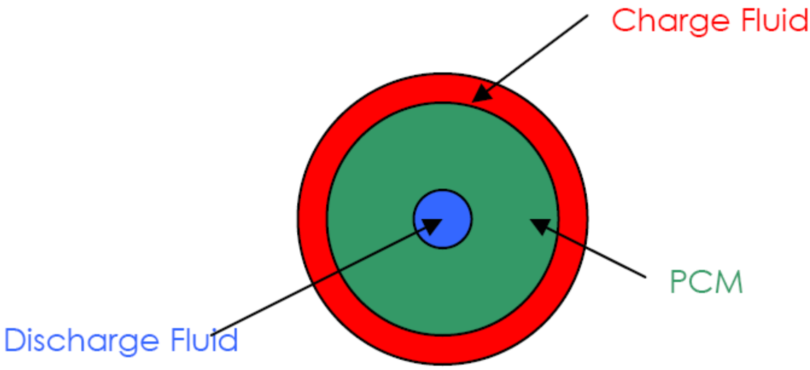

Figure D- Tube to tube concept[40]

D-3 PCM Application: CH2 Office Building

To efficiently passive cool CH2 office building, the Phase Change Material will used as a base material much like a battery to storing coolness for providing cold water to be used in radiant cooling the building during the day. chilled water is supplied to the ceiling panels by three large tanks in the basement. Each of the tanks contains nearly 10,000 small stainless steel balls filled with a form of Phase Change Material (PCM). CH2's PCM's are a salt suspension which freezes at 16°C. Water cooled by the cooling towers and chillers will travel through the tank and add coolness to the whole system to freeze the PCM spheres.

A separate sealed water system will pass through the tank to be chilled then travel through the chilled ceiling panels and chilled beams to cool the building and then run back into the tank.The water that returns from this circulation is usually about 2-3 degree

s warmer. The PCM balls continue to absorb heat (which is energy) enabling the material to have enough energy to break-down the molecular bonds and move from solid into liquid phase. Essentially, the balls absorb heat until they melt. When the PCM has melted into liquid phase, and can no longer absorb heat, the PCM system is shut down until it recharged by the chilled water coming from the shower towers or in very hot months the chillers (in the rooftop plant room) provide chilled water to the basement to freeze the PCM

[40] Ibid

balls. it is expected that the cooling tower charging of the PCMs will occur 63% of the year. At other times, the chillers will be used. This charging will occur at night to ensure that the chillers are operating as efficiently as possible. The maintenance required for the PCM modules is limited.

جامعة عين شمس
كلية الهندسة
قسم الهندسة المعمارية

تقنيات التبريد السلبي
لتطوير و تنمية العمارة المستدامة

رسالة مقدمة من:
المهندسة/ هاله محمد علي حماد
بكالوريوس الهندسة المعمارية- جامعة عين شمس 2004

للحصول على درجة
الماجستير في الهندسة المعمارية

تحت اشراف:
ا.د. ياسرمحمد منصور
استاذ و رئيس قسم الهندسة المعمارية
كلية الهندسة- جامعة عين شمس

ا.د. خالد محمد دويدار
استاذ بقسم الهندسة المعمارية
كلية الهندسة- جامعة عين شمس

ا.د. حنان مصطفى كمال صبري
استاذ بقسم الهندسة المعمارية
كلية الهندسة- جامعة عين شمس

جامعة عين شمس
2009

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كلية الهندسة
قسم الهندسة المعمارية

اسم الطالب: هاله محمد على حماد
عنوان الرسالة: تقنيات التبريد السلبي لتطوير و تنمية العمارة المستدامة
الدرجة العلمية: الماجستير

لجنة الممتحنين	**التوقيع**
أ.د. مراد عبد القادر عبد المحسن استاذ بقسم الهندسة المعمارية كلية الهندسة, جامعة عين شمس	
ا.د. ياسرمحمد منصور استاذ و رئيس قسم الهندسة المعمارية كلية الهندسة, جامعة عين شمس	
ا.د. محمد مؤمن عفيفي استاذ بقسم الهندسة المعمارية كلية الهندسة, جامعة القاهرة	
ا.د. حنان مصطفى كمال صبري استاذ بقسم الهندسة المعمارية كلية الهندسة, جامعة عين شمس	

التعرف بالباحث

أسم الطالب: هالة محمد على حماد
تاريخ الميلاد: أكتوبر 1982
الدرجة السابقة: بكالوريوس الهندسة المعمارية
جهة التخرج: جامعة عين شمس
تاريخ التخرج: يونيو 2004
الوظيفة الحالية: معيد بقسم العمارة- كلية الهندسة- جامعة عين شمس

ملخص الرسالة

مقدمة البحث:

