POLITECNICO DI MILNO
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Institute of Graduate Studies and Research
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Achieving Thermal Comfort in Existing Buildings using Passive Cooling Techniques

" Case study of Retrofitting an Existing Office Building in Milan, Italy"

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I declare that no part of the work referred to in this thesis has been submitted in support of An application for another degree or qualification from this or any other University or Institutions.

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ABSTRACT

Building sector accounted for more than 30% of global energy consumption and the importance of energy-efficient buildings has been frequently highlighted. Energy consumption for cooling represents approximately 10% of the total energy consumption specially for commercial office buildings. The percentage of fully air-conditioned office floor area is increasing. The increasing use of information technology has led to an increasing demand for cooling in office buildings. There are a lot of problems of air condition systems on the environment, also the impact of air conditioner on electricity demand is an important problem as peak electricity load increases continuously. Southern European countries face a very steep increase of their peak electricity load mainly because of the very rapid penetration of air conditioning.

Retrofitting an existing building can oftentimes be more cost-effective than building a new facility. particularly for heating and cooling and because existing buildings comprise the largest segment of the built environment, it is important to initiate energy conservation retrofits to reduce energy consumption and the cost of heating, cooling, and lighting buildings. But conserving energy is not the only reason for retrofitting existing buildings. The goal should be to create a high-performance building by applying the integrated, whole-building design process, to the project during the planning or charrette phase that ensures all key design objectives are met. Doing so will mean that the building will be less costly to operate, will increase in value, last longer, and contribute to a better, healthier, more comfortable environment for people in which to live and work. Improving indoor environmental quality, decreasing moisture penetration, and reducing mold all will result in improved occupant health and productivity. Further, when deciding on a retrofit, consider upgrading for accessibility, safety and security at the same time. Designing major renovations and retrofits for existing buildings to include sustainability initiatives will reduce operation costs and environmental impacts, and can increase building adaptability, durability, and resiliency.

This study at the beginning shows the energy use in office buildings, the cooling load inside the buildings and the problems of air condition systems. After that the passive cooling techniques that may be used as alternative of air condition systems in the retrofitting phase. Then there are some examples for office buildings in Italy, that already have been retrofitted by applied some of the passive cooling techniques. Then, applying some of passive cooling techniques to decrease the cooling load and increase the hours of thermal comfort inside office building in Milan, Italy (Lampedusa office building). At the end, ensure the results by using simulation programs.

So, this study reviews and analyses the performance of various passive cooling systems and their role in providing thermal comfort and its significance in energy conservation with the help of Architectural interventions.

"*Keywords:* *Energy Consumption, Building Performance, Cooling Load, Natural Ventilation, Cooling Mechanisms, Passive Cooling Techniques, Thermal Comfort, Retrofitting and Simulation Program*".

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
ISO	International Organization for Standardization.
DOE	United States Department of Energy.
A/C	Air Conditioning system.
HVAC	Heating, Ventilating, and Air-Conditioning.
CO2	Carbon dioxide.
GDP	Gross Domestic Product.
KWh	Kilowatts (10^3 watts) per hour.
GWh	Gigawatts (10^9 watts) per hour.
TWh	Terawatts (10^{12} watts) per hour.
BTU	British Thermal Unit.
LED	Light-emitting diode.
LEED	Leadership in Energy and Efficiency Design.
SHGC	Solar Heat Gain Coefficient.
PCM	Phase Change Material.
RCC	Roof Cutting Machine.
U-Value	Thermal Transmittance.
PVC	Polyvinyl Chloride.
λ	Thermal Conductivity.

LIST OF DEFINITIONS

"Sustainable Architecture" (Williams, 2007) (Maciel, 2007)	Sustainable architecture adds to quality of the environment, to clean air, to water, to renewing and protecting life. It must be economically viable and socially equitable achieving the "3 E's" of sustainability -environment, economy and equity. The sustainable approach is looked from the perspective of the impact of the building on the local environment in which it also embraces the embodied energy of the material and its durability and the use of water and energy.
"Bioclimatic Architecture" (Maciel, 2007)	The bioclimatic design is an approach that takes advantage of the climate through the right application of design elements and building technology for energy saving as well as to ensure comfortable conditions into buildings.
"Sustainability" (UIA/AIA, 1993)	Sustainability means meeting the needs of the current generation without compromising the ability of future generations to meet their own needs.
"Energy" (Szokolay, 2008) (Brown, 2009)	The ability or capacity for doing work and it is measured in the same unit: J (joule) Energy may exist in a variety of forms, as potential energy, chemical energy, kinetic energy, nuclear energy, electrical energy, and the heat energy in steam. Energy may be converted between different forms, but the converted energy will always be less than the initial energy after accounting for losses in the conversion.
"HVAC (Heating, Ventilation and Air Conditioning)"	The technology of indoor environmental comfort. HVAC system design is based on the principles of thermodynamics, fluid mechanics, and heat transfer.
"Design" (Kwok and Grondzik,2007)	Design is a process of inquiry. Every project presents a unique response to the particular combinations of site, climate, user, budget, and program that define context.

"Integrated Design" (Kwok and Grondzik,2007)	Is a process that applies the skills and knowledge of different disciplines and the interactions of different building systems to synergistically produce a better, more efficient, and more responsible building occasionally for lower first cost, but more typically for lower life-cycle cost.
"Solar Thermal" (Gevorkian, 2010)	A form of power generation using concentrated sunlight to heat water or other fluid that is then used to drive a motor or turbine.
"Psychometric Chart" (Hootman, 2013)	A useful tool for understanding the role of temperature and humidity in thermal comfort and can be used for evaluating the effectiveness of design strategies in providing thermal comfort.
"Thermal Comfort" (ASHRAE, 1966)	That condition of mind, which expresses satisfaction with the thermal environment.
"Thermal Loads" (Hootman, 2013)	It is a complex combination of exterior thermal conditions that transmits through the building envelope and internal thermal conditions through internal heat gain from people, lighting and equipment.
"U-Value" (Kwok and Grondzik,2007)	The amount of light (or solar radiation) that passes through a substance; expressed as a percentage of incident light (or solar radiation).
"Relative Humidity" (Kwok and Grondzik,2007)	A measure of the moisture content of the air; the amount of moisture actually held by the air compared to the maximum amount that could be held at the same temperature; expressed as a percentage.

CHAPTER ONE

Introduction

1-1 Introduction
1-2 Research Questions
1-3 Statement of the Problem
1-4 Delimitations
1-5 Significance of the Study
1-6 Aim of the Study
1-7 Methodology
1-8 Structure of the Thesis

1-1 INTRODUCTION

As the population of the world increases and people strive for a higher standard of living, the amount of energy necessary to sustain the society is ever increasing. At the same time, the availability of nonrenewable sources, particularly liquid fuels, is rapidly shrinking. The potential for crisis if we run out of energy is real but it will take time to occur. Therefore, there is a general agreement that to avoid energy crisis, renewable sources will have to be used. As a consequence, conservation and renewable energy technologies; their availability, efficiency, and cost are necessary for planning a secure energy future [1].

Driven by population growth, the building sector is a significant contributor to economic growth, both at global and national levels. In addition, harmful emissions caused by the burning of fossil fuels in energy production contributes to environmental degradation. Although the building sector is the largest contributor to energy demand, it also holds the greatest potential to reduce these demands [2].

Unfortunately, building envelope designs are developed to meet the client's requirements without much concern to the local climate and with no objective to conserve energy. This has certainly disregarded the climate as a design determinant in building envelope design process. As a result, these have contributed to an overall poor thermal performance of the buildings, which became more dependent on artificial means to provide comfortable thermal environment at high-energy consumption [3].

In the meanwhile, the thermal performance of any building requires complex interactions between the exterior environment and the internal loads that must be mediated by the building envelope and mechanical systems. The difficulty is that these various load conditions are constantly changing from hour to hour and season to season [4] [5].

Buildings consume approximately 40 to 50% of primary energy. Energy consumption for cooling represents approximately 10% of the total consumption for commercial office buildings. The percentage of fully air-conditioned office floor area is increasing, where full air conditioning is the current de facto standard in new or re-constructed office buildings. The increasing use of information technology has led to an increasing demand for cooling in office buildings. Cooling thus accounts for a significant proportion of the total energy consumption in buildings, and its impact on greenhouse gas emissions [6].

Improving the energy performance in buildings can be done by retrofitting the building envelope, using more efficient energy-using equipment such as lighting and air conditioners, using renewable energy sources, and altering the occupants' behavior concerning energy usage. The procedures that be implementation in existing office buildings will make energy saving and have environmental benefits. Energy conservation actions in the existing office building can save energy, decrease fuel imports to operate power plants, decrease the need to build new power plants, decrease the associated carbon dioxide emissions and improve the overall economic situation of the country [7].

One of the most important loads in the existing buildings are the cooling loads as it need high energy to cool the building by mechanical methods, So that there are a way towards using Low energy cooling technologies provide cooling in an energy efficient manner, thus reducing energy consumption and peak electricity demand this technologies called passive cooling methods to save energy and to achieve a high performance for cooling the existing buildings in summer session which is focused on reducing the cooling load [6].

1-2 RESEARCH QUESTIONS

- What is the performance of the existing office buildings in summer session in Mediterranean area?
  - What are the strategies of cooling in existing office building?
  - What is the cost of energy consumption for cooling office building in summer session?
  - How to reduce the cooling loads in existing office building?
- What is the passive cooling?
  - What is the purpose of using passive cooling in existing office building?
  - What are the technologies of passive cooling that can be used for retrofitting an existing office building?
- How to simulate the passive cooling technologies for retrofitting an existing office building?
  - What is the performance of office building after using passive cooling technologies?

1-3 STATEMENT OF THE PROBLEM

Office buildings became more and more aesthetically pleasing but not energy efficient. This entails the use of excessive energy in cooling. The problem here is the disregard for energy efficiency and the electricity consumption for cooling. That is why we must apply some passive techniques to see how the principles can be applied to provide energy efficient buildings and natural cooling. Most of the existing buildings façades are exposed to solar radiations that absorb heat during the day. This heat is transferred to the inner spaces, thereby creating thermal discomfort for the building occupants. Externally generated cooling loads are due to sunshine through windows or on the outside of walls or roofs, hot air entering the building or heat conducted from hot outside air to the inside.

The thermal comfort inside office buildings achieved by the mechanical cooling systems that need high consumption of electricity and we have now in all over the world crisis because of electricity and nonrenewable resources that begin to be depleted, So the energy demand need to be decreased and the resources need to be conserved. To solve this problem, it is the way to use the applications of some passive cooling techniques to create energy efficient in an existing office building.

1-4 DELIMITATIONS

- **Theoretically:** Study different cooling techniques that cool the air and responsible for flowing the air inside the office buildings in summer session in Mediterranean climate.
- **Practically:** Retrofit an existing office building by using passive cooling strategies to achieve the thermal comfort and reduce the cooling loads in the building.

1-5 SIGNIFICANCE OF THE STUDY

In the past the architects were concerned about the air flow and cooling the building by passive techniques in the design stage, unfortunately now the buildings cooled by the mechanical techniques. So, this study will show the importance of the passive cooling techniques in the buildings nowadays and how their advantages can be applied in retrofitting an existing office building.

1-6 AIM OF THE STUDY

1-Reduce the consumption of the energy demand for mechanical cooling in existing office building in summer session.

2-Use passive technologies for cooling in existing office building to reduce cooling loads.

3-Applying passive cooling techniques by retrofitting an existing office building to achieve thermal comfort inside the building in summer session.

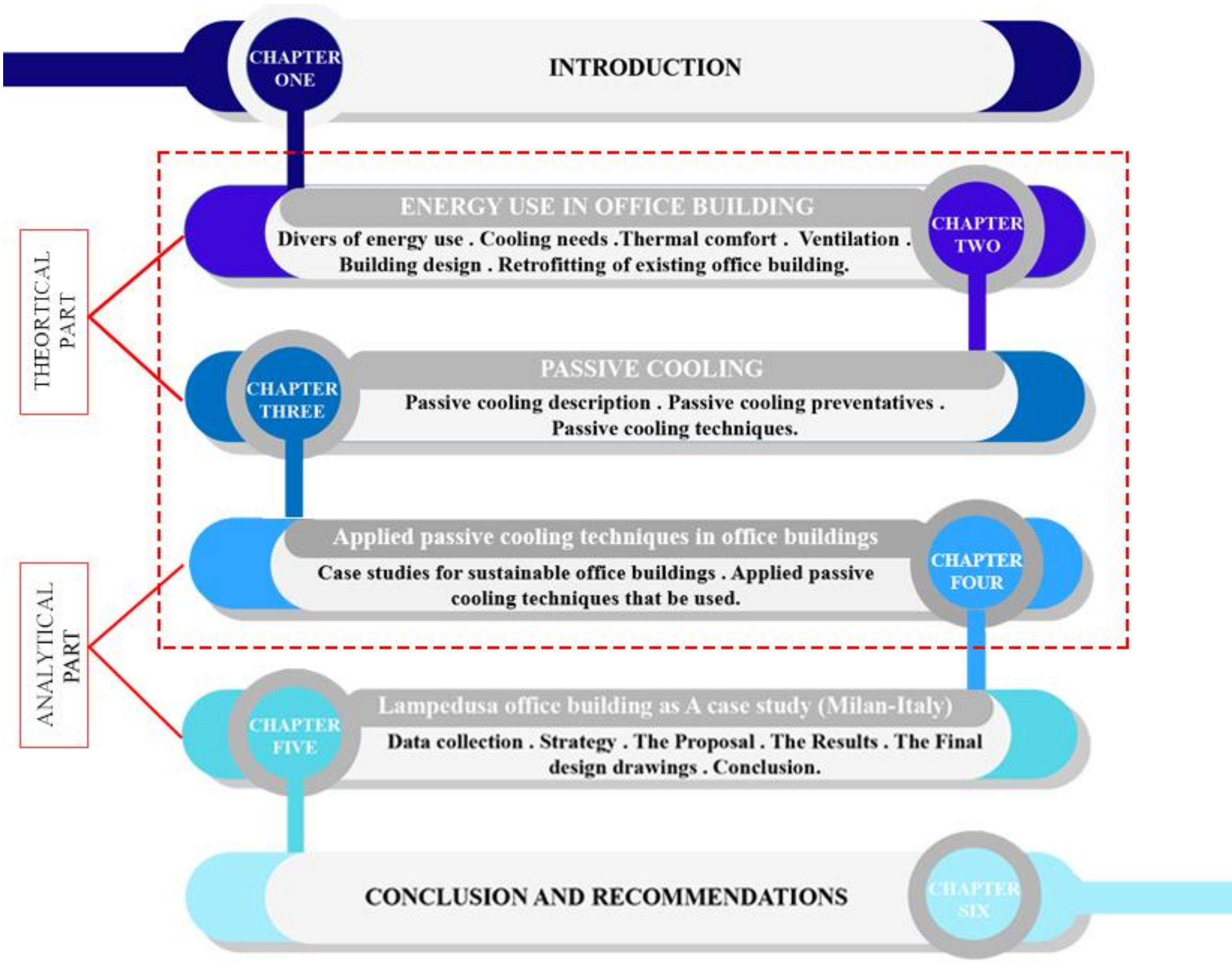
1-7 METHODOLOGY

The research is conducted through:

- **Theoretical Methods:**
  - Overview about cooling in buildings.
  - The principles of cooling in buildings.

  - Strategies of passive cooling in office buildings.
  - Purpose and benefits of passive cooling in existing office buildings.
  - Design consideration for passive cooling in existing office buildings.
- **Analytical Methods:**
  - Simulation for passive cooling technologies.
  - Use passive cooling technologies in existing office building to improve the performance of the building in summer session.
  - Simulate the office building after using the passive cooling technologies.
  - Comparison between the performance of office building before using the passive cooling technologies and after.

1-8 THE STRUCTURE OF THE THESIS



CHAPTER TWO

Energy Use in Office Building

2-1 Introduction

Construction is one of the most important economic sectors worldwide. The total world's annual output of construction is close to $3 trillion and constitutes almost one-tenth of the global economy [8]. About 30% of the business is in Europe, 22% in the United States, 21% in Japan, 23% in developing countries and 4% in the rest of the developed countries.

Buildings use almost 40% of the world's energy, 16% of the fresh water and 25% of the forest timber [9], while is responsible for almost 70% of emitted Sulphur oxides and 50% of the CO_2 [10].

Energy consumption of the building sector is high. Although figures differ from country to country, buildings are responsible for about 30-40% of the total energy demand. Application of intensive energy conservation measures has stabilized energy consumption for heating in developed countries. However, energy needs for cooling increases in a dramatic way. The increase of family income in developed countries has made the use of air conditioning systems highly popular. In Europe the main commercial market for cooling and air conditioning systems totals 8 billion Euros. Almost 6% of office, commercial and industry buildings are cooled, making a total volume of about 20 million cubic meters [11].

In the United States, the penetration of air conditioning is extremely high. More than 3.5 billion m2 of commercial buildings are cooled. The total cooling energy consumption for the commercial sector is close to 250 Twh/y, while the necessary peak power demand for summer cooling of the commercial buildings is close to 109 GW.

The impact of air conditioner usage on electricity demand is an important problem as peak electricity load increases continuously, forcing utilities to build additional plants. In parallel, serious environmental problems are associated with the use of air conditioning.

Passive and hybrid cooling techniques involving microclimate improvements, heat and solar protection, and heat modulation and dissipation methods and systems can greatly contribute to building's cooling load reduction and increase thermal comfort during the summer.

Results of the European Research Project PASCOOL, [12], showed improved knowledge on this specific topic and develop design tools, advanced techniques to better implement natural cooling techniques and new techniques to characterize the performance of passive cooling components have been developed as an aid to designers [12].

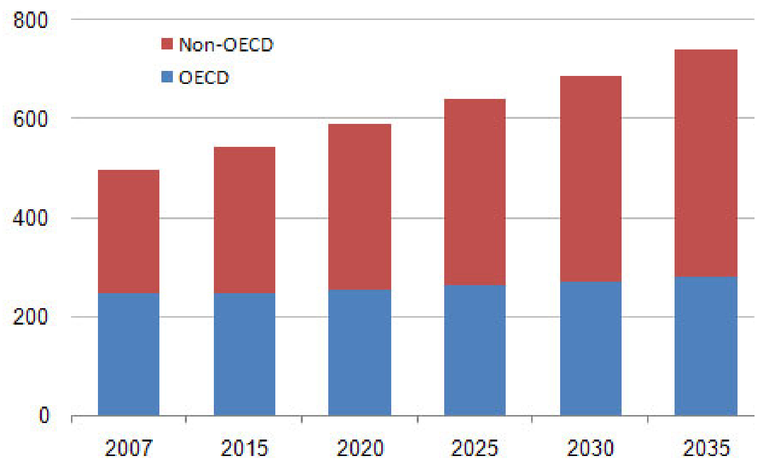


Figure 1: World Marketed Energy Consumption in BTU, (Source: U.S Energy Information Administration).

2-2 Drivers of Energy Use in Buildings

The services demanded of buildings - lighting, warmth in the winter, cooling in the summer, water heating, electronic entertainment, computing, refrigeration, and cooking - require significant energy use, about 40 quadrillion Btu (quads) per year. Energy consumption in buildings has been growing in aggregate over time. Today the nation's 114 million households and more than 4.7 million commercial buildings consume more energy than the transportation or industry sectors, accounting for nearly 40 percent of total U.S. energy use.

This energy use is driven by:

- Population, which drives the number of homes, schools, and other community buildings.
- Economic growth (real GDP), which is a major driver of new floorspace in offices and retail buildings.
- Building size (the amount of commercial floorspace and the size of homes).
- Service demands (lighting and space conditioning, electronics, process loads).
- Real energy prices.
- The efficiency with which energy service demands are met [13].

The commercial sector is considerably more heterogeneous than residential buildings, encompassing hospitals, schools, offices, houses of worship, lodging, and the retail sector with its big box stores, enclosed malls, strip malls, grocery stores and fast food and sit-down restaurants. Each of these commercial sub-sectors is unique in its market structure, energy use, and energy intensity, and in the set of decision makers involved in design and construction projects [14]. The two largest energy-using sectors are offices and retail [15].

Energy use in offices has risen in recent years because of the growth in information technology, air-conditioning, density of use, and a competitive market where tenants see high value in a comfortable workplace. Two-thirds of all energy consumed in an average office building is electricity. Lighting, office equipment and HVAC account for 90 percent of this expenditure. Certainly, the trend of high energy demand is offset by the considerable improvements over time in design, construction, insulation, lighting, and controls. Yet as energy costs continue to climb, improvements and innovation on the consumption side will not be able to keep pace [16].