على مدار السنوات القليلة الماضية زاد الأهتمام تجاه التصميم السلبي و تنمية المباني المستدامة. في العمارة القديمة كان الاعتماد على النظم الطبيعية لتحقيق أقصى قدر من الراحة, أما في العمارة الحديثة فقد أهتمت بالنواحي التكنولوجية في التصميم دون الأهتمام بالنواحي البيئية والاجتماعية والاقتصادية مما أدى الى تصميم مبنى ليس له هوية و لا يهتم براحة مستخدميه. مما خلق الحاجة إلى تصميم جديد للمباني المستدامة التي تهتم بالراحة الجسدية والنفسية لمستخدمي المبنى وبالتقنية الحديثة لتحقيق الزيادة الأنتاجية. ويعتبر التبريد السلبي واحدة من المبادئ الهامة في تصميم المبانى المستدامة فهو يعتبر حل مثالى لتحقيق المعادلة الصعبة بين الراحة المناخية و توفير الطاقة (التى اصبحت من أهم المشاكل التى تواجهنا اليوم). فهو يعتبر بديل للتبريد الميكانيكي الذي أصبح أقصر السبل الفعالة لتحقيق الراحة الحرارية الداخلية للأماكن المغلقة و قد أثبتت الأبحاث مؤخرا المشاكل الصحية الكثيرة لمستخدميالتبريد الميكانيكي, مما خلق الحاجة للأتجاه لنظم التبريد السلبي بديلا للأنظمة الميكانيكية. وتوجد أمثلة كثيرة لأنظمة التبريد التقليدية السلبية التي طبقت في المناطق الحارة من أجل تحقيق مناخ مريح لداخل المبنى.

الجزء الأول من هذا البحث سوف يعرض بعض نظم التبريد السلبي التي توفر الطاقة بنسبة كبيرة للمباني وعرض لاستراتيجيات التبريد السلبي وهي: الأشعاع, التهوية, التبخر, التظليل, و العزل لتعزيز استدامة البناء في المناطق الجافة و الحارة. و سوف يتم شرح كل نظام من هذة الأنظمة و معرفة محدداتة و ايجابياته. أما الجزء الثاني من البحث سوف يتم تطبيق هذه النظم على مباني تم بنائها فعليا على أسس التبريد السلبي و سوف يتم تقييم كفائتها و قدرتها على توفير الطاقة.

الأبحاث السابقة

بعد الأطلاع على الأبحاث و الرسائل السابقة التي تهتم بالنواحي البيئية. فقد اتضح أن معظم هذه الأبحاث تهتم بشكل رئيسي على التبريد السلبي في المبانى السكنية أما المباني التجارية تعتمد في معظمها على التبريد الميكانيكي. يتركيز هذا البحث على دراسة كيفية تطبيق تقنيات التبريد السلبي في المبانى التجارية للوصول لكفائة تبريد داخل المبنى مساؤية لها في حالة أستخدام التبريد الميكانيكي دون الحاجة لاستهلاك المزيد من الطاقة.

المشكلة البحثية

تعتمد العمارة بشكل أساسي على استخدام الوقود كمصدر رئيسي للطاقة مما ينتج عنها ارتفاع في تكلفة التشغيل. أما توليد الطاقة عن طريق حرق الفحم، والنفط، والغاز الطبيعي هو المصدر الرئيسي لتلوث الغلاف الجوي والاحتباس الحراري. تعتبر المباني أكبر مستهلك للطاقة ليس فقط في بنائها و لكن أيضا لأغراض التدفئة والتبريد والإنارة. و من المعروف أن أغلب الطاقة المستخدمة في هذه المباني من الموارد غير المتجددة مما خلق الحاجة للأتجاه للطرق الطبيعية و الموارد المتجددة في جميع المرافق. فمثلا خلال العام الماضي 2007/ 2008 بلغت ذروة الطلب للطاقة الكهربائية الى 19738 ميغاواط ، والطاقة المولدة فقط 125 تيراواط ساعة. مما أصبح هناك حاجة ملحة لتطبيق نظم تستهلك طاقة أقل. و يعتبر التبريد الميكانيكى أكبر مستهلك للطاقة خاصة في المباني التجارية التى

تعتمد معظمها على التكييفات الميكانيكية التي لديها مشاكل كثيرة في النواحي الأقتصادية و الصحية. نظرا لهذه المشاكل، أصبحت هناك حاجة ملحة للوصول للراحة الحرارية لمستهلكي هذه المباني دون استهلاك كل هذة الطاقات.

المحددات

. أولا: المناطق الحارة و الجافة التى سوف يتم تطبيق نظم التبريد السلبي بها هى المحور الرئيسي لهذا البحث.
. ثانيا: تطبيق تقنيات مبتكرة للتبريد السلبي على المباني التجارية قليلة الأستهلاك للطاقة مع تطبيق هذه تقنيات على ثلاثة أمثلة مختلفة لمبانى إدارية.

أهداف البحث

الهدف الرئيسي من البحث هو تحقيق بيئة داخلية صحية من ناحية (البيئة ، الطاقة المستهلكه ، مناخ صحي ، ومبانى تجاريه أكثر أنتاجا) وهذا الهدف يمكن أن يتحقق و ذلك بعناية اختيار استراتيجيات التبريد. بما أن زيادة الحراره هى أكثر المشكلات الرئيسية التى تؤدى إلى تقليل الراحة و تقليل الإنتاجية ، وبالتالي فإن الهدف الرئيسي هو:

"تحديد الأستراتيجيا ت و المعايير التصميمية للتبريد السلبي من أجل الوصول لفراغات داخليه مريحة, موفرة للطاقة, وتساعد على الأنتاجية من أجل الغاء أو تقليص حجم وتكلفة معدات التبريد الميكانيكي في المبانى العامة"

وهذا الهدف يمكن أن يتحقق من خلال النظر في بعض الأهداف الفرعية:

- دراسة المبادئ الرئيسبة و المعايير التصميمية الداخلية التي تؤثر على تبريد الفراغ
- دراسة المبادئ و النظم الفعالة لمختلف استراتيجيات التبريد السلبي (الإشعاع ، والتبخر ، والتهوية ، لتظليل, و العزل).
- دراسة و تحليل ثلاث مباني إدارية و كيفية تطبيقها لنظم و أساليب التبريد السلبي.

منهجية البحث

المنهج النظري

و قد تحققت هذه المنهجية عن طريق مراجعة الأبحاث السابقة والكتب والدوريات المتعلقة بالأعتبارات و أسس العمارة المستدامة واستراتيجيات التبريد السلبي مع استعراضها وتحليلها وتصنيفها. و هذه المنهجية تظهر في الباب الأول.

المنهج التحليلي و التحليلي المقارن

هذا المنهج تحقق من خلال تحليل أنظمة التبريد السلبي ومكوناتها ، وتطبيقاتها و معرفة مزاياها و محدداتها. و هذه المنهجية تم اتباعها في الباب الثاني، الثالث، و الرابع. أما الباب الخامس فكان دراسة تحليلية مقارنة لثلاث أمثلة تطبيقية لمباني إدارية.

المنهج الأستنباطي

تم تحقيق هذا المنهج عن طريق تحديد المعايير التصميمية لكل النظم التي تم عرضها في البحث و أستخلاص النتائج والتوصيات للوصول إلى الهدف الرئيسي من البحث و هذه المنهجية قد اتبعت في الباب الاخير.

محتويات البحث

الهدف الرئيسي من هذا البحث سوف يتحقق من خلال ستة أبواب :

الباب الأول: نظرة عامة على الاستراتيجيات الرئيسية للمباني المستدامة

هذا الباب يقدم لمحة عامة عن الأسس العامة للمباني المستدامة و الأهداف الرئيسية منها و يقدم لمحه تاريخيه للعمارة المستدامه. فهو يعرض ثلاث عناصر أساسيه التى تؤثرعلى التبريد السلبى للمبانى العامه المستدامة و هي: تحليل الموقع , توفير الطاقه , تحسين البيئه الداخليه. و في نهاية الفصل يتم عرض المزايا التي سوف تتحقق بالوصول بالمبنى لفكرة الأستدامة الكاملة.

الباب الثاني: إعتبارات و إستراتيجيات التبريد السلبي للمباني المستدامة

هذا الباب يستعرض المبادىء العامة للتبريد السلبي و الاعتبارات والعناصر المعمارية الرئيسية التي من الممكن أن تؤثرعلى التحسين من الحرارة الداخلية و ينقسم إلى قسمين :

أولا: يقدم الاعتبارات الرئيسية لتعزيزالحرارة الداخلية عن طريق منع أشعة الشمس المباشرة، وتناقص النفاذية من ارتفاع في درجة الحرارة الخارجية، والتقليل من مصادر داخلية لانبعاث طاقة حرارية.

ثانيا: يقوم بطرح أنظمة التبريد السلبي التي يمكن تطبيقها على المباني المستدامة .وعلاوة على ذلك، فإنه يقدم المبادئ الأساسية، و;كيفية ملائمة هذة الأنظمة للمناخ الحار الجاف. أنظمة التبريد السلبي تعتمد على خمس إستراتيجيات و هي: التبريد من طريق الأشعاع، التهوية، التبخر، التظليل، و العزل.

الباب الثالث: إستراتيجيات التهوية الطبيعية

و هذا الباب يستعرض الفكرة الرئيسية للتهوية الطبيعية و اعتباراتها لتعزيز التبريد السلبي للفراغات الداخلية. فأنه يقدم استراتيجيات التهوية الطبيعية التي تؤثر على تصميم المبنى. وعلاوة على ذلك، فإنه يقدم ثلاثة أساليب مبتكرة لتحقيق كفاءة التهوية الداخلية مع تحديد نظام التصميم والمكونات الرئيسية.