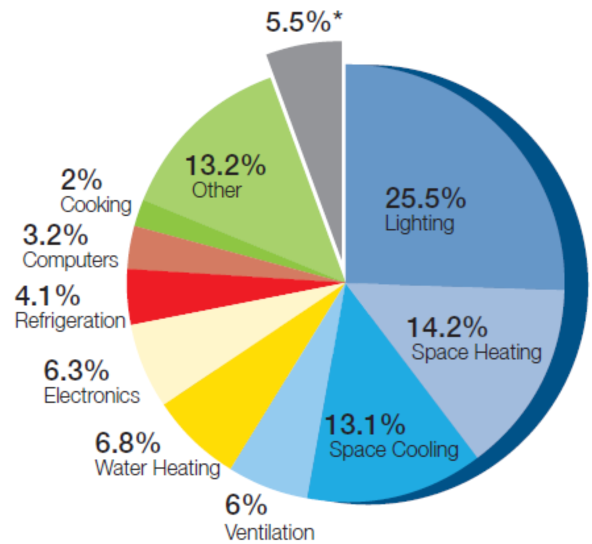


Figure 2: Commercial Primary Energy End-Use, in Commercial Buildings, (Source: BED, Table 1.3.3, 2005).

Energy used in a commercial building has a large effect on energy efficiency strategies. The most important energy end-use across the stock of commercial buildings is lighting, accounting for fully one-quarter of total primary energy use. Heating and cooling are next in importance, each at about one-seventh of the total. Equal in magnitude — although not well defined by the Energy Information Administration — is a catch-all category of "other uses" such as service station equipment, ATM machines, medical equipment, and telecommunications equipment. Water heating, ventilation, and non-PC office equipment are each around 6 percent of the total, followed by refrigeration, computer use, and cooking [13].

2-3 The Cooling Needs of Buildings

Increased living standards in the developed world using non-climatically responsive architectural standards have made air conditioning quite popular. Importantly, this has increased energy consumption in the building sector. There are more than 240 million air conditioning units and 110 heat pumps installed worldwide according to the International Institute of Refrigeration. IIR's study shows that the refrigeration and air conditioning sectors consume about 15% of all electricity consumed worldwide [17]. In Europe it is estimated that air conditioning increases the total energy consumption of commercial buildings on average to about 40 kWh/m2/year [18].

It is evident that the total energy consumption of buildings for cooling purposes varies as a function of the quality of design and climatic conditions. In hot climates, as in the Mediterranean, commercial buildings with appropriate heat and solar protection and careful management of internal loads may reduce their cooling load down to 5 kWh/m2/year [19], while buildings of low-quality environmental design may present loads up to 450 kWh/m2/y [20]. Under the same climatic conditions and when internal gains are not important, such as in residential buildings, the use of air conditioning may be completely avoided when efficient solar and heat protection as well as heat modulation techniques are used [17].

According to Adnot, J. et al. [21], In Europe and worldwide the energy consumption for the cooling of buildings is increasing dramatically. Studies like ―Energy Efficiency and Certification of Central Air Conditioners‖(EECCAC) and ―Energy Efficiency of Room Air Conditioners‖ (EERAC) predict a four-fold growth of energy demand for cooling between 1990 and 2020 in the EU-15.

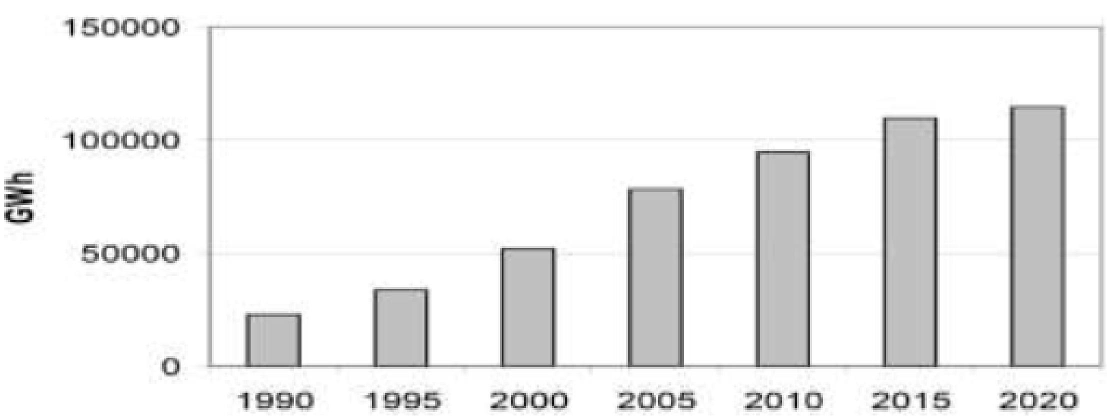


Figure 3: Estimated increase of Annual Cooling Energy in the EU-15 from 1990 to 2020, (Source: [21]).

The reasons for this development are manifold. As main causes can be identified:

- Inefficient building design (e.g. orientation and size of transparent building elements).
- Increase of internal loads (IT-equipment, lighting).
- Climate change aspects (increase of outdoor temperatures in the summer period).
- Tightened requirements on indoor comfort (e.g. caused by standardization and building directives, comfort claims by occupants).
- Misconduct of the occupants (misappropriate ventilation by occupants in the cooling period).

Before the invention of mechanical refrigeration, ingenious use was made of the many means of cooling (e.g. damp cloths hung in draughts created by the connective stack effect in buildings). So, dwellings and lifestyles were developed to make best possible use of these sources of cooling. The introduction of mechanical refrigeration permitted not only the ability to increase the likelihood of achieving complete thermal comfort for more extended periods, but also a great deal of flexibility in building design, and simultaneously led to changes in lifestyle and work habits. However, increasingly, the use of a 'higher technology' resulted in natural-cooling systems being ignored. Now with the growing realization of the rapid depletion of non-renewable energy sources and of the adverse environmental impacts of fossil-fuel dissipating processes, it is accepted that it is foolish to continue consuming vast amounts of non-renewable fuels for the air-conditioning of buildings, when our ancestors achieved thermal comfort by natural means. Hence to reduce the emission of greenhouse gases, caused by fossil fuels to power the cooling requirement of the buildings has stimulated the interest towards adoption of passive cooling techniques for buildings [22].

2-3.1 Urban Microclimate and Its Impact on the Cooling Needs of Buildings

Cities or urban areas are defined as the physical environment that is composed of "a complex mix of natural elements including air, water, land, climate, flora and fauna, and the built. buildings, infrastructure and urban open spaces" [23]. The last 50 years was a period of the most intensive urbanization that our planet has ever experienced. Urban population has increased from 160 million to about 3 billion in just 100 years, and it is expected to increase to about 5 billion by 2025.

An increase of the urban population by 1% increases the energy consumption by 2.2%, thus the rate of change in energy use is twice the rate of change in urbanization [24].

Increasing urbanization has deteriorated the urban environment. Deficiencies in development control have seriously impacted the urban climate and environmental performance of urban buildings. As reported by Akbari, New York City has lost 175,000 trees, or 20% of its urban forest in the last ten years [25].

Because of heat balance, air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country. This phenomenon known as 'heat island', exacerbates electricity demand for air conditioning of buildings and increases smog production, while contributing to increased emission of pollutants from power plants [26].

2-3.2 Cooling Mechanisms

There are different cooling systems available for electronics and power systems whose applications depend on different factors. Required cooling capacity, physical confinements, environmental conditions, cost and compatibility requirements are some of the most important criteria that can determine which method to use for a system. Cooling methods in general can be categorized in two major groups:

I. Active cooling methods are the ones in which a power source is required to run the cooling system. There are different types of active cooling mechanisms, such as fan-assisted cooling, spray cooling, refrigeration cycles, jet-impingement cooling, and electro-wetting cooling. Each of these methods has its own range of applicability in term of heat dissipation capacity. Among mentioned methods, two-phase cooling mechanisms due to very large value of boiling latent heat of coolant have much higher capacity than single-phase methods. In most of the high and ultrahigh heat flux systems single phase methods do not meet the requirements and two phases should be implemented.

II. Passive cooling methods which do not require a power source to operate. These methods have generally less heat dissipation capacity compared to active ones, but they are widely preferred for electronic and power electronic devices since they provide low-cost, no parasitic power, quiet operation and reliable cooling solutions. Due to the absence of moving parts in most of the passive cooling systems, they do not need regular maintenance and are very reliable. The most important component of a passive-cooled system is heat sink which is in direct contact with the ambient. Such passive techniques are drawing more attention because they are green‖ and air is the most accessible coolant, particularly for applications in hostile environments, e.g. contaminated air, vibrations, noise, and humidity. Other components of such systems may include heat spreaders, heat pipes, and thermal energy storage systems that may include phase change materials (PCM) [22].

2-3.3 Recent Penetration of Air Conditioning systems

According to JRAIA, the 2017 world Room Air Conditioners (RAC) demand is estimated to reach 96.05 million units with 8.2% increase compared with the previous year. The largest market is China, whose demand reached 43.49 million units with 13.2% increase. The second largest market is Asia, excluding Japan and China, whose demand reached 15.74 million units with 5.4% increase. The third largest market is Japan, whose demand reached 8.93 million units with 6.9% increase. North America reached 8.13 million units with 1.2% increase, followed by Latin America with 6.09 million units and 5.3% increase, and Europe with 5.83 million units and 8.7% increase.

The 2017 world Packaged Air Conditioners (PAC) demand is estimated to reach 14.51 million units with 7.5% increase compared with the previous year. The largest market is North America, whose demand reached 7.18 million units with 9.4% increase. The second largest market is China, whose demand reached 2.46 million units with 12.9% increase. The third largest market is Asia, excluding the countries of Japan and China, whose demand reached 1.57 million units with 5.2% increase. Japan reached 0.82 million units with 3.2% increase, followed by Europe with 0.73 million units and 2.9% increase, and Middle East with 0.64 million units and 2.6% decrease

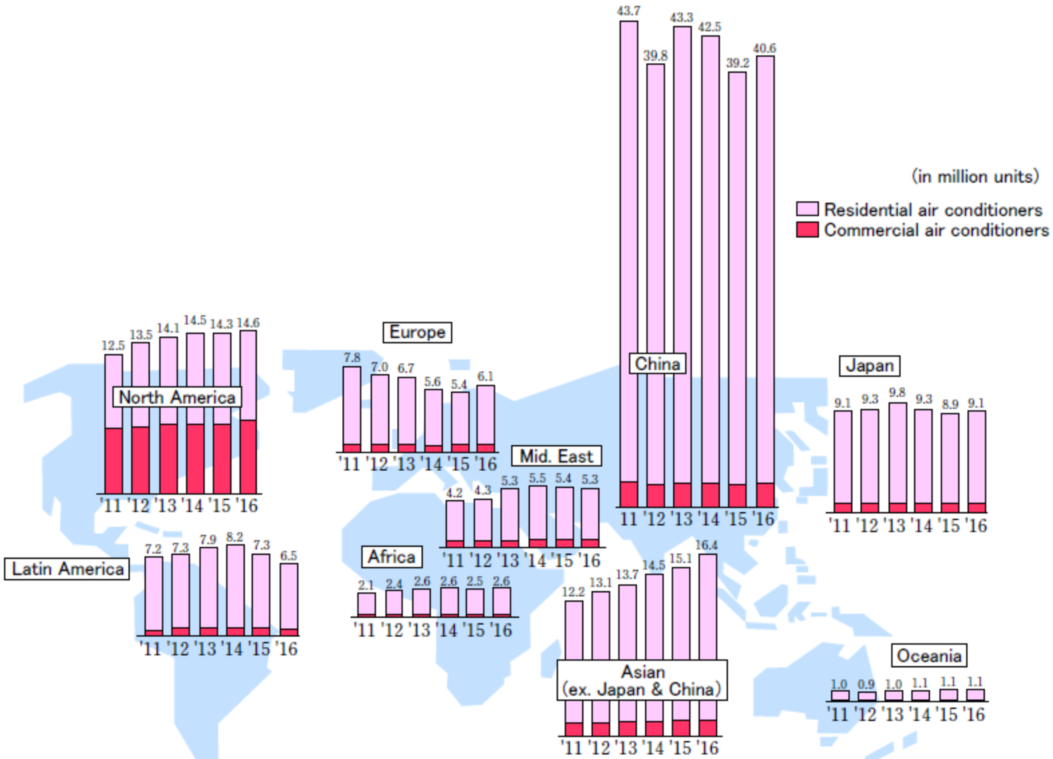


Figure 4: The graph shows RAC and PAC demand by region from 2012 to 2017, Source (JRAIA, April 2018).

2-3.4 Main Problems of Air Conditioning

There are different problems associated with the use of air conditioning. Apart from the serious increase of the absolute energy consumption of buildings, other important impacts include:

- The increase of the peak electricity load.
- Environmental problems associated with the ozone depletion and global warming.
- Indoor air quality problems.

High peak electricity loads oblige utilities to build additional plants in order to satisfy the demand, but as these plants are used for short periods, the average cost of electricity increases considerably. Southern European countries face a very steep increase of their peak electricity load mainly because of the very rapid penetration of air conditioning. It is expected that the future increase of the peak load may necessitate doubling installed power by 2020 [11].

The main environmental problems of air conditioning are associated with:

- Emissions from refrigerants used in air conditioning which adversely impact ozone levels and global climate. Refrigeration and air conditioning related emissions represent almost 64% of all CFC's and HCFC's produced [28].
- Cooling systems' energy consumption contribute to CO_2 emissions.

Refrigerant gases used in air conditioning are either CFC's, HCFC's or HFC's. Chlorofluorocarbons have a very important impact on ozone depletion and they also exert global warming effects. According to the Montreal Protocol, CFC's production and use was banned by

1996 in the developed countries. In Europe, "Regulation 2037/2000" totally bans their use for maintenance and servicing of equipment as of January 1, 2001.

Hydrochlorofluorocarbons, HCFC's have less of an impact on ozone depletion and a lower global warming potential than the CFC's. The Montreal Protocol has banned the use of HCFC's in developed countries by 2030 and by 2040 in developing countries. In Europe, HCFC's production will be banned as of 2025, and by 2010 the use of virgin HCFC's will be banned for maintenance and servicing.

Hydrofluorocarbons, HFC's, do not have an ozone depleting effect and their global warming impact is less than CFC's. An important market shift is being made to HFC's (R-407C and increasingly R-410A) in Japan, where more than 50% of room air conditioners produced are HFC models. Unlike the Japanese and European markets, the US industry keeps R22 (HCFC) equipment longer and aims to shift directly to R410A instead of going through R407C (HFCs).

Air conditioning systems may be an important source of indoor contamination. Cooling coils and condensate trays can become contaminated with organic dust. This may lead to microbial growth. The organic dust may also cause mold and fungal growth in fans and fan housings. Inefficient and dirty filters may also lead to unfiltered air in the building. Contaminated emissions from cooling towers may cause spread of diseases like Legionelea from poorly maintained systems. A very comprehensive analysis of all studies related to indoor air quality problems caused by HVAC systems is given by Limb and Lloyd [29] [30].

2-3.5 Recent developments on the field of Air Conditioning, High Efficiency A/C systems

The A/C industry has steadily improved the energy efficiency of A/C systems through a combination of technological innovation and market transformation strategies. From 1990 to 2013, U.S. shipment-weighted efficiency for residential split-system A/Cs increased from 9.5 SEER (~2.2 COP) to 14.9 SEER (~3.8 COP) [31] [32]. Manufacturers made these improvements through the introduction of many individual technologies that collectively improve overall system efficiency, including multi- and variable-speed drives, novel compressor, fan, motor, and heat exchanger designs, electronic expansion valves, and advanced controls.

Government and industry programs have significantly increased adoption of high efficiency A/C systems through minimum efficiency standards, comparative and endorsement labels (e.g., ENERGY STAR), public challenges and awards, and incentive programs. These programs result in significant emissions reductions and cost savings for consumers [33]. In the U.S., updated efficiency standards published by DOE at the end of 2015 for commercial HVAC systems are expected to save more energy than any other standard issued by DOE to date [34]. In June of 2016, the Clean Energy Ministerial (CEM) launched an Advanced Cooling Challenge with the support of numerous governments, manufacturers, and non-profit groups, which aims to improve average A/C system efficiency by 30% by 2030. Comprehensive approaches that combine efficiency with effective refrigerant management practices, high-performance building design, and renewable energy integration will be the most effective means of reducing both direct and indirect A/C emissions going forward [35].

2-3.6 Alternative Techniques to Air Conditioning - Passive Cooling

Addressing successful solutions to reduce energy and environmental effects of air conditioning is a strong requirement for the future. Possible solutions include:

I. Adaptation of buildings to the specific environmental conditions of cities in order to efficiently incorporate energy efficient renewable technologies to address the radical changes and transformations of the radiative, thermal, moisture and aerodynamic characteristics of the urban environment. This involves the use of passive and hybrid cooling techniques to decrease cooling energy consumption and improve thermal comfort.

II. Improvement of the urban microclimate to fight the effect of heat island and temperature increase and the corresponding increase of the cooling demand in buildings. This may involve the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies, etc.

Additionally, alternative strategies may be followed to decrease the impact of air conditioning, such as:

- Utilizing centralized or semi-centralized cooling production, and distribution networks based on renewable energies or waste heat (district cooling), together with demand-side management actions like local or remote cycling [36].
- Using more efficient air conditioning equipment for individual buildings with optimized COP curves, using renewable sources or waste heat.

None of these be isolated areas of concern. The interrelated nature of the parameters defining performance efficiency of buildings during summer requires that practical actions be undertaken as an integrated approach [37].

2-4 Thermal Comfort in Offices

Variable indoor temperature comfort standards for air-conditioned buildings may result in remarkable energy savings [38]. Energy savings of about 18% are estimated over that from using a constant indoor temperature in Southern Europe [39], while the corresponding energy savings for UK conditions have been estimated close to 10%.

2-4.1 Thermal comfort models

Relevant literature comprises four major approaches. On the one hand there is the PMV-Model of Fanger (ISO 7730) and its modification by Mayer 1998. Both approaches determine the Predicted Mean Vote (PMV) in dependence on the momentary air and radiant temperatures, air velocity, relative humidity, metabolism and clothing insulation value. Both authors calculate Predicted Percentage of Dissatisfied Persons as a function of PMV. On the other hand, there are two adaptive approaches: a Dutch guideline [40], and the ASHRAE approach [41]. Contrary to the PMV-Model the adaptive models relate the indoor comfort temperature to mean outside temperatures.

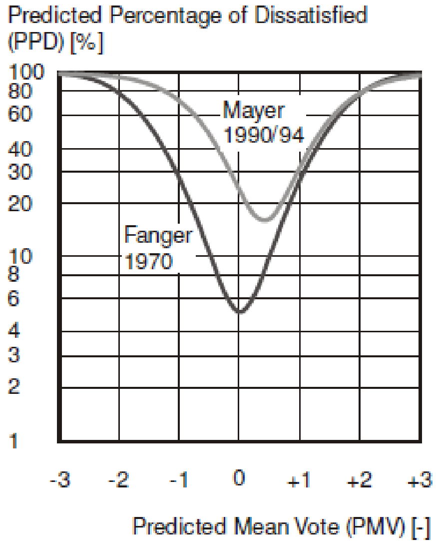


Figure 5: Predicted percentage of dissatisfied (PPD) in dependence on the predicted mean vote (PMV) according to Fanger (ISO 7730) and Mayer 1998. (Source: [41]).

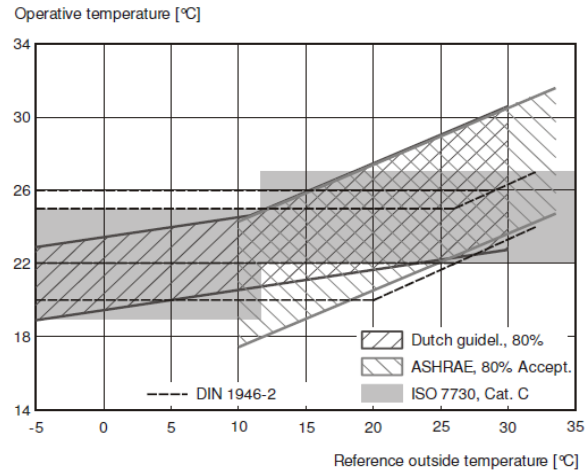


Figure 6: Comparison of different indoor temperature limits for naturally ventilated buildings in dependence on the reference outside temperature with the temperature limits from German DIB 1946-2 and ISO 7730. (Source: [42]).

Fig. 5 shows the PMV-PPD-Model of Fanger (ISO 7730) was modified by Mayer 1998. Mayer investigated the relation between PMV and PPD by asking not only for thermal sensation but also for preference. He found that a vote of slightly cool (-1) is already regarded as uncomfortable. His modification of the PMV-PPD relation is shown in addition to Fanger's relation. According to Mayer the minimum percentage dissatisfied can be reached at a PMV of +0.4. This means that a thermal environment which is slightly warmer than neutral is regarded as comfortable. The minimum percentage of dissatisfied is 16% which is much higher than Fanger's minimum of 5% [41].

Fig. 6 shows the comfort temperatures for office work in the adaptive models in comparison with the former German standard DIN 1946-2 (for mechanically ventilated buildings) and ISO 7730, category C. The reference outside temperatures of the adaptive models and DIN 1946-2 are different. The comfort temperature according to DIN 1946-2 depends on the momentary outside temperature. Last year DIN 1946-2 was replaced by DIN EN 13779 which refers to ISO 7730. Thus, the PMV-model is mandatory for both naturally and mechanically ventilated buildings in Germany. The upper temperature limits of ASHRAE Standard 55 and the Dutch guideline are identical. In comparison, the upper temperature limit of DIN 1946-2 is4°C lower. The maximum allowed temperature of DIN 1946-2 in summer lies within the comfort zone of ISO 7730, category C, summer conditions. The lower limits of ASHRAE Standard 55 and the Dutch guideline have a different slope. The Dutch guideline refers to the lower limit of the ASHRAE Rep. 884 [42], for air-conditioned buildings.