الباب الرابع: النظم المستحدثة للتظليل و تقنيات الزجاج المعزول للتحكم في الأشعاع الشمسي

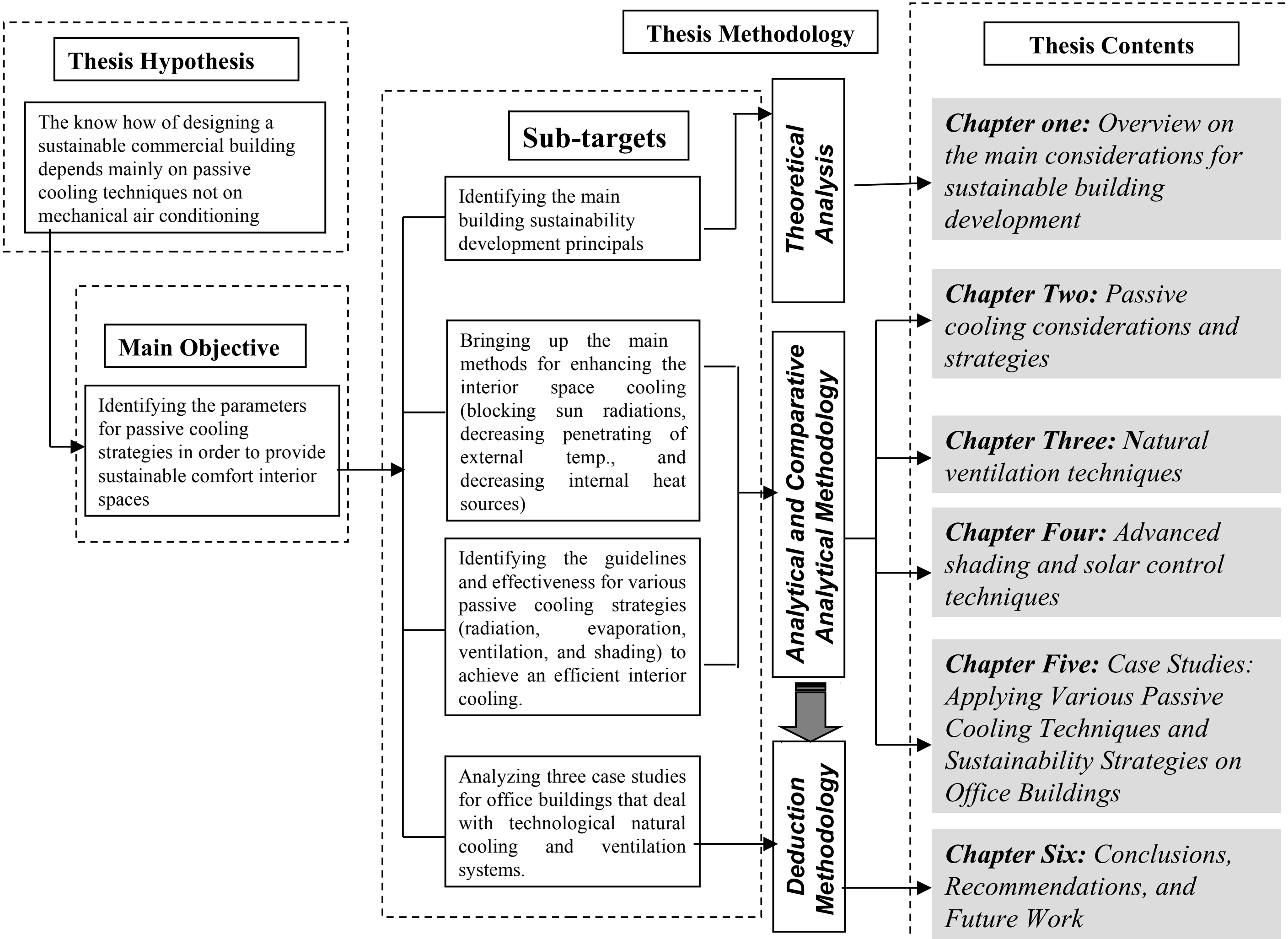
هذا الباب يعرض أهمية أجهزة الرقابة الشمسية والتظليل لتعزيز نظم التبريد للفراغات الداخلية للمبني. وهو ينقسم إلى قسمين أولا نظم التظليل مبتكرة. ثانيا يتناول نظم الزجاج المعزول .

الباب الخامس: دراسات حالة : تطبيق مختلف أساليب التبريد المستدامة على مباني إدارية

هذا الباب يقدم تطبيق لنظم التبريد السلبي التي تم عرضها في الجزء السابق من البحث و استراتيجيات الاستدامة على ثلاثة مبان مكاتب. فإنه يضمن دراسة لفعالية التبريد السلبي و الأستراتيجيات المختلفة التي تم تطبيقها في كل حالة على حدا بالأضافة الى دراسة خصائص المواقع المختلفة لتلك المباني.

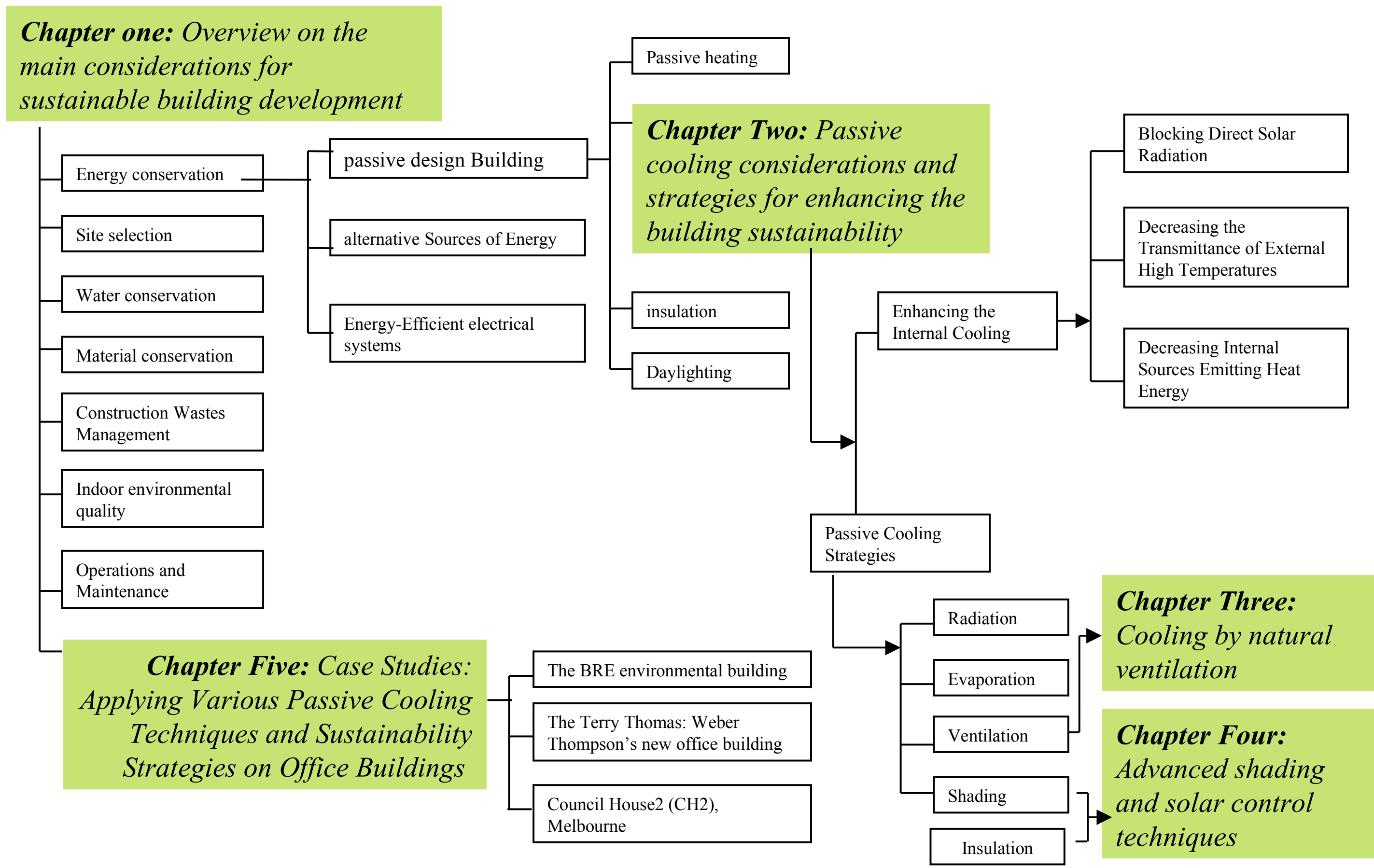
الباب السادس : النتائج و التوصيات

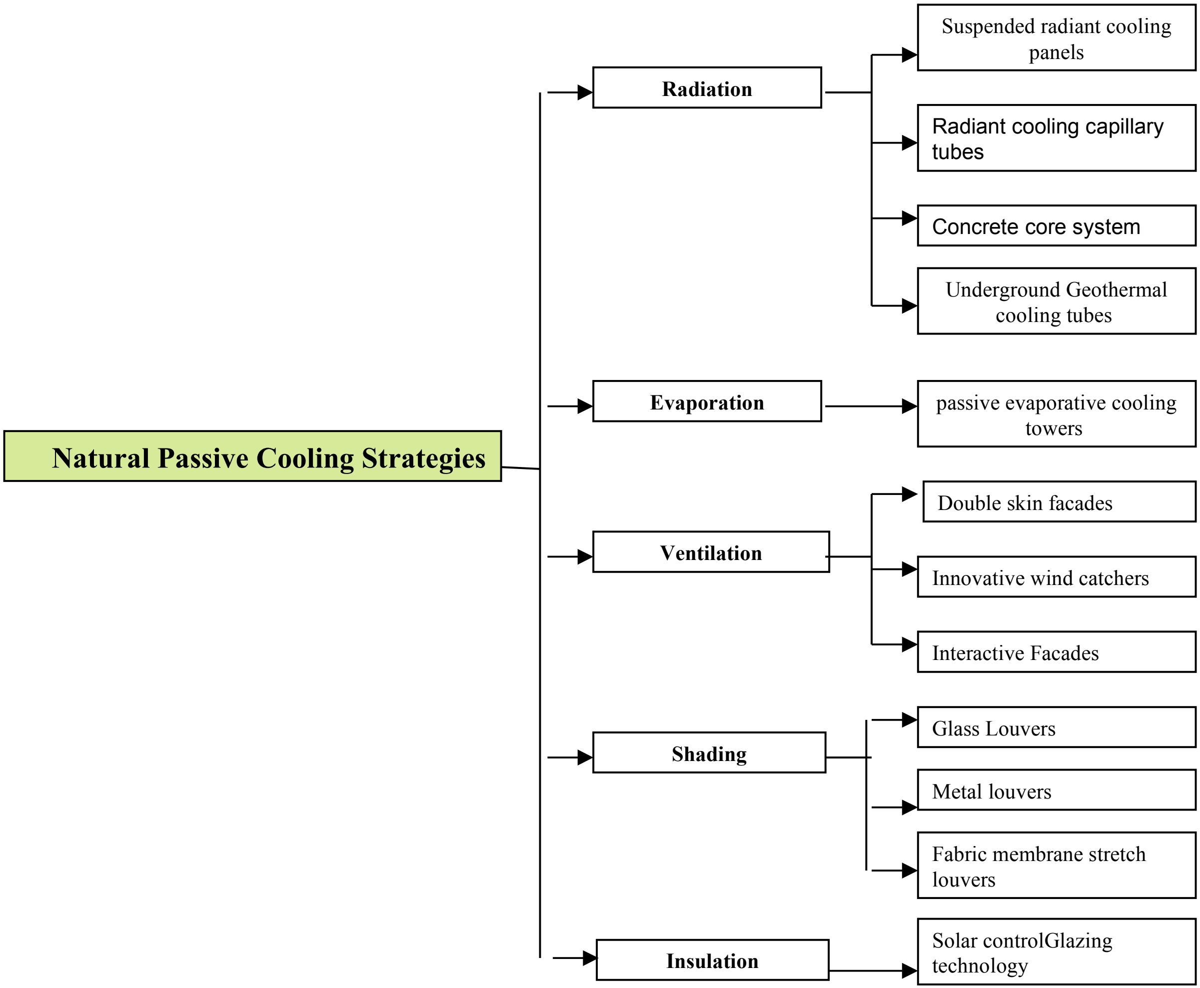
هذا الباب يقدم نتائج الاستنتاجات التي تم دراستها في ابواب هذا البحث الى جانب بعض التوصيات التي تخص المعماريين و الحكومات من أجل تعزيزو تطوير استدامة البناء.



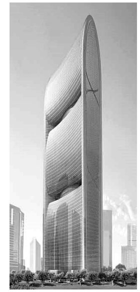
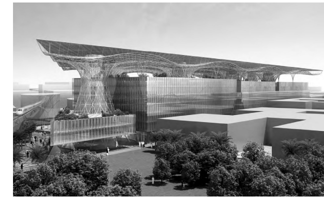
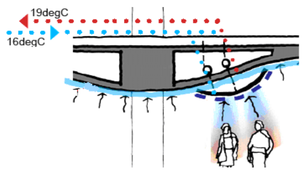
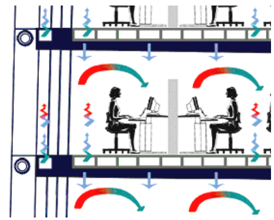
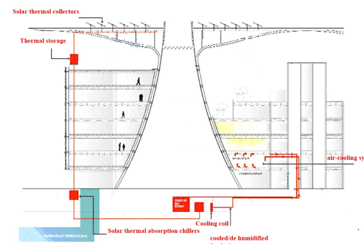
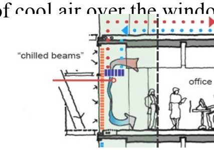
Thesis Hypothesis
The know how of designing a sustainable commercial building depends mainly on passive cooling techniques not on mechanical air conditioning
Main Objective
Identifying the parameters for passive cooling strategies in order to provide sustainable comfort interior spaces
Sub-targets
Identifying the main building sustainability development principals
Bringing up the main methods for enhancing the interior space cooling (blocking sun radiations, decreasing penetrating of external temp., and decreasing internal heat sources)
Identifying the guidelines and effectiveness for various passive cooling strategies (radiation, evaporation, ventilation, and shading) to achieve an efficient interior cooling.
Analyzing three case studies for office buildings that deal with technological natural cooling and ventilation systems.
Thesis Methodology
Theoretical Analysis
Analytical and Comparative Analytical Methodology
Deduction Methodology
Thesis Contents
Chapter one: Overview on the main considerations for sustainable building development
Chapter Two: Passive cooling considerations and strategies
Chapter Three: Natural ventilation techniques
Chapter Four: Advanced shading and solar control techniques
Chapter Five: Case Studies: Applying Various Passive Cooling Techniques and Sustainability Strategies on Office Buildings
Chapter Six: Conclusions, Recommendations, and Future Work