2-4.2 Parameters influencing thermal comfort

A review of relevant literature showed that interactions between thermal comfort and several parameters can be assumed. These parameters can be divided into three groups:

I- Architectural parameters and parameters concerning the heating and ventilation system.

II- Psychosocial parameters.

III- Perception of other indoor climate parameters.

I. Architectural parameters and parameters concerning the heating and Ventilation system

The following architectural parameters and parameters concerning the heating and ventilation system shows a strong connection with thermal comfort:

- Type of ventilation (natural or mechanical).
- Type of air-conditioning system (natural ventilation, partial air-conditioning, full air-conditioning).
- Type of heating and cooling system.
- Position of air supply and extract.
- Humidification of supply air.
- Percentage of glazed area of the façade.
- Solar gain value of the façade.
- Type of windows (sealed, openable).
- Construction type (low – medium thermal storage properties).
- Perceived control over indoor environment.

At the same time, parameters such as the type of heating or cooling system and the construction type has a strong connection with the type of ventilation and air-conditioning system respectively. Therefore, only the type of ventilation / air-conditioning was used for further multivariate statistical analysis.

An important parameter which is influenced mainly by the ventilation system is perceived control. This parameter does not describe whether a room is equipped, or not, with objective control facilities like thermostats; perceived control describes to what extent occupants feel they have control over their indoor environment [43].

II. Psychosocial parameters

The relation between thermal comfort and the following psychosocial parameters was investigated:

- Sex (confounder).
- Age (confounder).
- Education.
- "Sick building syndrome" case.
- Hyper sensation to warmth or cold (confounder).
- Job satisfaction.
- Life satisfaction.
- Work-related strain.
- General strain.

For psychosocial parameters such as job satisfaction, work-related and general strain, life satisfaction and education, only weak coefficients of contingency were determined. This is contrary to the results of Cena and de Dear 1998, who found a strong significant relation between job satisfaction and satisfaction with indoor temperature. Further investigation seems to be required.

The results of the present investigation indicate that the link between thermal sensation and thermal comfort is, in contrast to the Sick-Building-Syndrome (SBS), less sensitive to psychosocial influences. The parameters sex, age and hypersensitivity to warmth or cold were considered as potential confounders in the advanced statistical analysis [44].

III. Perception of other indoor climate parameters

The following condensed factors were developed:

- Acoustical quality:
  (noisy – quiet; many – few distracting noises; low – high sound absorption).
- olfactory quality:
  (unpleasant – pleasant odours; pleasant-smelling – foul-smelling, high – low olfactory load).
- Lighting conditions:
  (good – bad illumination; light – dark).
- Condition of air:
  (dry – humid air; fresh – stale air).
- Draught / variability of temperature:
  (varying – stable temperature; weak – strong air movement).
- Glare: glaring vs. non-glaring light.

The above mentioned potentially influencing variables were reduced to a few important variables during a logistic regression procedure. The impact of the variables on thermal comfort depends on the type of ventilation and perception of the indoor environment temperature (hot or cold). For each of the important variables so called odds ratios were determined. The odds ratio (OR) describes the change of the chance of feeling uncomfortably cool or warm in dependence on an influence variable [43].

2-4.3 Importance of achieving Thermal Comfort in Buildings

Constant thermal discomfort is likely to lead either to "sick building syndrome" (SBS) or "building related illness" (BRI). The term SBS is used to describe acute health and comfort effects of occupants related to the time spent in a building, without specific illness or cause. The ailment may be localized in a certain room or may be widespread all over the building. On the other hand, the term BRI is used when symptoms of diagnosable illness are identified and can be attributed directly to airborne building contaminants. Problems appear when a building is operated or maintained inconsistently to its original design or prescribed operating procedures [45]. For example, high temperature and high relative humidity jointly serve to reduce thermal comfort and indoor air quality. Poor building design or occupant inconsiderate activities could also lead to indoor air problems [46].

Some of the indicators of SBS include symptoms associated with acute discomfort, (eye, nose, or throat irritation; a headache; dry or itchy skin; a dry cough; difficulty in concentrating; dizziness and nausea; fatigue) and sensitivity to scents. Generally, the cause of the symptoms are unknown. However, most of the people who express these symptoms, report relief soon after leaving the building. On the other hand, indicators of BRI may include symptoms such as chest tightness; a cough; chills; fever, and muscle aches. These symptoms can be clinically determined and have clear causes. It usually takes some time after leaving the building to recover [45].

So far, findings have proved that intellectual, working and observing abilities are showing the most in a pleasant environment. Based on researches conducted in the USA, Kosonen [47] suggested that potential yearly gain due to increased productivity achieved by reduction of respiratory infections could be about 6 to 14 billion of dollars. Furthermore, SBS diseases reduction could increase income from 15 to 38 billion of dollars, while increased working productivity could raise income 20 to 200 billion of dollars. Seppänen [48] found that bad occupancy condition in Finland cause losses around 2,7 billion of Euros. Thus, growing interest among the scientist in finding a relation between establishing thermal comfort in the closed areas and the man's ability to perform work duties is no surprise.

Today, most of the office buildings use mechanical HVAC systems. However, such systems are not capable of providing thermal comfort for all the occupants. Existing literature [49]. provides consistent evidence that sensitivity to hot and cold surfaces declines with age. There is also some evidence of a gradual reduction in the effectiveness of the body in thermoregulation after the age of sixty. Studies [50] have found males report discomfort due to rises in temperature much earlier than females. This is because females prefer higher temperatures in general. Nevertheless, while females are more sensitive to temperatures, males tend to be more sensitive to relative humidity levels.

Providing a comfortable and healthy interior environment is one of the core functions of building energy systems and accounts for about a third of total building energy use. New technologies for heating, cooling, and ventilation not only can achieve large gains in efficiency, but they can improve the way building systems meet occupant needs and preferences by providing greater control, reducing unwanted temperature variations, and improving indoor air quality. Opportunities for improvements fall into the following basic categories:

- Good building design, including passive systems and landscaping
- Improved building envelope, including roofs, walls, and windows
- Improved equipment for heating and cooling air and removing humidity
- Thermal energy storage that can be a part of the building structure or separate equipment
- Improved sensors, control systems, and control algorithms for optimizing system performance.

Both building designs and the selection of equipment depend on the climate where the building operates [51].

2-5 Ventilation and Air Quality in Offices

Many people spend most of their time indoors, and the quality of indoor air has a significant impact on their health and comfort [52]. Inadequate ventilation can make a room stuffy and uncomfortable. Exposure to indoor pollutants such as mold, radon, secondhand smoke, pressed wood products (that may contain formaldehyde), and other materials can lead to health effects, including asthma and lung cancer. Moisture buildups can also lead to structural damage to the building [53].

These problems can be addressed most effectively by minimizing and managing pollutant sources in the building. Problems that remain after steps have been taken to reduce pollutants can be addressed by improved building design and operations, as well as by systems bringing in filtered, outside air and exhausting contaminated interior air [54]. Fresh air may infiltrate the building unintentionally through leaks or through controlled ventilation. Standards typically require different minimum-ventilation rates for different space-use types and occupant densities. Some facilities, such as hospitals and labs, require significantly more fresh air than others [55]. However, increased ventilation increases energy consumption when unconditioned, outside air must be heated or cooled as it replaces conditioned, indoor air that is being exhausted. In 2010, unwanted residential air leaks were responsible for more than two quads of space-heating energy loss and one-half quads of space-cooling energy loss, and more than one quad of commercial heating energy loss [56]. Building codes specify maximum allowed leakage, but detecting leaks can be difficult and expensive, and compliance rates are often poor [57]. New technologies, such as the Acoustic Building Infiltration Measuring System, may improve accuracy and reduce costs [58].

There are many ways to reduce the energy lost in ventilation systems, which include the following:

I. Reduce leaks in building shells and ducts:

While minimizing uncontrolled infiltration is a critical part of building design and construction, locating and fixing leaks in existing buildings presents a greater challenge, especially in commercial buildings where pressurization tests cannot be easily used to measure and locate leaks. DOE research led to the development of material that can be sprayed into existing ducts to seal leaks from the inside [59].

II. Use natural ventilation where possible:

In some climates and at certain times of the year, natural ventilation can be used to introduce fresh air using natural circulation or fans. Good building design, carefully chosen orientation, windows that open, and ridge vents are some of the many strategies that can be used [60]. Economizers are devices that bring in fresh air when appropriate and can reduce cooling loads by 30% when operated by a well-designed control system. Economizer designs that minimize or eliminate failures can be important for efficiency, but a significant fraction of installed economizers may not be operative because of poor maintenance [61]. The next generation of sensors and controls can automate detection and maintenance notification to help address this issue, and economizer designs can be improved to minimize maintenance.

III. Advanced sensor and control systems provide ventilation only where and when it's needed:

Most installed systems implement fixed air-exchange rates as specified by code, but ventilation needs depend upon occupancy, building purpose and internal activities, and other factors (e.g., a hospital). Significant efficiencies could be gained if ventilation systems provided only the fresh air needed to maintain required levels of carbon dioxide (CO_2) and other compounds. Such systems are known as demand-controlled ventilation. Modern systems can use sensors to detect concentrations of CO_2 and other contaminants, and this information can be used to make appropriate adjustments to ventilation rates. However, keeping them in calibration has proven difficult. Good control systems may be able to reduce ventilation-related energy use in residences by as much as 40% [62].

IV. Use efficient, variable speed motors:

Most ventilation systems adjust flow rates only by turning motors off and on or by using dampers. Significant energy savings can be achieved using efficient, variable air volume systems with variable-speed fans along with properly designed and sealed ducts [63]. There are also major opportunities for improving the efficiency and lowering the cost of variable speed motors and motor controls [64]. Innovations that improve the performance and lower the cost of wide bandgap semiconductors are an important part of this work.

V. Use heat and moisture exchange devices:

Even greater energy savings can be achieved by using heat exchangers that allow incoming cool air to be heated by warm building air being exhausted (or the reverse if the building is cooled). Advanced systems can also exchange moisture (i.e., enthalpy exchangers). These systems are discussed in the section on heat pumps.

It has been particularly difficult to get advanced systems into smaller buildings. More than half of buildings larger than 10,000 square feet use economizers and variable air volume systems, but less than 10% of buildings smaller than 10,000 square feet use them [65]. Technologies that are inexpensive and easy to use in smaller buildings would be particularly useful.

2-6 Building Design and Operation

Well-designed buildings, systems, and control strategies can improve comfort levels, increase reliability, and reduce costs by optimizing use of component technologies. Often these low-energy buildings can be built with little or no extra cost. Advanced software that models buildings as integrated systems provides a powerful set of tools for ensuring effective building design and operations. These systems can predict building energy use given a description of its geometry, construction, systems, operations, occupancy, and local weather conditions. Whole-building energy modeling allows architects, engineers, and energy consultants to design a building's envelope, systems, and operation schemes to match its anticipated use profile and local conditions and to maximize energy-efficiency or return on investment while subject to constraints such as first cost. Innovations in the process of construction itself, such as greater use of modular components that could minimize air leaks and other problems associated with site-construction, might make this easier to accomplish.

A 2013 study of 1,112 design projects submitted to the American Institute of Architects 2030 Commitment program shows that buildings designed using energy modeling have a design energy consumption that is 44% lower than the 2003 stock. Buildings designed using prescriptive one-system-at-a-time rules outperform stock by only 29% [66].

Unfortunately, only 55% of commercial building projects used modeling anywhere in the design process, including for either code compliance or green certification after the design had been finalized. However, thanks in part to DOE investments in the open-source modeling engine Energy Plus and in the testing and long-term support for the validation of energy simulation engines, whole-building energy modeling has become more capable, robust, and consistent. DOE's open-source energy simulation software development platform Open Studio is helping make energy modeling easier to use [67]. Nevertheless, more work remains to be done.

Integrative design must also fit gracefully into existing relationships between owners, architects, engineers, and other stakeholders.

In addition to supporting system-level design, whole-building energy modeling can also be used to maintain, diagnose, and improve building energy performance during occupancy. Comparing modeled operations to actual operations supports detection and diagnosis of equipment and control faults, and, more generally, any divergences from design intent. Model-predictive control uses energy modeling, as well as real-time weather forecasts and (price) signals from the grid to tailor short-term control strategies for energy reduction, peak demand reduction, or other objectives energy reductions of 15%–40% have been demonstrated [68]. Energy models can act as an intelligent interface for a building's on-site generation, energy storage, and thermal storage capabilities, and can be an integral part of systems that provide services to the utility grid.

The actual impact of building technologies depends on how they are used by building occupants and operators, purchasing decisions, and many other factors that depend on aspects of human decision making. Building systems must be designed with the clearest possible understanding of user needs and preferences and the way they choose to interact with the technology [69] [70].

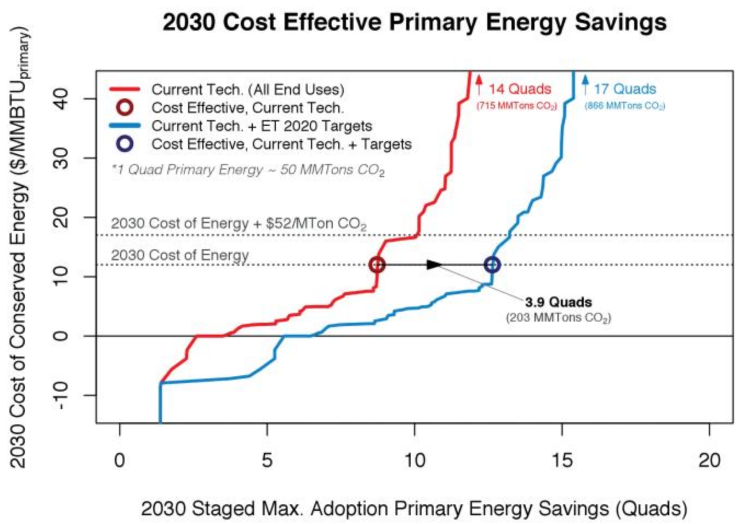


Figure 7: The red "Current Tech" curve shows the costs of efficiency measures now on the market. All the measures below the "2030 cost of energy" line—roughly nine quads—could be saved if all cost-effective measures were purchased.118 This would reduce building consumption by about 23%. If the 2020 goals described, (Source: EIA Annual Energy Outlook 2014).

2-7 Retrofitting of Existing Commercial Buildings

"Periodically throughout history a gaping divergence occurs between what societies know to be the visual reality of their cities and what they hold as the visual ideal of what their cities should look like" – Thayer and Richman (1984:192-193)

Although it is most cost effective to implement the principles of sustainable design in the "Design and Build Phase" (Civil Engineering 2009), an existing building can be retrofitted in order to improve its energy efficiency, thereby holistically making it in total a more sustainable building. It can be said that a city is largely identified and defined by its skyline, which gives it its distinct character. Existing buildings largely make up this character. These buildings, although the primary asset of any city, can also expend a significant amount of resources, such as energy. Retrofitting these buildings can aid in relieving the high demand on resources.

Retrofitting is an exercise that involves altering some physical aspect of the existing building. Although a building can be retrofitted in order to improve several aspects relating to the building, this research paper will only focus of the energy aspect of a retrofit.

Investment into retrofitting a building in order to improve its overall energy efficiency does come with an obvious capital cost and associated risk, and although there is currently a huge worldwide drive towards more sustainable construction, these costs cannot be ignored. In the 2005 RICS Green Value Report, Chris Corps was quoted saying: "*Change is not easy. But to all the developers, investors, owners, lenders, appraisers, valuers, agents and especially occupiers, the conclusion is that you ignore green buildings at your cost. Green buildings can provide financial benefit*".

The associated benefits relating to a new build are somewhat different to those associated with an existing retrofitted building. When designing a new building one has the distinct advantage of being able to look holistically at the overall performance of the building, designing it in order to work efficiently, with one element complimenting the next. However, when retrofitting existing buildings, the focus generally shifts to energy (cost) saving initiatives [71], as this is seen to be an area which will result in the highest possible associated financial saving which will justify the capital spent.

2-7.1 Process of Retrofitting an Existing Building

The process of retrofitting does not simply involve converting the building to be more efficient. In order to effectively carry out an energy retrofitting it is important that the following guidelines be adhered to in order to achieve maximum results:

I. *Assessment of the building*: This can also be referred to as an energy audit. This involves baselining the buildings performance. This is done in order to understand the starting point.
II. *Planning:* A proper understanding of the asset / building is required - what is the intended primary use of the building going forward.
III. *Implementation of the change*.
IV. *Measurement of performance*: It is important that the improved results be measured, so that the market executives or internal stakeholders can understand that the initial capital outlay did result in the objective of a reduction in operating costs being achieved.

2-7.2 Behavior Change

Although it is important to identify the cost of a retrofit, one needs to be aware that simply retrofitting a building will not result in the most effective reduction in energy consumption. The most effective reduction in energy consumption will only be achieved if / when the behavior of the occupants of that building changes.

Behavior change, although an intangible measurable, can have a significant impact on the ultimate success on an energy retrofit [72].

Fulford (2011), pointed out that there are three elements that one will need to address when implementing an energy retrofit:

I. Gain an understanding of the issues and behavior of occupants.
II. Communicate the impact of changes to occupants of buildings.
III. Focus on collaboration (ie) “a carbon reduction programmed is an opportunity to create a positive partnership between property managers and occupants where all parties are helping to achieve a common goal”.

2-7.3 Energy Audits

When embarking on an energy retrofit exercise it is important that goals be established. One will need to first establish the current energy efficiency and current system performance. It is important to note that only ten percent of the energy consumed by an incandescent light bulb provides light, while the remaining 90% is released as heat, which will result in the building requiring additional cooling of up to 30%.

An energy audit can help to establish how much, and where most of the energy is being consumed. An energy audit can be defined as “an investigation of building energy use and identification of efficiency and cost reduction opportunities”.

Energy audits are usually conducted in the following manner:

I. Collect and analyze historical energy usage data.
II. Establish an energy breakdown framework for potential energy savings.
III. Review building documentation.
IV. Assess equipment.
V. Estimate cost / savings for each energy efficient measure.

(The above measure complies with those set out by ASHRAE Level 1).

An energy audit is a very useful tool for existing commercial buildings; however, it is also important to ensure that buildings are properly commissioned.

2-7.3.1 Commissioning of Existing Buildings

Commissioning is an up-front cost where a commissioning agent verifies that a building’s systems are performing correctly before occupancy. Commissioning can also be defined as a verification that the buildings energy related systems are installed, calibrated and perform according to the intended design and are based on construction documents.

The commissioning exercise will aid in exposing equipment problems early on, usually before one-year warranties are up, thus preventing long-term unknown problems for the life of the building. In return, the expenditure here ultimately results in savings and utility and maintenance costs during building operation (South face. “Lifecycle Economics”). Some people recommend that an ‘annual audit’ be conducted every quarter, for the first year, after a building has been retrofitted in order to ensure that one is deriving the maximum benefit from the retrofit exercise.

New construction commissioning is somewhat different to commissioning an existing building. When commissioning a new build, one can focus on the design and deliverables and make “performance” a priority, focusing on aspects such as thermal comfort and energy efficiency. Commissioning of an existing building is different as it involves identifying existing “defects” within the building that are preventing it from performing at an optimal level [71]. It is prudent from a financial point of view, to approach a retrofit in an open-minded manner, focusing on the buildings, and upgrading it at a single point in time [73].

Historically commissioning of buildings has proven to improve a buildings' energy efficiency, and as a result lower the associated operating costs [74]. When considering the decision to retrofit a building, consumers are often focused on a single aspect, and often fail to examine the building in its entirely. This is required in order to achieve the inevitable goal of lowering operating costs in the most cost-effective manner [73].

There are a significant number of spins off benefits, or rather non-energy related benefits that can be achieved via the retrofitting process. These benefits are however often overlooked as a result of the increased associated capital cost [73]. The energy and non-energy benefits associated with energy efficient technology are discussed further below.

2-7.3.2 Energy and Non-energy Benefits

Energy-efficiency advocates argue that there are several non-energy related benefits that can be derived from the utilization of energy efficient technology. It is often argued that the social benefits associated include things such as: increased productivity and employment; and improved comfort and public health [75]. Although hard to prove, it is also argued by many that these associated benefits can sometimes outweigh the direct financial benefit gained.

I. Improved indoor air quality and comfort

A study completed in the United States of America revealed that approximately 90% of the average Americans day is spent indoors. It is therefore imperative that the quality of indoor air be maintained at a superior level. One can improve the indoor air by examining and improving: air-conditioning systems, lighting levels, examine types of cleaning materials utilized within the building.

Non-energy benefits include better airflow which could help to improve employee health, and as a result productivity. When one examines the cost of salary, and improved productivity in relation to the savings in energy it is very apparent that the non-energy benefits out way that of the cost of energy saved [76].

An article published in the '*Existing buildings survival strategy*' journal, listed the following advantages of retrofitting a building:

- Value adding.
- Advantageous when you have acquired an undervalued property.
- Makes portfolio work hard.
- Aids in complying with recent / upcoming legislation.
- Reinforces / strengthens brand reputation.
- Improves corporate / social responsibility.
- Adapts building portfolio to climate changes where they are occurring.
- Carbon disclosure and carbon constraints are becoming unavoidable.
- Differentiate portfolio against competition.
- Prevent building from being unnecessarily vulnerable to utility blackouts and increases severe weather events.

Although there may be a significant amount of energy efficiency advantages associated with energy retrofitting, these advantages may not necessarily be translated into an economic efficiency advantage. It is important that in achieving energy efficiency the goal of economic efficiency is also achieved.

2-8 Conclusion

The construction sector is one of the most important economic sectors worldwide. So, that the energy consumption for this sector is high as the energy use for the building is driven by the population, building size, service demand (lighting, electronics, process loads and air condition systems).

As the commercial sector is more than heterogeneous than residential buildings. Increasing living standards for living increase using of air condition systems and that increase the energy consumption, as one of the main percentages of the energy consumption is the cooling energy demand. Cooling methods in general can be categorized in two major groups (Active cooling methods and Passive cooling methods). There are some problems for using air condition systems behind it increasing the beak electricity load, problems associated with the ozone depletion and global warming and indoor air quality problems.

Using the natural ventilation techniques and thermal comfort techniques decreasing the total, energy consumption and poor building design or occupant inconsiderate activities could also lead to indoor air problems, so it is important to take the way of retrofitting the old buildings.

Investment into retrofitting a building in order to improve its overall energy efficiency, and although there is currently a huge worldwide drive towards more sustainable construction, so, an existing building can be retrofitted in order to improve its energy efficiency,

CHAPTER THREE

Passive Cooling

3-1 Introduction

There has been a drastic increase in the use of air conditioning system for cooling the buildings all around the world. There is energy crisis in developing countries especially during summer season primarily due to cooling load requirements of buildings. Increasing consumption of energy has led to environmental pollution resulting in global warming and ozone layer depletion. Passive cooling systems use non-mechanical methods to maintain a comfortable indoor temperature and are a key factor in mitigating the impact of buildings on the environment. Passive cooling techniques can reduce the peak cooling load in buildings, thus reducing the size of the air conditioning equipment and the period for which it is generally required [77].

In Europe, commercial buildings have experienced an uptrend in cooling demand over the last few decades. An increase in internal loads coupled with higher solar gains — especially in modern, highly glazed buildings — has fed the demand for air-conditioning systems, even in moderate and cold climates such as in Central or Northern Europe. Additionally, increased comfort expectations in summertime and the gradual warming of our climate are pushing up the cooling demand. While the heating requirement can be effectively reduced by installing thermal insulation, cooling plays a more significant role in the overall energy demand of buildings [78] [79].

Before the advent of mechanical refrigeration, ingenious use was made of the many means of cooling (e.g. damp cloths hung in draughts created by the connective stack effect in buildings). So, dwellings and lifestyles were developed to make best possible use of these sources of cooling. The introduction of mechanical refrigeration permitted not only the ability to increase the likelihood of achieving complete thermal comfort for more extended periods, but also a great deal of flexibility in building design, and simultaneously led to changes in lifestyle and work habits. However, increasingly, the use of a 'higher technology' resulted in natural-cooling techniques being ignored. Now with the growing realization of the rapid depletion of non-renewable energy sources and of the adverse environmental impacts of fossil-fuel dissipating processes, it is accepted that it is foolish to continue consuming vast amounts of non-renewable fuels for the air-conditioning of buildings.

When our ancestors achieved thermal comfort by natural means [80]. Hence to reduce the emission of greenhouse gases, caused by fossil fuels to power the cooling requirement of the buildings has stimulated the interest towards adoption of passive cooling techniques for buildings. discusses in detail various passive cooling techniques with a special focus on solar shading techniques, as they are most economical and thus most suitable for houses in developing countries.

3-2 Passive Cooling

3-2.1 Passive Cooling Description

A ‘passive’ solar design involves the use of natural processes for heating or cooling to achieve balanced interior conditions. The flow of energy in passive design is by natural means: (radiation, conduction, or convection), without using any electrical device. Maintaining a comfortable environment within a building in a hot climate relies on reducing the rate of heat gains into the building and encouraging the removal of excess heat from the building. To prevent

heat from entering the building or to remove once it has entered is the underlying principle for accomplishing cooling in passive cooling concepts.
This depends on two conditions:
- The availability of a heat sink which is at a lower temperature than indoor air.
- The promotion of heat transfer towards the sink.

Environmental heat sinks are:

- Outdoor air (heat transfer mainly by convection through openings)
- Water (heat transfer by evaporation inside and / or outside the building envelope)
- The (night) sky (heat transfer by long wave radiation through the roof and/or other surface adjacent to a building.
- Ground (heat transfer by conduction through the building envelope) [81].

3-2.2 Passive Cooling Preventatives

3-2.2.1 Climatic Cooling Potential

Degree-days or degree-hours methods are often used to characterize a climate's impact on the thermal behavior of a building. The climatic potential for ventilate cooling, *CCP*, is defined as the sum of degree-hours for the difference between building and external air temperature. As a certain temperature difference is needed for effective convection, night ventilation is only applied if the difference between building temperature.

3-2.2.2 Building Temperature

As heat gains and night-time ventilation are not simultaneous, energy storage is an integral part of the concept. In the case of sensible energy storage, this is associated with a variable temperature of the building structure. The maximum building temperature occurs at the initial time of night ventilation and, given a ventilation time of 12 hours, the minimum building temperature occurs at the final time [82] [83].

3-2.2.3 Climatic data

Hourly air temperature data are needed to analyses the climatic potential for the passive cooling of buildings by ventilation using the presented approach [84]. Hourly air temperature data are generated based on measured long-term monthly mean values. For analysis of the climatic cooling potential in Europe, data were selected from 259 meteorological stations at densely populated locations. The solar and internal gains of an office space can vary substantially depending on the local climate, orientation and total solar energy transmittance of the façade, building geometry and type of building [85].

3-2.2.4 Building Orientation

Building orientation refers to the way a building is situated on a site and the positioning of windows, rooflines, and other features. A building oriented for solar design takes advantage of passive and active solar strategies. Passive solar strategies use energy from the sun to heat and illuminate buildings. Building orientation and building materials also facilitate temperature moderation and natural daylighting. Active solar systems use solar collectors and additional electricity to power pumps or fans to distribute the sun's energy. Heat is absorbed and transferred to another location for immediate heating or for storage for use later. Water, antifreeze or sometimes air circulates to transfer heat [86]. Unlike active solar strategies, a passive design does not involve the use of mechanical and electrical devices, such as pumps, fans, or electrical controls [87].

Passive cooling techniques can reduce the peak cooling load in buildings, thus reducing the size of the air conditioning equipment and the period for which it is generally required. The important cooling techniques will be discussed in detail [81].

3-3 Passive Cooling Techniques in Buildings

3-3.1 Solar Shading

Among all other solar passive cooling techniques solar shading is relevant to thermal cooling of buildings especially in a developing country owing to their cost effectiveness and easy to implement. Rural India and developing countries in Middle east region have witnessed a steep rise masonry house with RCC roofs. However, the availability of electric power in the villages especially during summer is limited. These RCC roofs tend to make the indoor temperature very high around 41°C: This is due to high roof top temperature of around 65°C in arid regions. Solar shading with locally available materials like terracotta tiles, hay, inverted earthen pots, date palm branches etc. can reduce this temperature significantly.

Shading with tree reduces ambient temperature near outer wall by 2°C to 2.5°C. On an average a depression of six degree centigrade in room temperature has been observed when solar shading techniques are adopted [81]. Kumar, Garg and Kaushik evaluated the performance of solar passive cooling techniques such as solar shading, insulation of building components and air exchange rate. In their study they found that a decrease in the indoor temperature by about 2.5°C to 4.5°C is noticed for solar shading. Results modified with insulation and controlled air exchange rate showed a further decrease of 4.4°C to 6.8°C in room temperature. The analysis suggested that solar shading is quite useful to development of passive cooling system to maintain indoor room air temperature lower than the conventional building without shade [88].

3-3.1.1 Shading by overhangs, louvers and awnings etc.

Well-designed sun control and shading devices, either as parts of a building or separately placed from a building facade, can dramatically reduce building peak heat gain and cooling requirements and improve the natural lighting quality of building interiors. The design of effective shading devices will depend on the solar orientation of a building facade. For example, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high.

However, the same horizontal device is ineffective at blocking low afternoon sun from entering west-facing windows during peak heat gain periods in the summer. (Fig. 8) shows the different types of shading devices.

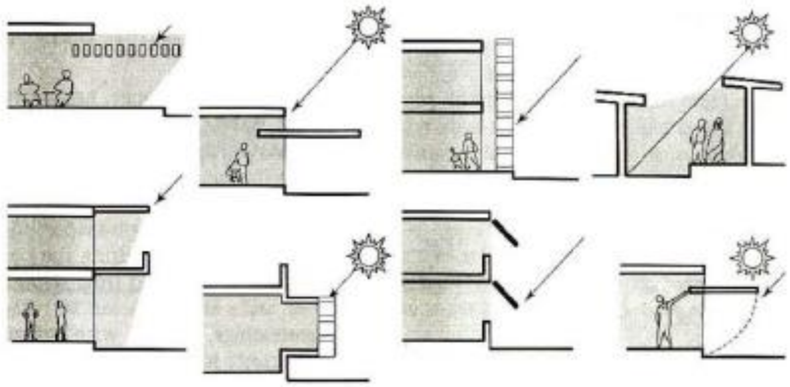


Figure 8: Different types of Shading devices, (Source: [89]).

3-3.1.2 Shading of Roof

Shading the roof is a very important method of reducing heat gain. Roofs can be shaded by providing roof cover of concrete or plants or canvas or earthen pots etc. Shading provided by external means should not interfere with night-time cooling. A cover over the roof, made of concrete or galvanized iron sheets, provides protection from direct radiation. Disadvantage of this system is that it does not permit escaping of heat to the sky at night-time (Fig. 9).

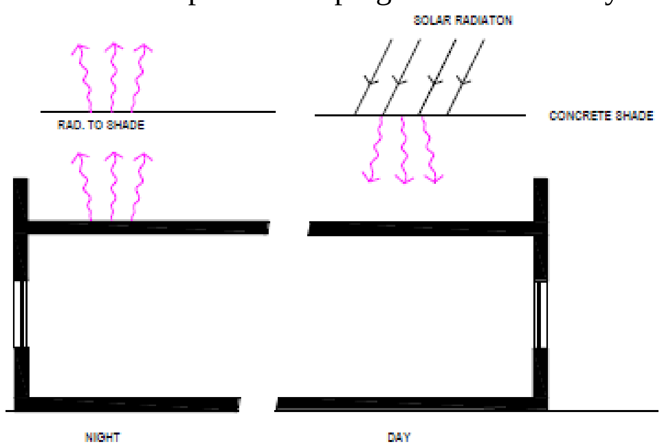


Figure 9: Roof Shading by Solid cover, (Source: [89]).

A cover of deciduous plants and creepers is a better alternative. Evaporation from the leaf surfaces brings down the temperature of the roof to a level than that of the daytime air temperature. At night, it is even lower than the sky temperature (Fig10).

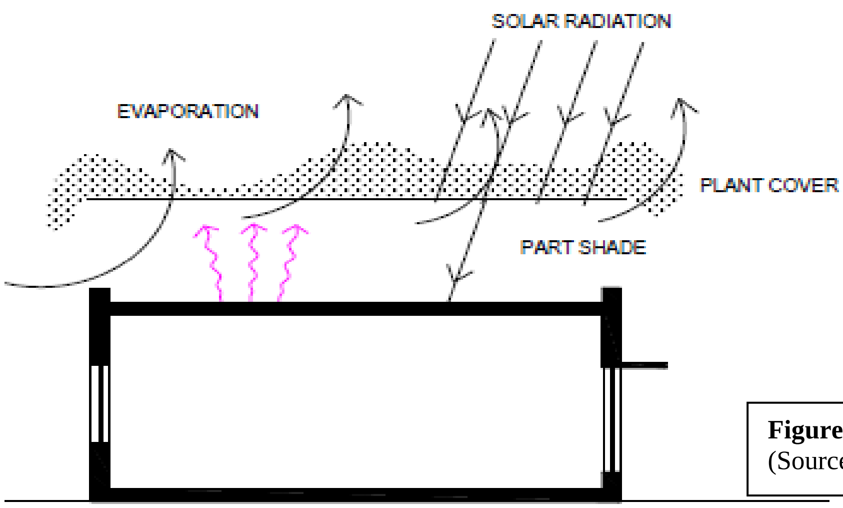


Figure 10: Roof Shading by Plant cover, (Source: [89]).

Covering of the entire surface area with the closely packed inverted earthen pots, as was being done in traditional buildings, increases the surface area for radiative emission. Insulating cover over the roof impedes heat flow into the building. However, it renders the roof unusable and maintenance difficult (Fig. 11). Broken china mosaic or ceramic tiles can also be used as topmost layer in roof for reflection of incident radiation.

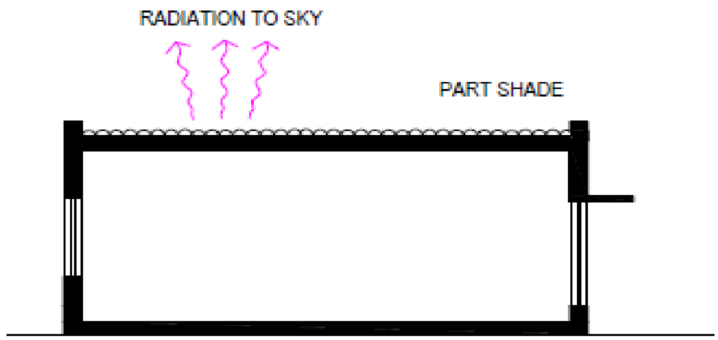


Figure 11: Roof Shading by Earthen pots, (Source: [89]).

Another inexpensive and effective device is a removable canvas cover mounted close to the roof. During daytime it prevents entry of heat and its removal at night, radiative cooling. (Fig. 12) shows the working principle of removable roof shades. Painting of the canvas white minimizes the radiative and conductive heat gain [89].

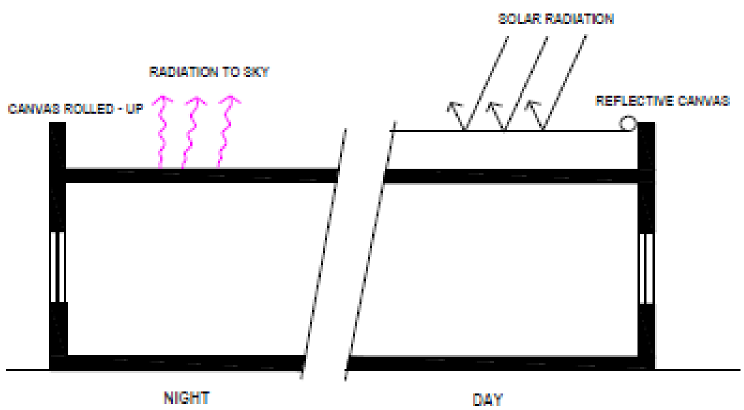


Figure 12: Removable roof shades, (Source: [89]).

3-3.1.3 Shading by Trees and Vegetation

Proper Landscaping can be one of the important factors for energy conservation in buildings. Vegetation and trees, very effectively shade and reduce heat gain. Trees can be used with advantage to shade roof, walls and windows. Shading and evapotranspiration (the process by which a plant actively release water vapor) from trees can reduce surrounding air temperatures as much as 5°C. Different types of plants (trees, shrubs, vines) can be selected based on their growth habit (tall, low, dense, light permeable) to provide the desired degree of shading for various window orientations and situations. The following points should be considered for summer shading [90]:

1. Deciduous trees and shrubs provide summer shade yet allow winter access. The best locations for deciduous trees are on the south and southwest side of the building. When these trees drop their leaves in the winter, sunlight can reach inside to heat the interiors.

2. Trees with heavy foliage are very effective in obstructing the sun's rays and casting a dense shadow. Dense shade is cooler than filtered sunlight. High branching canopy trees can be used to shade the roof, walls and windows.

3. Evergreen trees on the south and west sides afford the best protection from the setting summer sun and cold winter winds.

4. Vertical shading is best for east and west walls and windows in summer, to protect from intense sun at low angles, e.g. screening by dense shrubs, trees, deciduous vines supported on a frame, shrubs used in combination with trees.

5. Shading and insulation for walls can be provided by plants that adhere to the wall, such as English ivy, or by plants supported by the wall, such as jasmine.

6. Horizontal shading is best for south-facing windows, e.g. deciduous vines (which lose foliage in the winter) such as ornamental grape or wisteria can be grown over a pergola for summer shading.

3-3.1.4 Shading by Textured Surfaces

Surface shading can be provided as an integral part of the building element also. Highly textured walls have a portion of their surface in shade. The increased surface area of such a wall results in an increased outer surface coefficient, which permits the sunlit surface to stay cooler as well as to cool down faster at night (Fig. 13) [91].

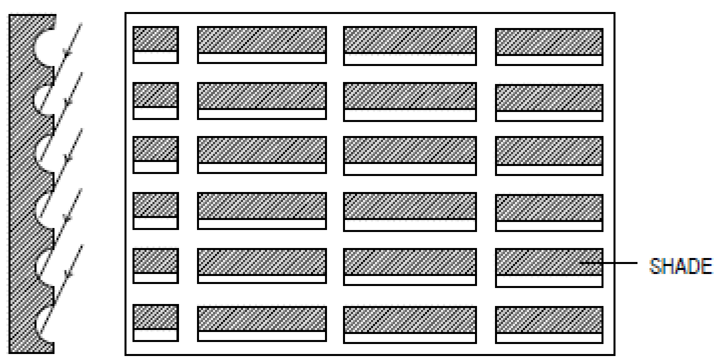


Figure 13: Shading due to surface texture, (Source: [91]).

3-3.2 Induced ventilation techniques

3-3.2.1 Solar Chimney

A solar chimney is a modern device that induces natural ventilation by the thermal-buoyancy effect. The structure of the chimney absorbs solar energy during the day, thereby heating the enclosed air within and causing it to rise. Thus, air is drawn from the building into an open near the bottom of the chimney. The air exhausted from the house, through the chimney, is replaced by ambient air. However, if the latter is warmer than the air inside the house, as it usually is during the day in hot climates, the continued use of the solar chimney will then begin to heat the structure of the building previously cooled overnight [92]. The solar chimney is used to exhaust hot air from the building at a quick rate, thus improving the cooling potential of incoming air from other openings. Thus, solar chimneys having a relatively low construction cost, can move air without the need for the expenditure of conventional forms of energy, and can help achieve comfort by cooling the building structure at night. They can also improve the comfort of the inhabitants during the day if they are combined with an evaporative-cooling device [93].

3-3.2.2 Trombe Wall

Trombe walls are mainly suited for sunny climates that have high day-night temperature swings. Today small-scale energy efficient buildings are developed on an ancient technique that incorporates a thermal mass and efficient delivery system called Trombe wall which continues to serve as an effective feature of passive solar design. The essential idea was first investigated by Edward S. Morse and patented by him in the year 1881. In the late 1960s it was fully developed and recognized as a sustainable architectural element by French engineer named Felix Trombe. Good thermal comfort can be created reasonably in the building with such a system (Trombe Wall) [94]. Many analytical and experimental researches have been done on the heat transfer, warmth mechanism, dynamics and performance analysis of Trombe wall [95].

Trombe wall is an “indirect-gain” system which works on the basic greenhouse principle that heat from the sun in the form of “shorter-wavelength & higher-energy U.V radiation” passes through glass panel in front of the wall and is absorbed by the wall. The air in between the wall and glass is heated through conduction. As air is heated, it passes through the top vent heating the room through convection and at the same time, the cold air is drawn in through the bottom vent heated by the sun and rises again. This creates a cycle of warm air flow. TRNSYS software is used for modeling of building having Trombe walls [96][97]. Trombe wall work differently in summers and winters as described below:

I. Trombe walls in the summer: In the summer season, the wall is shaded by the overhang and does not receive direct sunlight. When a Trombe wall is sheltered, it will remain cool and its intrinsic qualities will absorb heat to keep the rest of the place cooler. The immanent materials in such walls are responsible for gradual heat absorption and transfer. The overhang area blocks the summer sun from hitting the Trombe Wall. Objects within the thermal mass can be taken as heat batteries.

II. Trombe walls in the winter: In the winter, when the sunlight hits the wall, the wall gets „charged‟ up to warm the house by transferring the sun’s heat inside. The thermal mass in the Trombe wall will gradually boost as it absorbs heat energy, and then will gently release it. In winters, when the surrounding ambient air temperature drops in the night, the thermal mass will extend to release its stored heat energy which would help the construction to stay relatively warm after the sunset for a longer period. After liberating all the heat, it will be ready once again to absorb the heat next day. Working of Trombe wall is shown in (Fig. 14) [96].