Passive Cooling Techniques for Enhancing the Building Sustainability Development



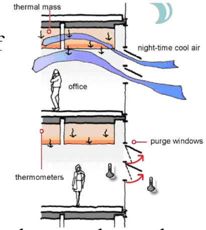

Natural Passive Cooling Strategies
Radiation
Suspended radiant cooling panels
Radiant cooling capillary tubes
Concrete core system
Underground Geothermal cooling tubes
Evaporation
passive evaporative cooling towers
Ventilation
Double skin facades
Innovative wind catchers
Interactive Facades
Shading
Glass Louvers
Metal louvers
Fabric membrane stretch louvers
Insulation
Solar controlGlazing technology

Comparison between three Case Studies: Applying Various Passive Cooling Techniques and Sustainability Strategies on Large Scale Office Buildings

		Council House 2 (CH2) *Melbourne, Australia*	**Pearl River Tower** *Guangzhou, China*	**Masdar Headquarters** *Abu Dhabi, United Arab Emirates*
				
Passive Cooling Stratigies	**Suspended radiant cooling panels**	CH2 is designed to maintain the offices temperature between 21ºC-23ºC as a mean of air and radiant temperatures 	The chilled panels cover 35 % of the curved ceiling. 	Solar thermal driven cooling and dehumidification system 
Radiation	**Chilled beams**	Warm air coming from the ceiling is dragged down to be cooled by chilled beam and producing a curtain of cool air over the window 	presence of chilled beams located in front of the windows around the perimeter of each office zone	
	Underground Geothermal Cooling	A geothermal heat sink is used to provide cooling water, so 38 °C water in the mechanical system return loop cooled to 24 °C to feed the cooling power needed, reducing the size of the mechanical plant by about 30 percent		Earth ducts which reduce temperature of outside air and provide underground pedestrian passages

Thermal massing and night cooling

Low points of the vaulted ceiling is automatically opened at night



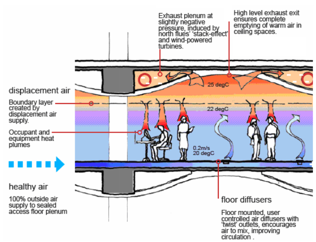
Vertical supply ducts on the south façade supply air to the offices through vents

The trapped hot air in the cavity is then extracted through the ceiling void until it is extracted to the vertical exhaustion ducts

Wind cones ventilates the building by exhausting warm air from the top and bringing cool air up from its lower levels

Ventilation

Passive Stack Driven Ventilation



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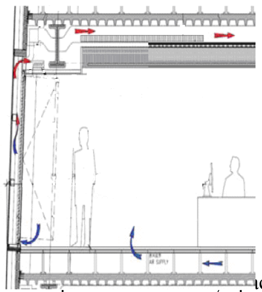
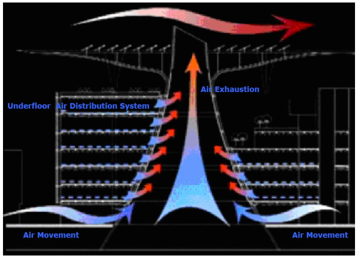
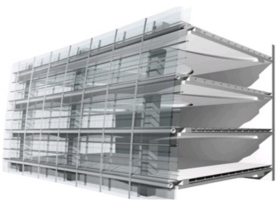


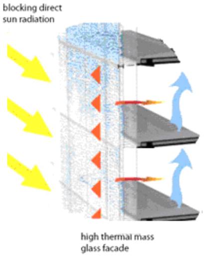


High performance Double Skin Façades

- Blinds in the upper and lower part of the window
- External plants on the northern façade
- Double glazing in the western facade
- Low conductor timber windows frames



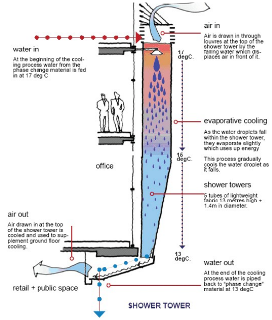
High-thermal-mass exterior glass cladding blocks direct solar radiations and decreases the internal cooling loads



Evaporation

Passive Evaporative Cooling Towers

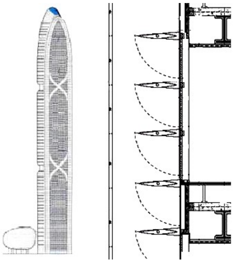
five shower towers that condition the air in the ground floor