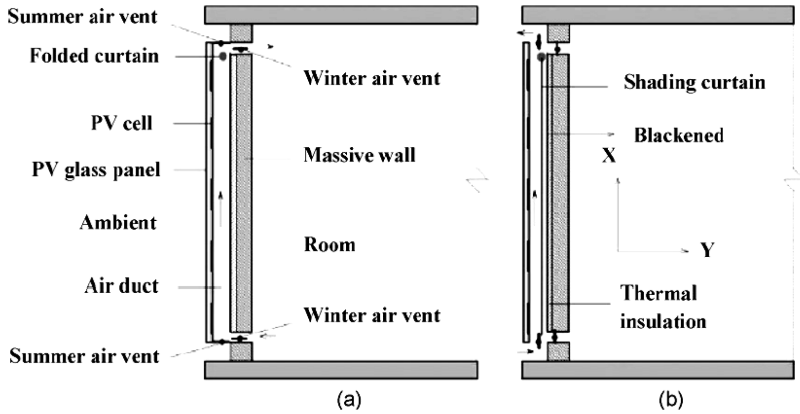


Figure 14: Trombe wall (a) Winter heating and (b) Summer cooling, (Source: [96]).

3-3.2.3 Air Vents

The shape of a building together with the location of the ventilation openings dictate the natural ventilation's manner of operation. One usually differentiates between three different ventilation principles for natural ventilation: [98] [99].

I. Single-sided ventilation

Single sided ventilation relies on opening(s) on only one side of the ventilated enclosure. Fresh air enters the room through the same side as used air is exhausted. A typical example is the rooms of a cellular building with openable windows on one side and closed internal doors on the other side. With a single ventilation opening in the room, the main driving force in summer is wind turbulence. In cases where ventilation openings are provided at different heights within the façade, the ventilation rate can be enhanced by the buoyancy effect. The contribution from thermal buoyancy depends on the temperature difference between the inside and the outside, the vertical distance between the openings, and the area of the openings. The greater vertical distance between the openings, and the greater temperature difference between the inside and the outside, the stronger is the effect of the buoyancy. Compared with other strategies, lower ventilation rates are generated, and the ventilation air does not penetrate so far into the space.

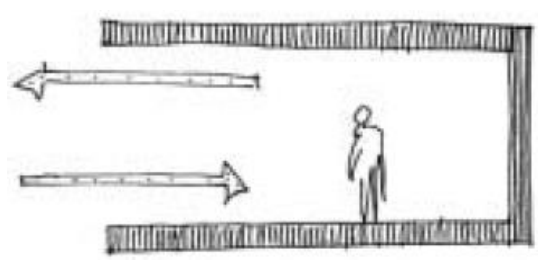


Figure 15: Sketch of Single sided ventilation. As a rule of thumb, single-sided ventilation is effective to a depth of about 2-2.5 times the floor to ceiling height, (Source: [98]).

II. Cross-ventilation

Cross-ventilation is the case when air flows between two sides of a building envelope by means of wind-induced pressure differentials between the two sides. The ventilation air enters and leaves commonly through windows, hatches or grills integrated in the façades. The ventilation air moves from the windward side to the leeward side. A typical example is an open-plan office landscape where the space stretches across the whole depth of the building. The airflow can also pass through several rooms through open doors or overflow grills. The term cross ventilation is also referred to when considering a single space where air enters one side of the space and leaves from the opposite side. In this case the ventilation principle on the system level can be either cross- or stack ventilation. As the air moves across an occupied space, it picks up heat and pollutants. Consequently, there is a limit to the depth of a space that can be effectively cross-ventilated.

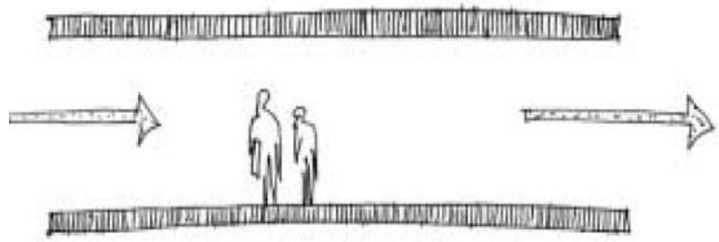


Figure 16: Sketch of Cross ventilation. As a rule of thumb, cross-ventilation is effective up to 5 times the floor to ceiling height, (Source: [98]).

III. Stack-ventilation

Stack ventilation occurs where the driving forces promote an outflow from the building, thereby drawing fresh air in via ventilation openings at a lower level. Fresh air typically enters through ventilation openings at a low level, while used and contaminated air is exhausted through high level ventilation openings (a reversed flow can occur during certain conditions). Designing the outlet to be in a region of wind-induced under pressure can enhance the effectiveness of stack ventilation. A typical example is a building with an elevated central part, in which warm and contaminated air from the surrounding spaces rises to be exhausted through wind towers located on the roof.

Due to its physical nature, the stack effect requires a certain height between the inlet and the outlet. This can be achieved by e.g. increasing the floor to ceiling height, tilting the profile of the roof, or applying a chimney or an atrium. By its nature, stack ventilation resembles cross ventilation as far as some individual spaces are concerned, in that air enters one side of the space and leaves from the opposite side [98]. The air may flow across the whole width of the building and be exhausted via a chimney, or it may flow from the edges to the middle to be exhausted via a central chimney or atrium.

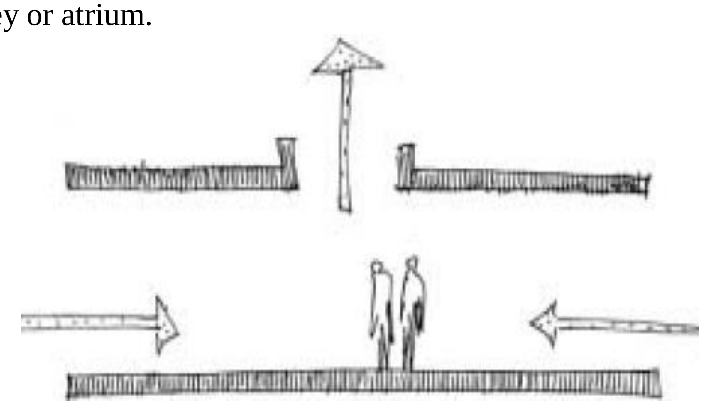


Figure 17: Sketch of Stack ventilation. As a rule of thumb, stack ventilation is effective across a width of 5 times the floor to ceiling height from the inlet to where the air is exhausted, (Source: [98]).

3-3.2.4 Wind Tower

In a wind tower, the hot ambient air enters the tower through the openings in the tower, gets cooled, and thus becomes heavier and sinks down. The inlet and outlet of rooms induce cool air movement. When an inlet is provided to the rooms with an outlet on the other side, there is a draft of cool air. It resembles a chimney, with one end in the basement or lower floor and the other on the roof. The top part is divided into several vertical air spaces ending in the openings in the sides of the tower (Fig. 18). In the presence of wind, air is cooled more effectively and flows faster down the tower and into the living area. The system works effectively in hot and dry climates where diurnal variations are high [100].

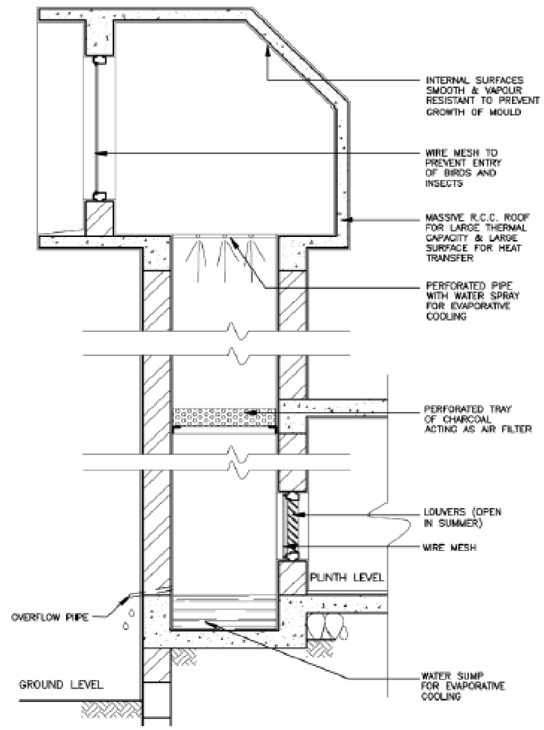


Figure 18: Section showing detail of a wind tower, (Source:[100]).

The wind tower, also called wind catcher is a traditional passive cooling technique of buildings, existed hundreds of years ago in the Middle East and Iran, known as "Burj al hawaa" i.e. the air tower. Basic structure of a wind tower is illustrated above. A capped tower with one face opening or multi-face openings at the top of tower, the tower is placed on the roof of a dwelling. Wind towers/catchers could be divided according airflow patterns inside the tower into downward airflow towers and upward airflow towers.

Downward airflow wind tower, also called "Passive downdraught tower (PDEC)", is driven by pressure difference between windward side and leeward sides of the tower. The tower catches the ambient air which enters at top of the tower and flow through it to the building providing fresh air. Water could be introduced into the tower geometry by several means i.e. water pool at bottom of tower, porous jars filled with water located in the tower airstream or wetted pads hanged at the top of the tower.

Upward airflow wind tower is driven by temperature difference between building interior and the outside environment. In this system, the air is drawn upwards via wind tower. Because of positive pressure on one sides of the building the hot air could be drown down via underground channels or water fountains before entering to the building as cooled air, while the hot interior air rises upward via the openings of the wind tower [101] [102].

3-3.3 Radiative Cooling

During the summer months, the absorption of solar energy by the buildings increases the required cooling load significantly. In warmer zones, and in Mediterranean countries, air conditioning applications are becoming more common with every passing year, with their sizable negative impact on energy use. A possible solution to this problem is the radiative cooling of the building surfaces and façades. This requires tailoring of the radiative properties of surfaces to decrease or increase their natural ability to absorb, emit, or reflect radiant energy. It is favorable to have the utmost emission from the surface with the highest reflection of solar energy and that is for situations where a surface is to be kept cool while exposed to the sun [103]. Towards this goal, we would like to list environmentally friendly, sustainable building materials that can also be used for Façades. Note that the Earth's atmosphere is relatively transparent between the wavelength of 8-13 am; therefore, buildings emitting this is called as 'transparency window for electromagnetic waves'. This window allows the radiation emitted by the earth to escape to space with no absorption within the atmosphere. This spectral energy loss, versus the radiation absorbed by the Earth is the reason for the atmospheric radiation cooling. If a building surface emits mostly in this window, then the building can be cooled effectively as well.

For daytime cooling, one must also consider solar absorption. In daytime radiative cooling to achieve an equilibrium temperature below the ambient, it is desirable to have better than 88% reflection of solar radiation, but coating or painting an object with a strong solar reflector significantly mutate its color, which may not be desired [104]. By manufacturing a surface that had an absorptivity large in the spectral region of short wavelengths about the peak solar energy, but small in the spectral region of longer wavelengths where the peak surface emission would occur, it might be possible to absorb almost as a blackbody while emitting very little energy that such surfaces are called "spectrally selective". Spectrally selective surfaces can also be useful where it is required to cool an object exposed to incident radiation from any high-temperature source. These situations are objects subjected to the sun, such as the roof of a building [103]. Here, we focus only selective building materials, although briefly mention other applications as well.

3-3.3.1 Base Materials

A material which is used on a building Façades might be designed with a surface that emits forcedly in preferable spectrum, while decreasing emission into unfavorable spectra [103]. Rare Earth metals are as selective emitters because they have high absorption in the infrared region [105] [106] [107]. Composition of these metals with ceramic materials like Titania is the perfect case but the problem is that, at high temperatures, emission from other constituents dominate these metals [108]. In (Table 1), we list the base materials that have been reported for radiative cooling in the literature.

Name	Advantage
Silicon	Having small absorption coefficient over thermal wavelengths.
α-quartz	Having two phonon polariton resonances. Being transparent over visible wavelengths. Having high emissivity in the atmospheric transparency window.
ZnS	Being mechanically strong. Being more transparent in atmospheric window in practical thickness. Not being able to damage by solar ultraviolet.
PPO (polyphonyoxide) resin	modified black polyphenylenoxid (PPO) resin can maintain the exposure to humidity and temperatures over 100°C.
Silicon Oxynitride	Absorption band principally declines within the atmospheric window and it can be modified from the SiO_2 absorption band to the Si_3N_4 one as a function of the chemical composition.
CdS	Having high IR band transmittance (0.80) and low IR band reflectance (below 0.02) across the atmospheric window.

Table1: Base Materials used for radiative cooling application, Source: ([109] [110] [111] [112] [113] [114]).

Volcanic soil and deposits have potential to be used as construction materials. Volcanoes helps cooling off the earth removing heat from its interior, and during their eruption send huge amounts of rocks and other sandy objects to the surface. These materials form porous structures by cooling off, which are extensively used as the building materials, due to their desired low-conductance properties. Among them, basalt and diabase are used for crushed stone: roofing granules. The other ones are pumice, volcanic ash and perlite. In ancient days, within the territories of the Roman Empire, pumice and volcanic ash were considered to make cement. In current days, pumice and volcanic ash are mixed to make cement for large construction projects, like dams. As expected, this is more common in places where volcanic activity has been significant, like in California and Oklahoma in the USA, Southern Italy and Sicily, as well as in Central and Eastern Turkey. However, they continue to be used as lightweight aggregate in concrete, especially precast concrete blocks. Another example of alternative building material, is pozzolans that is mainly used in Uganda, based on the abundant volcanic ashes in that area. Pozzolans will be cementitious by activating with cement or lime and when they transformed to pozzolan cement, they may be used to produce wall panels, blocks, and produce binders to manufacture a cheap alternative building and will decrease the cost of the buildings in Uganda [115].

3-3.3.2 Paints

Paints are coatings on surfaces with zero transparency and they are the composition of pigment plus resin [107]. In radiative cooling applications, highly reflective paints are favorable; however, high absorption or emission are also important, therefore, the pigment must have high absorptivity [106]. Pigments are metal oxides and semiconductors. Carbon [116], FeOx [117], Melanin (natural pigment) [118], Zn powder[119], Silicon [104] [120], PbS [121], Organic soot [122] [123], TiO2 [124] and FeMnOx (best for solar thermal because of high absorption) [125], are the examples of pigments that might be used for radiative cooling. The design and structure of these paints are considered in two-layer structures of TSSS paints (thickness sensitive spectrally selective) on the top and infrared selective metal in the bottom [126] [127].

In one study, Baneshi et al. [128] presented a new optimization method in designing pigmented coatings that it was considered both thermal and aesthetic effects and controlling the material, size and concentration of pigment particles was the advantage of their optimization. Cupric oxide (CuO) and cuprous oxide (Cu2O) were considered
and results showed that cupric oxide had much better efficiency in this case rather than cuprous oxide and titanium dioxide. However, for many applications, TiO2 is considered as the most appropriate filling material for radiative cooling [124].

3-3.3.3 Roof Cool Paintings

Building roofs play a very important role in the energy balance of buildings, especially in summer, when they are hit by a rather high solar irradiance. Depending on the type of finishing layer, roofs can absorb a great amount of heat and reach quite high temperatures on their outermost surface, which determines significant room overheating. However, the use of highly reflective cool materials can help to maintain low outer surface temperatures; this practice may improve indoor thermal comfort and reduce the cooling energy need during the hot season. This technology is currently well known and widely used in the USA, while receiving increasing attention in Europe. In order to investigate the effectiveness of cool roofs as a passive strategy for passive cooling in moderately hot climates [129].

The roof surface represents about 20–25% of urban surfaces and 60–70% of the building envelope on average in Italy, depending on the building typology [130]; thus, it plays a very important role in the energy balance of buildings, and it is important to find appropriate solutions to improve its energy performance, also in relation to the specific climate. In particular, the solar radiation impinging on the roofs can easily raise their outer surface temperature up to 50–60∘C 10–15∘C higher than the surrounding green areas [131]. Now, most of the energy regulations in Mediterranean countries currently prescribe high thickness for the insulation of the envelope, especially for roofs. This approach is appropriate to reduce the energy needs in winter, but it is not very effective in summer as a tool for reducing the room overheating. As a matter of fact, the use of high insulation levels in hot climates strongly reduces the effectiveness of passive cooling strategies, traditionally based on high thermal inertia, air permeability, and light colors as far as roof is concerned [132]. Moreover, as discussed by Masoso and Grobler [133], it is not always true that lower values of the thermal transmittance of the envelope reduce the annual energy consumption for space heating and cooling. In fact, it is possible to determine a threshold value of thermal transmittance (point of thermal inflexion) that, if overtaken, brings to negative energy savings on an annual basis. Similar results were determined by Li et al. [134], who highlighted how insulation in general tends to be more effective in heating-dominated buildings in colder climates than in cooling-dominated ones, because of the heat trapped inside the building. Moreover, the use of a high thickness of insulation material, by breaking the thermal behavior of the inner part of the envelope (depending on the interior conditions) and the upper part (subject to climatic conditions), leads to a rapid decay of the roof. As an example, D’Orazio et al. [135] and Gagliano et al. [136] performed a series of thermal analyses for different types of roof technology (ventilated and nonventilated) by varying the thickness of insulation. The results show how all the roofs exhibit similar behavior on the inner side but a very different one on the outer side: the mean difference between ventilated and non-ventilated roof, in terms of inner surface temperature and incoming heat flux are constant and amounts to 1.5∘C and $3W{\cdot}m^{-2}$, respectively, whatever the common insulation thickness is. On the other hand, a sensible difference holds between the outer surface temperatures, due to the overheating of the finishing layer; in fact, clay tile roofs show better performance than copper roofs (or metal roofs in general), because of them air permeability and their more balanced radiant properties (solar reflectance and infrared emissivity). In this context, cool materials represent an efficient way to cope with both the increase of energy consumption in summer and turbinate island effect, without introducing sensible changes in the aesthetic feature [137].

3-3.3.4 Coatings

Control of emission can be achieved using coatings as much as paints. Metal films are good examples for radiative cooling applications, as they have high reflectance in infrared and are semitransparent in the visible spectrum. Other examples of coatings are thin-film coatings like oxides, nitrides, oxynitrides and sulfides of Si (SiO or Si_3N_4) which used for radiative cooling [138] [139]. In (Table 2), different coating materials used for radiative cooling applications are listed.

Name	Advantage
Polished Aluminium coated with evaporated SiO_2 and Si_3N_4	The advantage of these surfaces is that there is low downward eadiation in atmospheric window, exclusively when the air is not humid and is dry.
Glass covered with SnO_2	The low-emittance coating may inhibit frost formation and s transparency of a window exposed to the clear sky.
Silicon oxinitride (SiO2+Si3N4) deposited onto aluminium-coated glass substrate	The optical properties of Silicon oxynitride is the reason that it is a favourable material for radiative cooling so the interface contributions, multilayered configurations provide a very promising way to enhance the device performances.
Pigmented polyethylene foils (with ZnS or ZnO) with thin films of PbO	Polymeric foils with non-absorbing pigment can add high reflectance of solar radiation with high transmittance in "atmospheric-window" region. Pigmented polyethylene films, included pigments such as ZnS, can display high solar reflection, while being highly transparent in the IR region.
PbS and PbSe onto polyethylene foils	Semiconductors with low band gap, such as PbS, PbSe and Te, are expected to block solar radiation, as being transparent in the "atmospheric window" if intrinsic and represent high reflectivity.

Table 2: Coating Materials used for radiative cooling, Source: ([140] [141] [142] [143]).

3-3.3.5 Thermal Energy Storage (Phase Change Material, PCM)

In 1983, Abhat [144] gave the general classification of energy storage material in (Fig.19) and by Lane [154] [155], Dinser and Rosen [156]. Zalba [145] listed the properties of different PCM's (Organic, Inorganic, Fatty acids) like density, specific heat, thermal conductivity and melting temperature. Some of the important properties required for PCM are:

- High latent heat of fusion per unit mass, so that a lesser amount of material stores a given amount of energy.
- High specific heat that provides additional sensible heat storage effect and avoid sub cooling.
- High thermal conductivity so that the temperature gradient required for charging the storage material is small.
- High density, so that a smaller container volume holds the material.
- A melting point in the desired operating temperature range.
- The phase change material should be non-poisonous, non-flammable and non-explosive and corrosiveness to construction material.
- No chemical decomposition, so that the (LHTS) system life is assured.
- PCM should exhibit little or no super cooling during freezing.

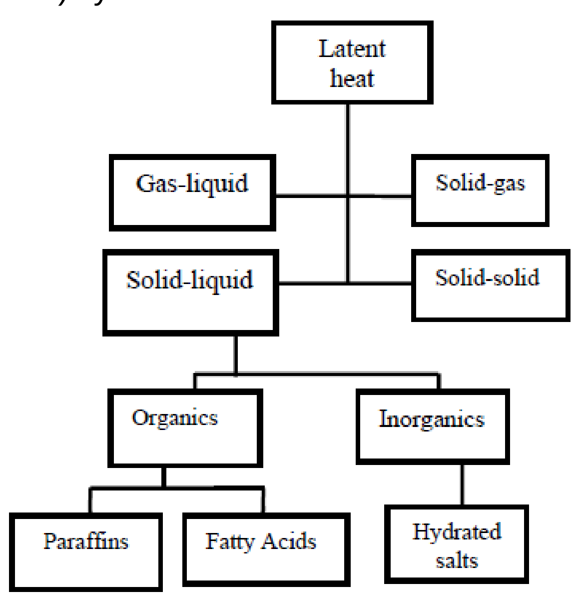


Figure 19: Classification of PCM, (Source: [144]).

I. Development of PCM for Cooling of Buildings

There are three different ways to use PCMs for heating and cooling of buildings exist:

- PCMs in building walls.
- PCMs in building components other than walls i.e. in ceilings and floors.
- PCMs in separate heat or cold stores.

In building applications, only PCMs that have a phase transition close to human comfort temperature (20–28ºC) can be used. Some Commercial PCMs have been also developed for building application. Hawes and Feldman [146] have considered the means of PCM incorporation into the building by direct incorporation, immersion and encapsulation. Peippo et al. [147] considered a PCM impregnated plasterboard as a storage component in a lightweight passive 120m2 solar house with good insulation and a large area of south facing glazing in Madison, Wisconsin. The house could save up to 3GJ in a year or 15% of the annual energy cost. Stetiu and Feustel [153] used a thermal building simulation program based on the finite difference approach to numerically evaluate the LHS performance of PCM wallboard in a building environment. Feustel and Stetiu also investigated using double PCM-wallboard to further increase the storage capacity of a building so that the room temperatures could be kept closer to the upper comfort limits without using mechanical cooling. Neeper [148] has examined the thermal dynamics of a gypsum wallboard impregnated by fatty acids and paraffin waxes as PCMs that are subjected to the diurnal variation of room temperature but are not directly illuminated by the sun. Atheneites et al. [149] conducted an extensive experimental and one dimensional nonlinear numerical simulation study in a full-scale outdoor test room with PCM gypsum board as inside wall lining. Lee et al. [150] have studied and presented the results of macro-scale tests that compare the thermal storage performance of ordinary concrete blocks with those that have been impregnated with two types of PCMs, BS and commercial paraffin. Hawes et al. [151] presented the thermal performance of PCM's (BS, dodecanol, paraffin, and tetradecanoyl) in different types of concrete blocks. Hadjieva et al. [152] have applied the same impregnation technique for concrete but with sodium thiosulphate penta hydrate ($Na_2S_2O_3.5H_2O$) as a PCM. A major development in this area is to develop a PCM which will maintain good heat storage during the day and heat loss to the environment during nighttime.

3-3.4 Evaporative Cooling

Evaporative cooling is a heat and mass transfer process that uses water evaporation for air cooling, in which large amount of heat is transferred from air to water, and consequently the air temperature decreases. Evaporative coolers could be classified into:

I. Direct evaporative coolers, in which the working fluids (water and air) are in direct contact.
II. Indirect evaporative coolers, where a surface/plate separates between the working fluids.
III. Combined system of direct and indirect evaporative coolers and/or with other cooling cycles [157].

(Fig. 20) illustrates a general classification of main types of evaporative cooling systems for building cooling.

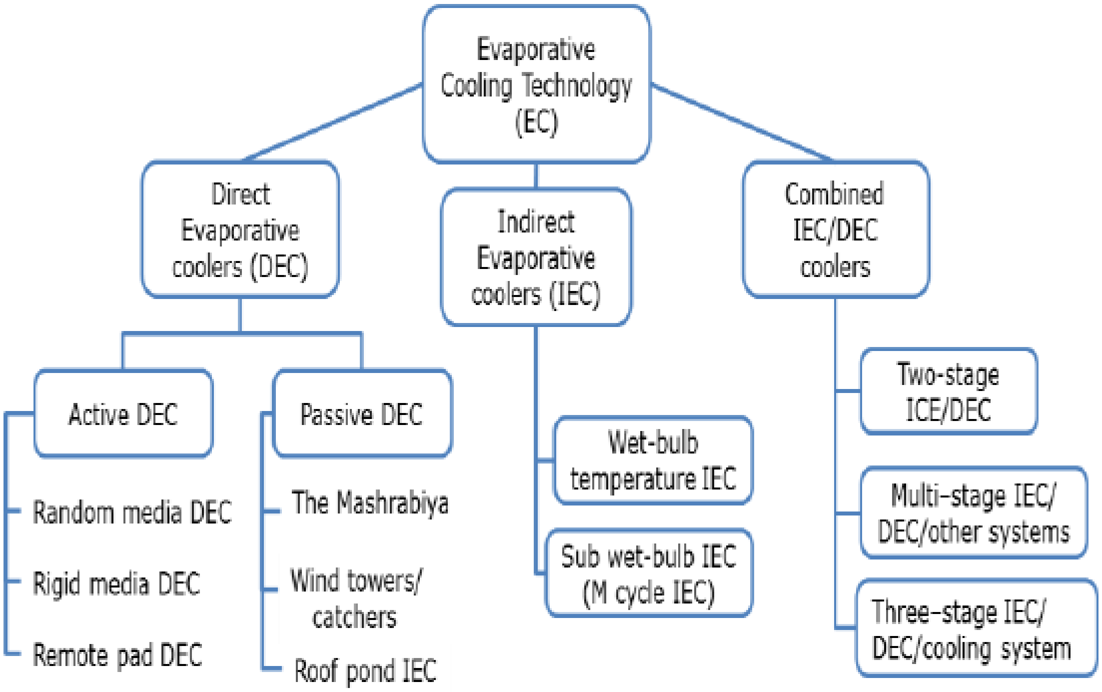


Figure 20: A Classification of evaporative cooling systems in building cooling, (Source: [157]).

3-3.4.1 Direct Evaporative Cooling (DEC)

This system is the oldest and the simplest type of evaporative cooling in which the outdoor air is brought into direct contact with water, i.e. cooling the air by converting sensible heat to latent heat. Ingenious techniques were used thousands of years ago by ancient civilizations in variety of configurations, some of it by using earthenware jar water contained, wetted pads/canvas located in the passages of the air.

Direct evaporative coolers in buildings vary in terms of operational power consumption from zero power to high power consumption systems. DEC systems could be divided into: Active DECs which are electrically powered to operate and Passive DECs that are naturally operated systems with zero power consumption. DEC is only suitable for dry and hot climates. In moist conditions, the relative humidity can reach as high as 80%, such a high humidity is not suitable for direct supply into buildings, because it may cause warping, rusting, and mildew of susceptible materials [158].

I. Active DEC Systems

The active direct evaporative coolers are electricity-driven systems; however, it uses a fraction of power for air and water circulation. So, it is considered much less energy intensive than other traditional cooling technologies, with energy saving up to 90% [158]. A typical direct evaporative cooler comprises of evaporative media (wet table and porous Pads), fan blows air through the wetted medium, water tank, recirculation pump and water distribution system, as illustrated schematically in (Fig. 21 a). The direct evaporative cooling is an adiabatic cooling process, i.e. the total enthalpy of the air is constant throughout the process, as shown in (Fig. 21 b). The water absorbs the sensible heat from the supply air and evaporates causing the air temperature decreases and its humidity to increase [159].

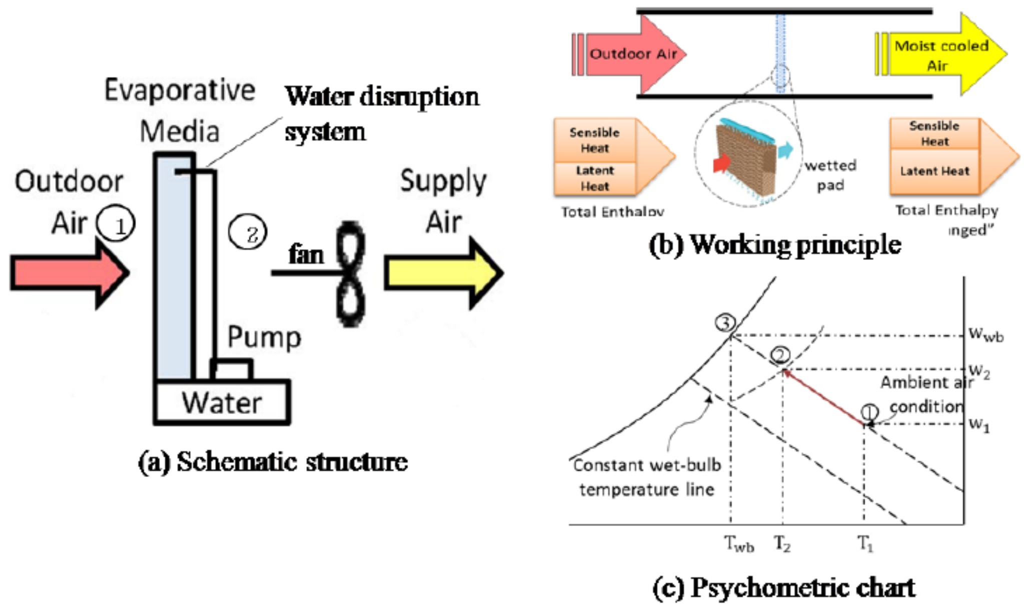


Figure 21: Structure, working principle and Psychometric chart of a direct evaporative cooler, (Source: [152])

Theoretically, the supply air could be cooled to 100% effectiveness, but in such process a wet-bulb effectiveness of 70%-80% only is achievable because of short contact time between the two fluids, insufficient wettability of the pads and since the circulated water and the supply air will reach an equilibrium point that is equal to the wet-bulb temperature of the supply air. Eventually the system would not be able to cool down the incoming air lower than its wet-bulb temperature. The wet-bulb effectiveness could reach range between 70-95% in most current commercial DEC coolers and mainly as a function of the type and thickness of evaporative media, working climate, and supply air flowrate [160].

According to ASHRAE Handbook-HVAC Systems and Equipment active DEC could be divided according to types of wet media into: Random media DEC, Rigid media DEC and Remote media DEC as shown in (Table. 3) [161]. However, active DEC coolers can be classified in terms of water distribution system type: spray (also called air washer), slinger (a rotating wheel), and drip (Misting) system [162].

Table II show the main types of active DEC systems:

Figure: Types of DEC system pads, (Source: [161]).

System type	Evaporative media	Effectiveness	Features
Random media	Excelsior or plastic fiber/foam supported by plastic frame.	>80%	Low effectiveness Short life-time. Hard to clean.
Rigid media	Blocks of corrugated materials: Cellulose, plastic, fiberglass.	75-95%	High initial cost. Longer life-time. Cleaner air.
Remote pad	Random or rigid Pads mounted on wall or roof of building	75-95%	Higher power consumption Bacteria growth

Table 3: Main Types of Active DEC systems, (Source: [152]).

II. Passive DEC Systems

Passive cooling techniques use natural phenomena, energies, and heat sinks for cooling buildings without the use of mechanical apparatus consume electrical energy. However, small fans and pumps could be required. Passive DEC is relied on the climate which means the techniques applied for hot and humid regions are different from those for hot and arid areas. This technology can reduce indoor air temperature by about 9 ℃ [162].
The main types of passive direct evaporative cooling building integrated systems are:

A) The mashrabiya

The mashrabiya is a traditional Islamic architecture element used for natural ventilation and cooling of buildings without requiring any energy. It is wooden screens/windows provides shad, protection from the sun and allows breezes to flow through into the building for cooling purpose. (Fig. 22 a) shows a mashrabiya system coupled with porous water-jugs to provide evaporative cooling effect for a dwelling and cooling water inside jugs for water drinking [163].

B) Roof-pound

Roof pond is a building-integrated evaporative cooling technique. It can contribute highly to mitigate heat by cooling the roof passively; therefore, the indoor air is cooled without increasing its moisture and reducing the energy consumption and heat gain during daytime. A typical roof pound consists of water pool in plastic or fiber-glass container stored on top of the roof of the building. The pond could be covered by a removable cover, a fixed cover or a fixed floating installation. A basic configuration of a shaded roof-pond system is shown in (Fig. 22 b). During summer, the ambient air flow over the pond causes the water to evaporate, thus, cools the pond and the roof structure which act as a heat sink of the building interior. During winter, the pond is emptied, and the shaded openings are closed. Roof-pond cooling systems may incorporate water spraying system to enhance evaporative cooling [158].

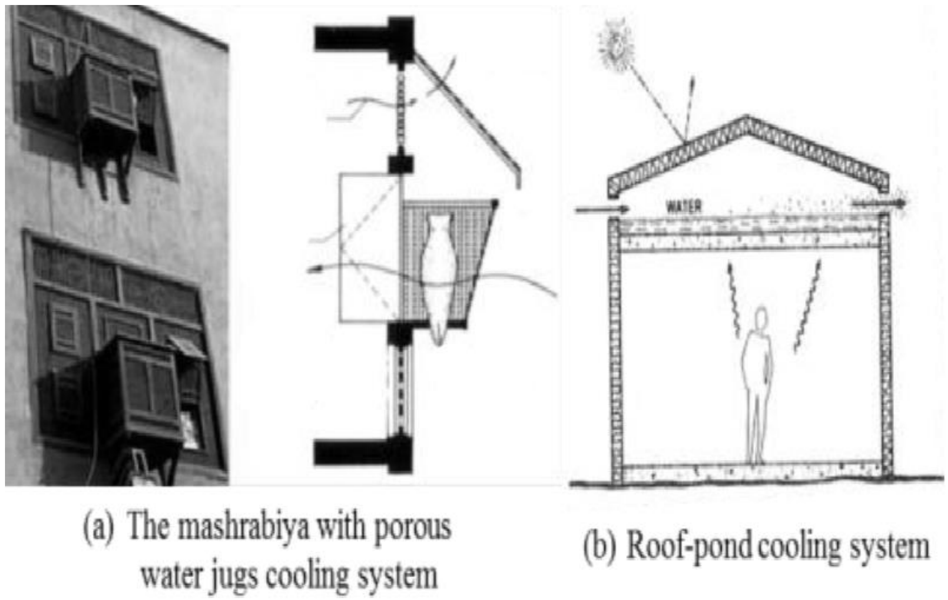


Figure 22: Types of passive cooling systems, (Source: [158]).

3-3.4.2 Indirect Evaporative Cooling (IEC)

The primary idea of the indirect evaporative coolers is cooling by decreasing air sensible heat without changing its humidity, which is a distinctive advantage over DEC systems. A common IEC unit comprises of a heat exchanger (HX), small fan, pump, water tank, and water distribution lines, Indirect evaporative coolers are classified into: Wet-bulb temperature IEC systems and Sub wet-bulb temperature ICE systems [157].

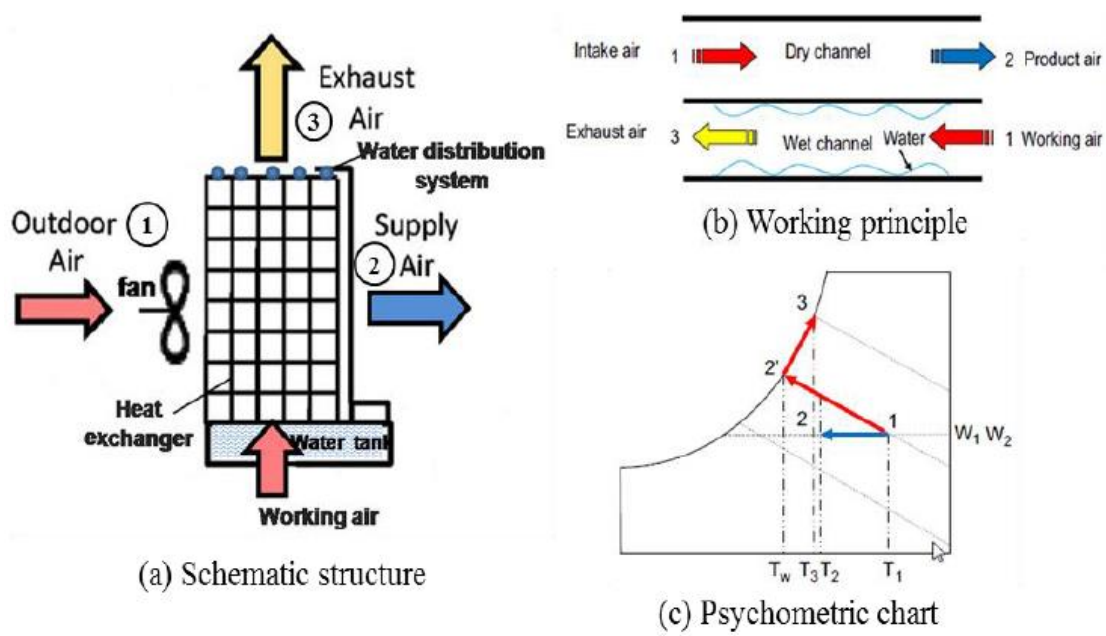


Figure 23: IEC Structure, working principle and its psychometric chart, (Source: [157] [159]).

I. Wet-Bulb Temperature IEC System

Wet-bulb temperature IEC system are packaged unit of flat-plate-stack, crossflow heat exchanger, the most common configuration and flow pattern, which can lower air temperature close to, but not below, the wet-bulb temperature of the inlet air. Fig. 5b shows a schematic drawing of the working principles of a typical HX configuration of a wet-bulb temperature IEC system which comprises of several pairs of adjacent channels: wet passages of the working (secondary) air and dry passages of the supply (primary) air. Heat transfer occurs between the two working fluids through a heat conductive plate; therefore, the supply air is cooled sensibly with no additional moisture introduced into the cooled supply air stream. While, heat transfer mechanism between the working air and water in wet channels is by latent heat of water vaporization. The wet-bulb effectiveness of this system is in the range of 40–80%, which is lower than that of the DEC systems [164]. Different types of IEC systems are existed which can be classified, according to the type of heat exchanger (HX), into plate-type IEC, tubular-type IEC and heat pipe IEC as summarized below:

-Plate-type HX based IEC: This type of heat exchanger is the most commonly used configuration, that is, flat-plate-stack HX with cross- or counter-flow arrangement of the primary and secondary airstreams. (Fig. 23 a) illustrates schematically a basic plate-type IEC system. Several researches conducted evaluation of energy saving [165] [166], mathematically modeling of the heat transfer process and performance evaluation [167] [168], studying the effects of channels dimensions, humidity ratio, primary and working air velocities, and plate wettability percentage on the efficiency of the system [169] [170]. However, the cooling effectiveness of plate type IEC system s is only in the range of 50–80%.

-Tubular-type HX based IEC: This configuration is usually built of circular tubes, as shown in (Fig. 23 b). However, other tubular shapes have been used such as elliptical and rectangular tubes [171]. A common configuration consists of a bundle of round tubes mounted in a cylindrical or rectangular shall, where the primary air flows inside the tubes and the secondary air flow across and/or along the tubes in the normal direction to the primary air, while the water is sprayed over the external surface of the tubes. So that it could offer more uniform water film over the tubes and less pressure losses comparing with plate-type IEC. Usually, the tubes are made of either polymer, metal, porous ceramic, PVC, or aluminum [160]. Another common configuration is a tube-fin HX based IEC in which round or rectangular tubes are fitted with outside fins by soldering, brazing, or welding. For example, Velasco Gomez *et al*. [172] introduced tube-fin HX based indirect evaporative cooler, that is, a bundle of porous ceramic tubes fitted with flat metallic fins. The results showed air dry-bulb temperature reduction of 9-14 °C was achieved. The system can be used for heat recovery in air conditioning systems [173].

-Heat pipe HX based IEC: Heat pipe is a light, simple and thermally conductive device available in shapes and sizes, can be applied to transport heat from the primary to secondary air passages for cooling applications. The configuration of heat pipe can be any type from thermo-syphon, cryogenic, rotating and revolving, flat plate and capillary pumped loop heat pipe [158]. In this structure, the heat pipe-based IEC, the condenser section of heat pipe is used in the secondary air (wet) channel, and the evaporator section is used in primary air (dry) channel, as shown in (Fig. 24).

-Limited studies [160] [174] carried out evaluating the performance of the heat pipe-based IEC systems for building cooling. A finned heat pipe was used to increase convective heat transfer between the primary air and the heat pipe, with different methods of heat eliminations from the condenser sections such as water sprayer on condensation section surface, the outdoor air is precooled by air washer before passed through the condensation section, the use of porous ceramic water container fitted around condensation section to assure even distribution of water. Also, In the literature many research studies conducted on heat pipes applications in building cooling includes HVAC systems [175] [176], and heat recovery systems [177] [178].

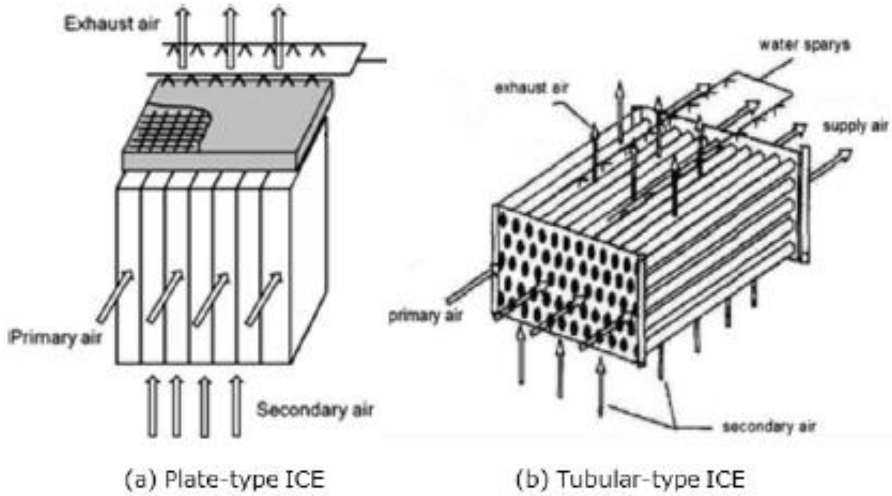


Figure 24: Schematics of plate-type and Tubular-type based IEC, (Source: [158]).