Shading

Glass Louvers

A motorized 50mm perforated silver Venetian blind is in the east and west double facades



roof with PV cells on the external side in order to reduce the solar gain

Wood louvers

The western façade is shaded by shutters made of recycled timber

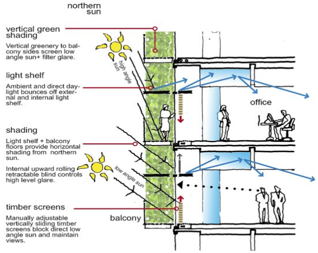
Energy Efficient and Sustainable Features

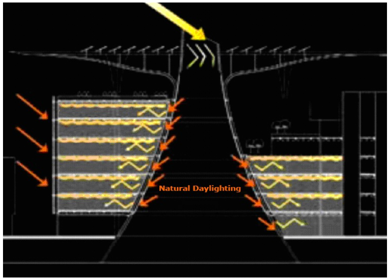
- Windows are located at the highest point
- visible light transmittance glazing
- Lighting shelves
- Movable timber shutter
- Glare control

integrated glass façade is providing high visual transmittance, enhancing daylight harvesting, and allowing for a reduction in the amount of artificial lighting required

staggered cones bring daylight deep inside the 1.5-million-square-foot complex. They are made from glass angled at 15-22 degrees that reflect between 15-20% of the light

Natural lighting



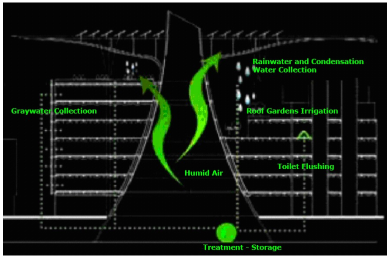


Water conservation

- Water recycling
- Rain water harvesting
- Water saving plumbing fixtures

- Using harvested water from chilled surfaces to control interior humidity.
- Reusing and recycling water to be used for interior plantings and toilet flushing.
- Using ultra Low Flow toilets, low flow sinks and waterless

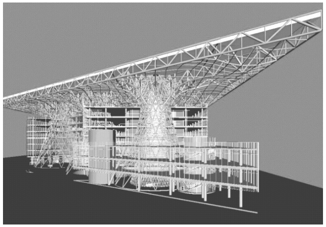
- Graywater is treated and stored for landscaping
- Rainwater is collected and stored as well



Sustainable construction

The building contains about 88% recycled contents (Timber western External metal cladding shutters, Structural Concrete, Wastes reduction)

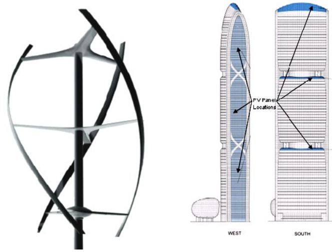
The building is constructed from high recycled materials content such as the use of recycled steel rather than concrete.



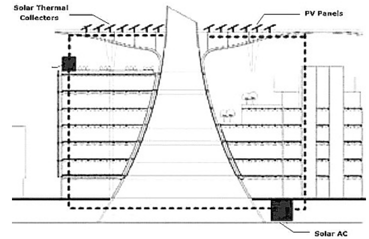
Energy generation

- Natural gas micro-turbine
- Wind-driven turbines
- Solar Power - Photovoltaic cells
- Solar hot water panels

The building design incorporated three power-generating technologies: wind turbines, integrated photovoltaic and hydrogen fuel cell.

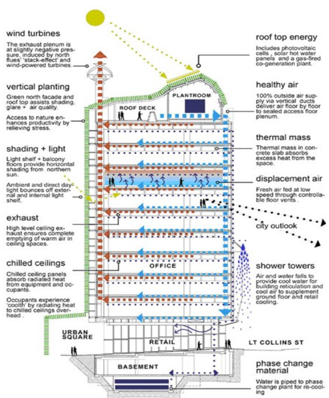


The 72,000 sq m roof contains one of the world's largest building integrated PV displays, it provides energy during building construction and during the building usage.

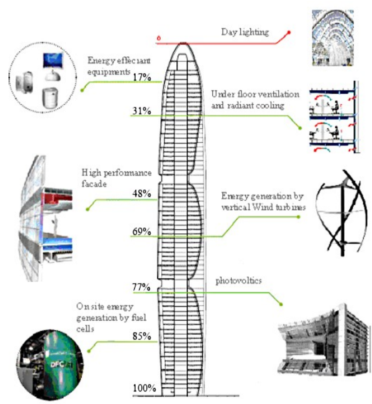


Building Performance

Reduction of electricity consumption by 85%,
Reduction of gas consumption by 87%,
Reduction of water mains supply by 72% from 31 liters per day per person to just 8.4 litres per day per person.
Light fittings consume 65% less energy,



Passive cooling strategies reduce the energy consumption by 44% from the annual energy consumption.



Consume 70 percent less water compared with typical mixed-use buildings of the same size.
Passive cooling strategies reduce the building energy consumption by 61.5 % from the annual energy consumption