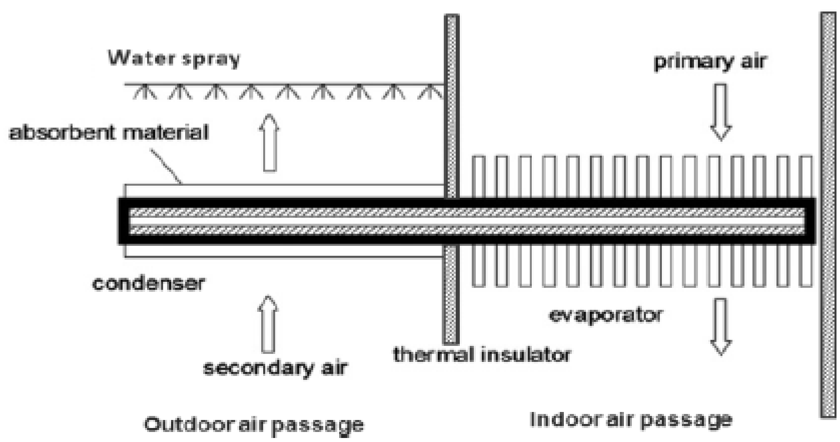


Figure 25: Schematic of heat pipe-based IEC, (Source: [160]).

II. Sub Wet-Bulb Temperature IEC Systems

To overcome some of the disadvantages of DEC systems and to enhance the effectiveness of wet-bulb temperature IEC, introduced a new design of the heat exchanger of IEC system [179]. The Maisotsenko-cycle (M-cycle) based IEC system is a combination of a cross-flow, multi-perforated flat-plate HX and evaporative cooling, in which, the secondary air is precooled in the dry channel before it is diverted to pass through the wet channel to achieve further heat transfer with the dry channel. Thus, the primary air temperature is lower than wet-bulb temperature and approach dew-point temperature of the incoming air. So, it is called Dew point IEC. The wet-bulb effectiveness is in the range of 110%-122% and a dew-point effectiveness of 55%-85%. Although the M-cycle heat exchanger has 10–30% higher effectiveness than that of the conventional heat exchangers, its operation is still facing some limitations; the secondary air is not fully cooled as high proportion of it is gradually diverted early into the wet channels, and cross-flow is unfavorable pattern for heat exchangers. An experimental test of the M-cycle based IEC system showed that its dewpoint/wet-bulb effectiveness was only around 50–60% and 80–90% respectively [180].

Several research studies conducted to develop and modify the thermal process of the M-cycle IEC to overcome the above-mentioned drawbacks and to enhance the efficiency and increase the thermal performance. Zhao *et al*. [181] introduced a new counter-flow heat and mass exchanger based on M-cycle of a dew-point evaporative cooling system. In this structure, unlike the crossflow Maisotsenko-cycle heat exchanger, holes are located at end of flow channels as presented in (Fig. 26). The product air flows through and along the dry channels losing sensible heat to wet channels and at the end of dry channels part of cooled product air is delivered to the conditioned space and the remaining air is diverted to the adjacent wet channels as cold working air transferring heat latently with the water and sensibly with the product air in the dry channel. It was found that the wet bulb effectiveness achieves up to 130% and dew-point effectiveness of up to 90%. Furthermore, a comparative study between crossflow and counter-flow M-cycle base IEC system showed that the counter-flow arrangement achieved around 20% higher cooling capacity and 15–23% higher dewpoint and wet-bulb effectiveness respectively under the same geometrical sizes and operational conditions. Contradictory, the crossflow exchanger has 10% higher performance which is due to an increase in power consumption of counter-flow heat exchanger [182].

Additionally, Zhao *et al*. [183] and [184] conducted a feasibility study in China and the UK respectively, using the proposed dew-point IEC system in [181].

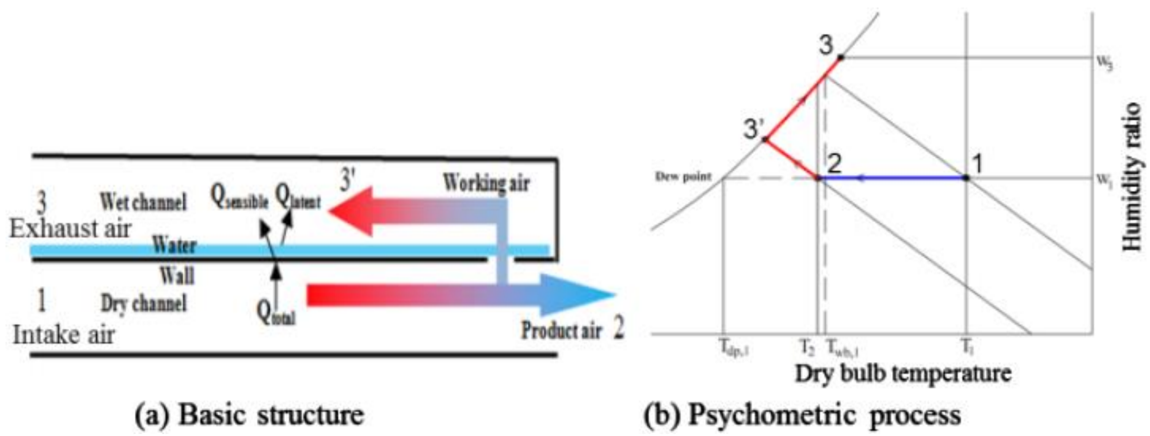


Figure 26: Working principle and psychometric chart of a sub wet-bulb IEC, (Source: [182]).

It was found that the dew-point IEC system is applicable for most of the UK and china regions, particularly where the climate is dry. Tap water is suitable as feed water with an adequate temperature for cooling and its consumption rate ranged from 2.1 to 3 l/kWh cooling output. The system cooling output is in the range of 3.1-4.3 W/m3/h air flow rate. Also, Rogdakis et al. [185] theoretically and experimentally evaluated the performance of an M-cycle based IEC system at Greek climate condition. It was found that the Maisotsenko cycle can be applied for most Greek cities without intensive consuming of electricity and water, the effectiveness ranged between 97% and 115%, while water consumption was in the range of 2.5 3.0 l kW/h.

3-3.4.3 Indirect-Direct Evaporative Cooling (IDEC)

Since DEC have higher effectiveness but humidity increases indoors while IEC have lower effectiveness and the humidity is constant, a combination of both systems or in conjunction with other cooling technologies can be a potential and achieve the best characteristics of both systems, such as cooler supply air at a lower relative humidity, higher efficiency and controlled humidity. The main components of IDEC system are heat exchanger of IEC unit, evaporative pad of DEC unit, water recirculation system, water reservoir, and blowers, as shown in (Fig. 27).

The effectiveness ranges from 90% to 115%. However, the high initial cost and system complexity are the obvious drawbacks [186]. The common types of the IDEC systems are:

Two-stage IDEC: in this configuration, the IDEC comprises of IEC stage followed by a DEC stage. The first indirect stage (state 1) cools the outdoor air, which is then flows through a direct stage (state 2) for further cooling to below its wet-bulb temperature, but with additional moisture added (state 3), as illustrated on the psychometric chart (Fig. 27-b). The effectiveness is in the range of 90–120%, but water consumption increases by 55% [186] [187].

Other two-stage IEC-DEC configurations reported by [188] [189] achieved effectiveness of 109%-116%.

Three-stage IDEC: this system consists of two-stage IDEC system in conjunction with a cooling cycle. For example, a solid desiccant dehumidification with an IEC and/or DEC unit [190] [192] gives COP of around 20. Several configurations have been reported: An IEC, cooling coil and DEC stage [193] [194]. An IEC and a DEC system to provide sensible and adiabatic cooling coupled with a desiccant system for dehumidification (Fig. 28) can offer energy saving of 54%-82% over the conventional cooling systems [191].

Multi-stage IDEC: a hybrid system of two-stage IDEC coupled with more than one cooling cycle. For instance, combined system of two-stage DEC-IEC coupled nocturnal radiative cooling and cooling coil (Fig. 29) has higher effectiveness than two-stage evaporative cooling system, with energy saving is between 75-79% compared to MVC systems [195].

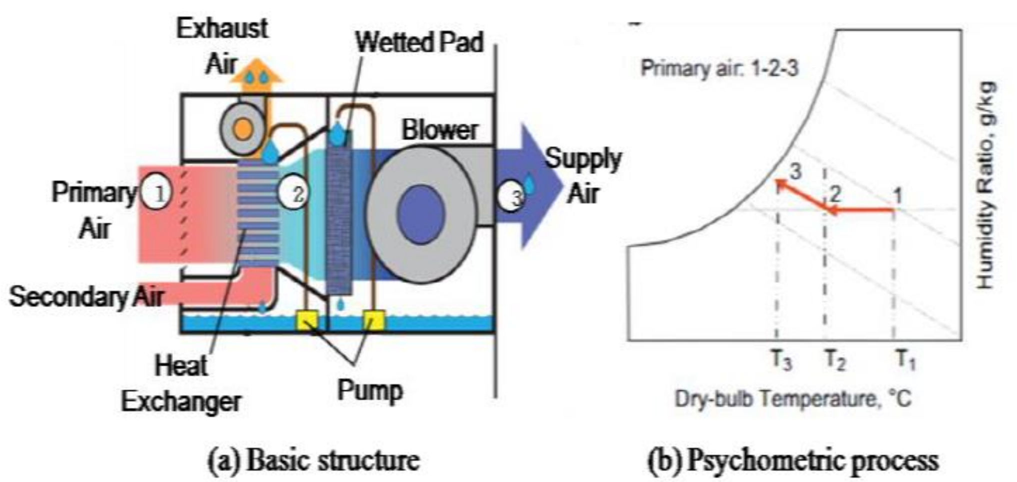


Figure 27: Two-stage IDEC system, (Source: [159]).

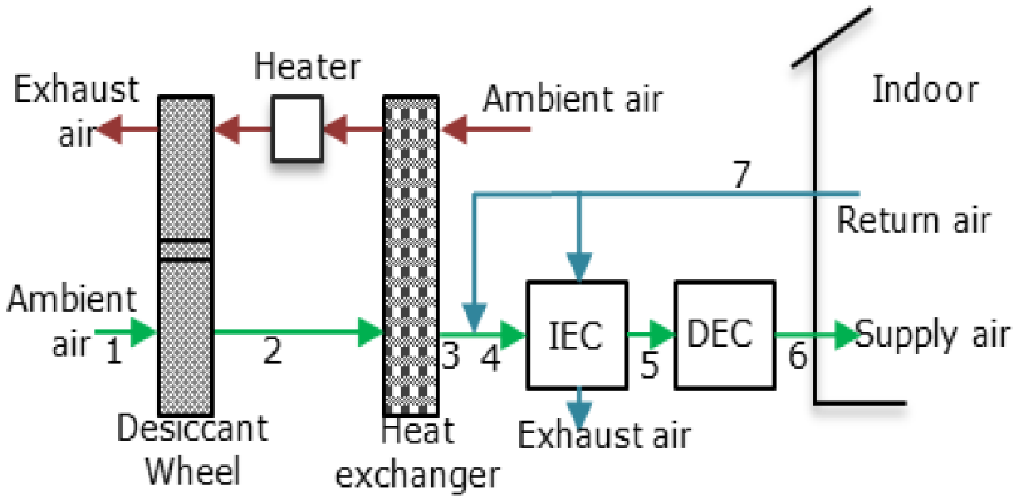


Figure 28: Schematics of solid desiccant and evaporative cooling systems, (Source: [158]).

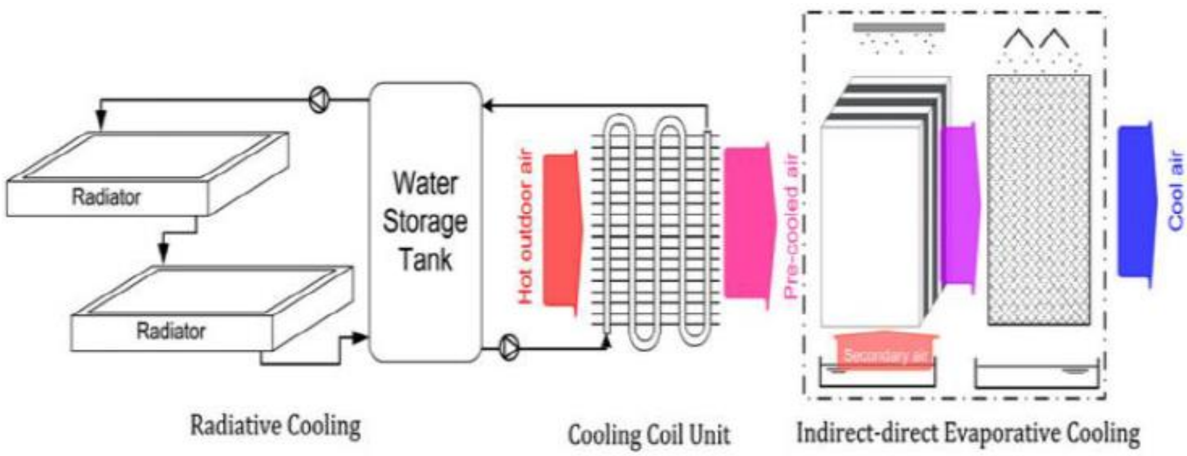


Figure 29: Hybrid system of radiative cooling, cooling coil, and two-stage IEC-DEC system, (Source: [195]).

3-3.5 Earth Coupling

It is a well notorious fact that if you get below the surface of the earth a few meters, the temperature tends to be constant and at 8 to 12 degrees, depending on latitude. So, it does not take an architect to appreciate that if you could move outside air through a buried pipe, you could alter its temperature and then move it into a house where it can warm or cool the home's interior. Underground temperatures can be very beneficial in balancing the thermal comfort of the house. Normally we think more about the above ground temperatures and other climatic elements in designing a house for thermal comfort. One of the important problems which architect must thinking on when he starts to create an efficient cooling system by using earth inertia is the amount of heat conducted and who widely it is diffused varies from one soil type to another. The moisture content of the soil is a major influence on conductivity and diffusivity, and accounts for large variations on how heat moves through the earth. Another problem is the sizing of the cooling system which must pass the living space area.

The better design use and understanding of these elements and resolve the problems for create a naturally comfortable house. This method of cooling is cost effective, not damaging to the environment, and is a natural way to cool off. The air cools in the chamber overnight and is circulated through the house during the heat of the day. Passive cooling is using natural building techniques for sustainable house design in indoor areas with extreme. It is important to understand that soils temperatures during the summer season at certain depths are considerably lower than ambient air temperature, thus providing an important source for dissipation of a houses excess heat. Conduction or convection can achieve heat dissipation to the ground. Earth sheltering achieves cooling by conduction where part of the building envelope is in direct contact with the soil. Totally underground spaces offer many additional advantages including protection from noise, dust, radiation and storms, limited air infiltration. The concept of earth cooling uses the thermal inertia of the earth to maintain internal temperatures below ambient in summer. This kind of energy is successful and efficient with employment air such element of transporting colt [196].

3-3.5.1 Cooling by Underground Earth Tubes

The subterranean world is only cooler in summer, when the surface is warmed by the sun. In winter, underground spots are relatively warmer because of their" thermal inertia". the cooling tubes system consist of long pipes buried underground with one end connected to the house and the other end to the outside. Hot exterior air is drawn through these pipes where it gives up some of its heat to the soil, which is at a much lower temperature at a depth of 3m to 4m below the surface. This cool air is then introduced into the house. Special problems associated with these systems are possible condensation of water within the pipes or evaporation of accumulated water and control of the system. The requirement of detailed data about the performance of such systems hinders the large-scale use of such systems.

In the 1980's, earth tubes approved a great deal of attention from architects and civil engineers, as an option or aid to conventional air conditioning. While the concept of routing air through underground tubes or chambers to achieve a cooling, effect appears like a good proposal. Possibly a few hundred systems were constructed, but information on the practical application of the concept is imperfect. 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, entering the house as cooler air. This will occur only if the earth is at least several degrees cooler than the incoming air. [197] A cooling tube system uses either an open- or closed-loop design.

- In an open loop system, the outdoor air is drawn into the tubes and transported directly to the inside of the house. This system provides ventilation while optimistically cooling the house's interior.
- In a closed-loop system interior air circulates through the earth cooling tubes. A closed loop system is more efficient than an open loop design. It does not exchange air with the outside.

I. Tubes material

The main considerations in selecting tube material are cost, strength, corrosion resistance, and durability. Tubes made of aluminum, plastic, and other materials have been used. The selection of material has modest influence on thermal performance. PVC or polypropylene tubes perform almost as well as metal tubes.

II. Tube diameter

Optimum tube diameter varies widely with tube length, tube cost, flow velocity, and flow volumes. Diameters between 10-25 centimeters come into view to be most appropriate.

III. Tube location

Earth temperatures and, as a result, cooling tube performances vary considerably from sunny to shady location. The optimal situation is to build the house on a hill which rises 3 meters above its surrounding area. A channel can then be dug from the home, 3 meters down, and then horizontally until it reaches daylight. This horizontal section is placed on a small incline to the exterior, like a drain line. Mind must be taken that this flow line is absolutely controlled as we do not want pockets of water building up within the tube. Therefore, the flow line must be right on grade. This means the air can come into the tube, flow up the slight incline, and drop its condensation as it is travelling through the tube, so the condensation drains out the tube's bottom portion. When there is humidity there will be a considerable amount of condensation. Obviously most houses are not built on 10-foot high hills, 30 meters from surrounding areas. Consequently, we need to consider how to put air tubes in flat land. We can place a tube 3 meters down and lay it horizontally for 30 meters, curved or straight, and then bring a riser back to the surface. The riser should have an upside down at its top so rain and debris cannot enter. And it should be screened so critters cannot use it as a back door into the house.

It is vital that the tube is sloped to a collection point. Water will run to this collection point where it must be removed. The collection point can be at either end of the tube or in the middle. It is left to the installer to decide its best location. Some tubes can all be drained to one collection point. This can be accomplished by simply installing cross connecting the pipes with drainpipes. Drainpipes. The estimate tube diameter can be 10 centimeters. At the collection point, a sump pump can be installed which will automatically turn on and off, pumping the condensation out of the ground and sprinkling it on top.

IV. Tube measurement lengthwise

There is no simple formula for determining the correct tube length in relation to the quantity of cooling preferred. Local soil conditions, soil moisture, tube depth, and other site-specific factors should be considered to determine the proper length.

V. Earth Tubes Types

A. Vertical closed- loop.

In the vertical closed-loop ground heat exchanger, an air can circulated through preserved pipe loops covered in vertical bore holes. The bore holes are typically 45-60 meters deep. Heat is transferred, from the ground during the winter and to the ground during the summer. A vertical heat exchanger can be installed on smaller lots somewhat than the horizontal system.

B. Horizontal closed- loop.

In horizontal closed-loop ground heat exchanger, an air is circulated through sealed pipe loops buried horizontally, about 2 meters underground. During cold weather the pipe lops absorb heat from the earth and deliver it the house. In the summer the processes are reversed for air conditioning, and the system transfers the heat from the house to the ground. The outer piping system can be either an open system or closed loop.

- An open system takes advantage of the heat retained in an underground body of air. The air or water is drawn up through a well directly to the heat exchanger, where its heat is extracted. The air is discharged either to an above-ground body of air or water, such as a stream or pond, or back to the underground air or water body through a separate well.

- Closed-loop systems collect heat from the ground by means of a continuous loop of piping buried underground.

3-3.5.2 Cooling by Parallel Systems

I. Cooling by using a free Underground space

That means an open space which can be used also such a functional space (social space for family meeting, living, or with an auxiliary function). It is necessary to appreciate that using of this space must be limited which means just in occasionally cases, because this space must be healthy, so it must be isolate from all negative exterior agent such dust, pollute air, humidity, etc. At the same time this space must be tightly to the house interior or/and exterior, and the connection must be just through the terminals, which have air filters against, dust, bacteria, humidity, and ionizer effects. This space is partial contact with earth ground, just in the floors.

II. Cooling by using rock bed on underground spaces

This includes a layer of thermal mass such as rock bed, where is the earth temperature transferred from/ to the rock bed, in this time thermal mass become as source of cooling in summer season.

The cooling of Living spaces can occur by radiation effect or by using of air such as cool transporter element, in which can be coordinate in corresponding of living space area and thermal mass cool capacity. For optimal working of system, we must take in evidence;

- Velocity of airflow must correspond the thermal internal comfort.
- Airflow circulation must be tightly to the exterior.
- Existing of air filter such healthy element in both terminals input/output.
- Easily to reparation and maintenance of the system.

This system can be used in correspondences with other types of cooling, all such as an intelligent complex system [196].

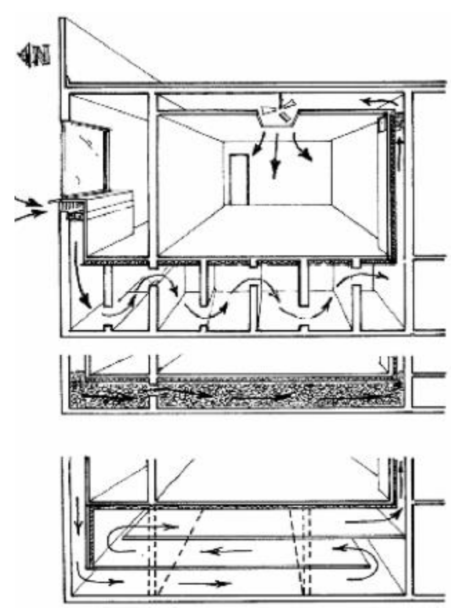


Figure 30: Different underground cooling systems, (Source: [196]).

3-3.5.3 Heat Pumps

Geothermal heat pumps are among the most efficient and comfortable heating and cooling technologies available because they use the earth's natural heat to provide heating, cooling, and often, water heating.

While many parts of the country experience seasonal temperature extremes – from scorching heat in the summer to sub-zero cold in the winter – a few feet below the earth's surface the ground remains a relatively constant temperature. The natural ground temperature is cooler than the natural air temperature in summer, and warmer than the natural air temperature in winter. While the margin of variation is small, seasonal changes in ground temperature give geothermal heat pumps a dependable and permanent wintertime heat source and summertime heat sink.

Geothermal heat pumps, also known as ground source heat pumps, geoex-change, water-source, earth-coupled, and earth energy heat pumps, take advantage of this resource and represent one of the most efficient and durable options on the market to heat and cool your home. Many heating, ventilation, and air conditioning systems use some sort of heat pump for heating and cooling.

I. Geothermal Heat Pumps

Using a heat exchanger, a geothermal heat pump can move heat from one space to another. In summer, the geothermal heat pump extracts heat from a building and transfers it to the ground for cooling. In winter, the geothermal heat pump takes natural heat from the ground and transfers it to the home or building for heating. Installing a geothermal heat pump system can be the most cost-effective and energy-efficient home heating and cooling option. Geothermal heat pumps are a particularly good option if you are building a new home or planning a major renovation to an existing home by replacing, for example, an HVAC system.

II. Air Source Heat Pumps

While geothermal heat pumps operate similarly to the far more common air-source heat pump (ASHP), geothermal heat pumps are substantially more energy-efficient than even ASHPs because they take advantage of the relatively consistent ground temperatures, which are far more uniform than air temperatures. Geothermal systems can reduce energy consumption by approximately 25% to 50% compared to air source heat pump systems. Geothermal heat pumps reach high efficiencies (300%-600%) on the coldest of winter nights.

As with any heat pump, geothermal heat pumps can heat, cool, and, if so equipped, supply the house with hot water. Some models of geothermal systems are available with two-speed compressors and variable fans for more comfort and energy savings. Relative to ASHPs, they are quieter, last longer, need little maintenance, and do not depend on the temperature of the outside air.

A dual-source heat pump combines an ASHP with a geothermal heat pump. These appliances simultaneously provide the consumer with a more efficient alternative to the ASHP, and a more affordable alternative to the geothermal heat pump. Dual-source heat pumps have higher efficiency ratings than air-source units but are not as efficient as geothermal units. The main advantage of dual-source systems is that they cost much less to install than a single geothermal unit, and work almost as well [198].

3-3.6 Desiccant Cooling

Desiccant cooling is effective in warm and humid climates. Natural cooling of human body through sweating does not occur in highly humid conditions. Therefore, a person's tolerance to high temperature is reduced and it becomes desirable to decrease the humidity level. In the desiccant cooling method, desiccant salts or mechanical dehumidifiers are used to reduce humidity in the atmosphere. Materials having high affinity for water are used for dehumidification. They can be solid like silica gel, alumina gel and activated alumina, or liquids like triethylene glycol. Air from the outside enters the unit containing desiccants and is dried adiabatically before entering the living space. The desiccants are regenerated by solar energy. Sometimes, desiccant cooling is employed in conjunction with evaporative cooling, which adjusts the temperature of air to the required comfort level [199].

Desiccant cooling systems are basically open cycle systems, using water as refrigerant in direct contact with air. The thermally driven cooling cycle is a combination of evaporative cooling with air dehumidification by a desiccant, i.e. a hygroscopic material. For this purpose, liquid or solid materials can be employed. The term 'open' is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop. Therefore, only water is possible as refrigerant with direct contact to the surrounding air. The common technology applied today uses rotating desiccant wheels, equipped either with silica gel or lithium-chloride as sorption material.

3-3.6.1 Solid Desiccant Cooling

The main components of a solar assisted desiccant cooling system are shown in the figure on the right. The basic process in providing conditioned air may be described as follows.

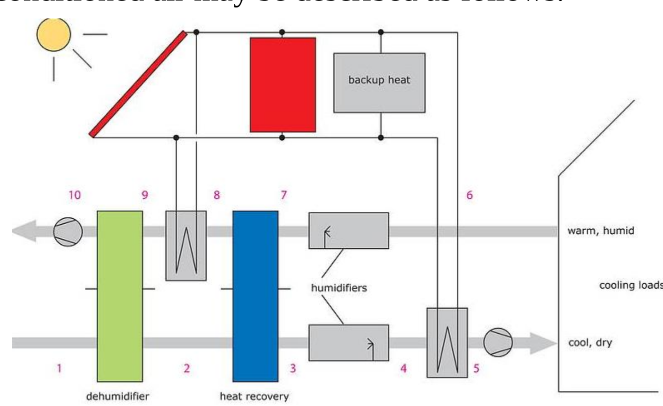


Figure 31: Basic process in providing conditioned air, (Source: [200]).

Warm and humid air enters the slowly rotating desiccant wheel and is dehumidified by adsorption of water (1-2). Since the air is heated up by the adsorption heat, a heat recovery wheel is passed (2-3), resulting in a significant pre-cooling of the supply air stream. Subsequently, the air is humidified and thus further cooled by a controlled humidifier (3-4) according to the set-values of supply air temperature and humidity. The exhaust air stream of the rooms is humidified (6-7) close to the saturation point to exploit the full cooling potential in order to allow an effective heat recovery (7-8). Finally, the sorption wheel must be regenerated (9-10) by applying heat in a comparatively low temperature range from 50 °C-75 °C and to allow a continuous operation of the dehumidification process.

Solid desiccant systems can also be used to provide heating for periods with low heating demand. Flat-plate solar thermal collectors are normally applied as heating system in solar assisted desiccant cooling systems. The solar system may consist of collectors using water as fluid and a water storage, which will increase the utilization of the solar system. This configuration however requires an additional water/air heat exchanger, to connect the solar system to the air system.

Special design of the desiccant cycle is needed in case of extreme outdoor conditions such as e.g. coastal areas of the Mediterranean region. Due to the high humidity of ambient air, a standard configuration of the desiccant cooling cycle is not able to reduce the humidity down to a level that is low enough to employ direct evaporative cooling. More complex designs of the desiccant air handling unit employing for instance another enthalpy wheel or additional air coolers supplied by chilled water can overcome this problem. A novel approach is the dehumidification and simultaneously cooling of the supply air in an air-to-air heat exchanger, in which the supply air is dehumidified through sorptive coatings at the heat exchanger wall, and cooled by the returned air, which was humidified close to saturation in order to lower the return air temperature before entering the heat exchanger. The simultaneously dehumidification and cooling improves the efficiency of the system. Therefore, the supply air humidification may be avoided in moderate climates. Since the sorption material in the supply side of the heat exchanger will be saturated after some time, a periodic operation with two heat exchangers of which one is regenerated, is required. A pilot project in Germany for testing this new concept is currently in the design phase.

3-3.6.2 Liquid Desiccant Cooling

A new technology, close to market introduction, are desiccant cooling systems using a liquid water-lithium chloride solution as sorption material. This type of systems shows several advantages like higher air dehumidification at the same driving temperature range of solid desiccant cooling systems, and the possibility of high energy storage by storing the concentrated solution. This technology is a promising option for a further increase in exploitation of solar thermal systems for air conditioning. Currently, a few systems of this type are installed in Germany in pilot and demonstration applications, driven either with solar thermal heat or from other heat sources [200].

3-4 Conclusion

Using the mechanical refrigeration permitted not only the ability to increase the thermal comfort for more extended periods, but also a great deal of flexibility in building design, and at the same time led to changes in lifestyle and work habits. Even so, increasingly, the use of a higher technology is the result for ignoring the natural-cooling techniques. So, nowadays there are a way to re-use the passive cooling techniques in the buildings as the flow of energy in passive design is by natural means (radiation, conduction, or convection), without using any electrical device. Preserving a comfortable environment within a building in a hot climate and using the passive cooling techniques helping in reducing the peak cooling load and the rate of heat gains into the building and encouraging the removal of excess heat from the building.

CHAPTER FOUR

Applied Passive Cooling Techniques

4-1 IGuzzini Headquarters

Headquarters office building located in Recanati, Italy. By Mario Cucinella Architects, the building consists of 4 floors, usable area is 580m2. The ground floor offers reception and meeting rooms as well as open office areas. The 1st and 2nd floors offer open office workplaces with direct access to the atrium. The 3rd floor accommodates the management level, which is fully air conditioned and not naturally ventilation.

Figure 32: IGUZZINI Building, **(**Source: [201]).

4-1.1 Dimension

The height of the building is about 13 m. The building has a rectangular floor plan with the dimensions 40 m x 19.3 m. The gross volume of the building, including the management level, is 10,000 m^3. The effective, naturally ventilated volume is approx. 7,660 m^3.

4-1.2 Floor area and Materials

The net usable area of the ground floor amounts to approx. 580 m^2, the area of the atrium approx. 200 m^2 and the office floors 580 m^2 each. The building is a composition of opaque and glazed surfaces. The ceiling is made of reinforced concrete. In the office zone, the clear room height is 3 m, while the height of the atrium is 13.80 m.

4-1.3 Facades

The south and north facades are completely transparent and have the following layer structure:
Horizontal sun blinds, Low E glass, clear float glass, non-ventilated space, clear float glass
The west and east facades are opaque and have the following layer structure:
Light plaster, hollow block masonry, air layer, mineral fiber insulation. The outer wall has a U - value of 0.7 W / m^2K.

4-1.4 Concept Components of the IGuzzini Project

- Natural ventilation.
- Daylighting.
- Use of a central atrium that brings light into the offices and allows natural ventilation.
- Transparent facades to obtain more lighting.
- Hybrid ventilation to compensate for internal heat gains by using the cool outside air.
- Use of thermal storage masses for the purpose of night cooling.

4-1.5 Sun Protection

The control strategy provided for the automatic opening of the lower vents as soon as the internal temperature rises above 22 ° C and they should remain open until the outside temperature reaches 25 ° C. After exceeding this temperature, the building should be switched to mechanical mode and air conditioned. After a first period of use, user’s dissatisfaction required the use of the upper vents and a change in the temperature at which the windows should open. Measurements of the monitoring system during this conversion have shown that it could not lead to ensuring the required thermal comfort during the summer and winter periods. For this reason, the building is now operated in mechanical mode for the entire year, with the exception of the spring and autumn periods. Recently the PMV values have not always been acceptable, while the CO_2 values have not exceeded the permissible level.

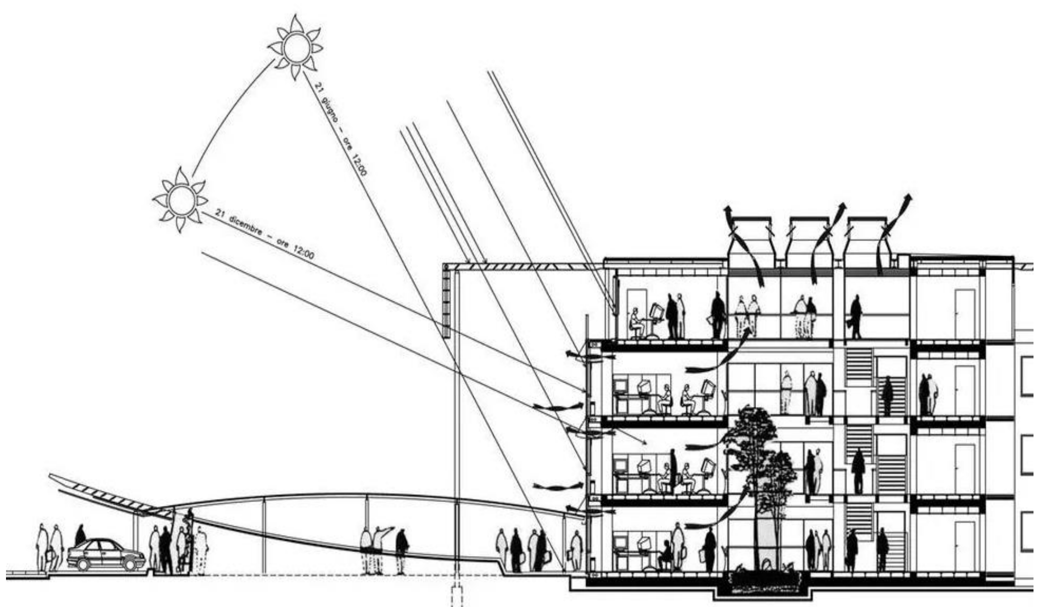


Figure 33: Show the sunshades that protect the sun rays from the building, (Source: [201])

4-1.6 Lighting

The design of the building with its transparent north and south facades allows the use of natural light in the offices. The shading system ensures an adapted, good daylight supply. In addition, light is brought into the building through the central glazed atrium. In the open office space, an artificial lighting is installed, which causes 30% of the electricity consumption.
The east and west facades are opaque. In order to avoid overheating and glare through the large glass facades, a sunshade was mounted on the south side.

Figure 34: Shows the green Atrium inside the building, (Source: [201])

4-1.7 Cooling

The IGuzzini Pallazzina building has been designed so that it can naturally be ventilated up to 55% of the year, of course, without additional mechanical ventilation and cooling or use of the ventilation equipment. The control strategy provided for the automatic opening of the lower vents as soon as the internal temperature rises above 22 ° C and they should remain open until the outside temperature reaches 25 ° C. After exceeding this temperature, the building should be switched to mechanical mode and air conditioned. After a first period of use, users' dissatisfaction required the use of the upper vents and a change in the temperature at which the windows should open. Measurements of the monitoring system during this conversion have shown that it could not lead to ensuring the required thermal comfort during the summer and winter periods.
For this reason, the building is now operated in mechanical mode for the entire year, with the exception of the spring and autumn periods.

Figure 35: The sunshades techniques, (Source: [201])

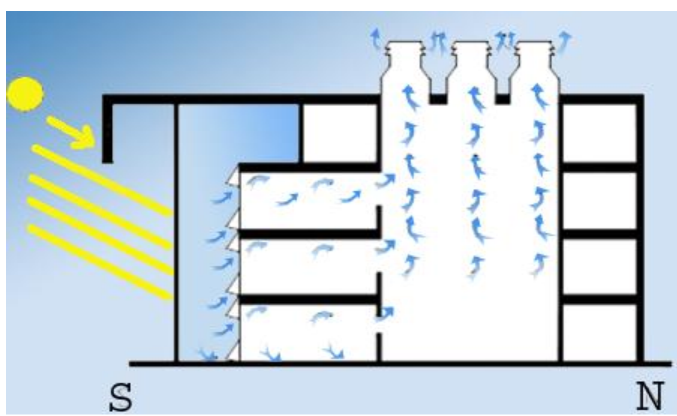


Figure 36: Section diagram to show the cool air flow inside the building, (Source: [201]).

4-1.8 Natural Ventilation

The natural ventilation is done by a kind of chimney effect, which is generated by the distribution of the air layers in the atrium. Fresh air flows through the open windows, through opening flaps at the highest point of the dividing wall between the open office area and the atrium, and finally reaches the "turrets" above the atrium. During use (during the day) all upper façade openings are 5 cm open, allowing natural ventilation. In night mode, all lower openings of the façade are opened in the maximum position of 25cm when the internal temperature (Ti)is higher than 17.5 ° C and the wind speed is below 4 m / s. If the wind speed is higher and the inside temperature is lower than 17.5 ° C, then the openings are closed. When the indoor temperature is less than 20 ° C or more than 23 ° C, the building is operated in mechanical mode, which activates the fan coil systems. Local thermostats at the workplace, allow the local temperature to be controlled by the value of 20 ° C to 23 ° C in the range of 3 ° C to achieve the desired thermal comfort.

Figure 37: Show the inlet for air in the facades, (Source: [201]).

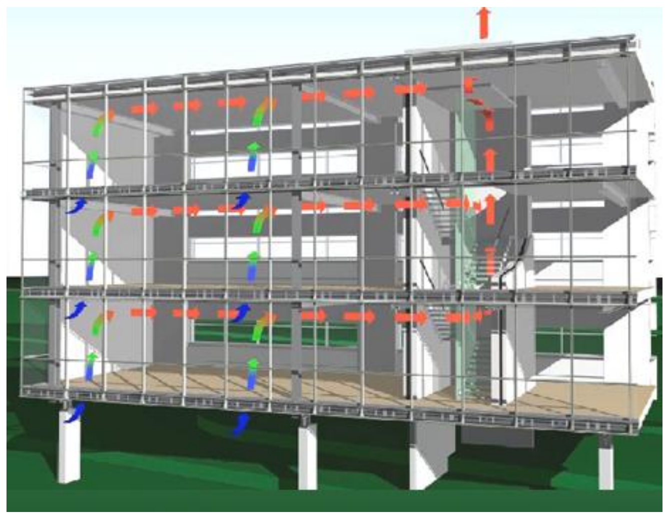


Figure 38: The movement of air inside the building, (Source: [201]).

When the inside temperature drops below 20 ° C, the fan coil system heats the room air, when it rises above 23 ° C, the system cools the indoor air. The hybrid ventilation is used to balance the internal heat gains with the help of the cooler ambient air. The amount of airflow required to maintain comfortable indoor temperatures depends on the temperature difference between the desired indoor temperature and ambient air and the level of internal heat gains. If this natural ventilation system does not provide the required cooling capacity, the "fan coil units" take over the cooling of the air required for comfort. The "fan coil units" supply the required heating in winter and peak load cooling in summer. Fans: Air entering through the opening flaps passes through the fan coils. These fan coil units are equipped with filters. Exhaust air outlets: The exhaust air is directed outside through the "turrets" above the atrium. In night mode, all open areas are naturally cooled by open windows. During the day in mechanical mode by the "fan coil system".

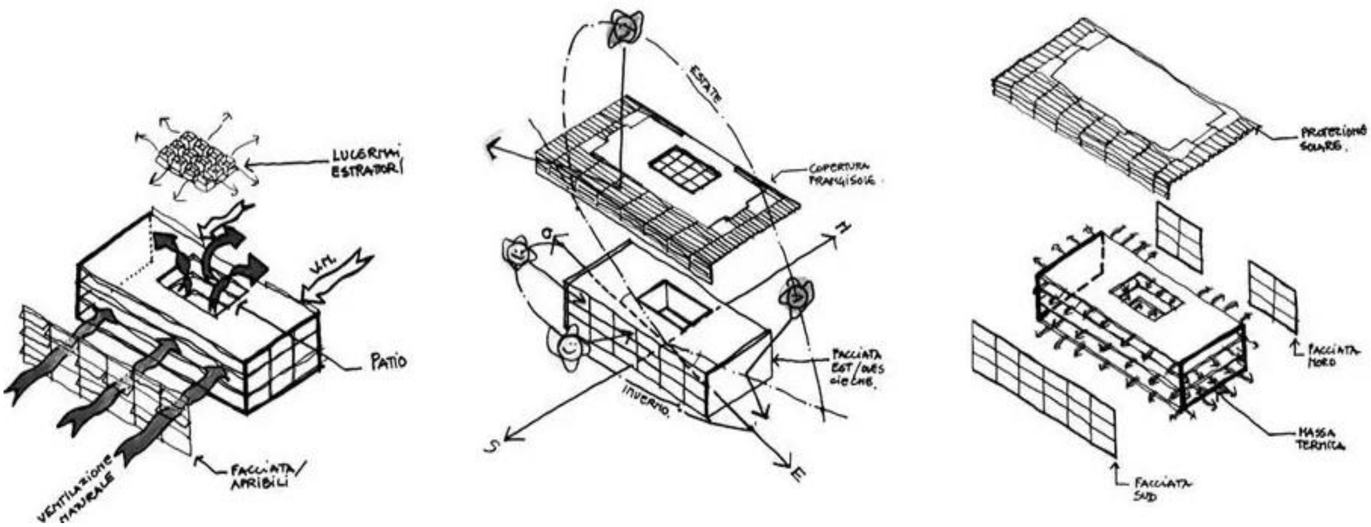


Figure 39: Diagrams shows the analysis for air flow, natural ventilation and Sun path, (Source: [201])

4-1.9 Energy Consumption

Total energy consumption was measured for 12 months (August 1998 to July 1999).
The specific final energy consumption was 130.4 kWh / m². The specific values (left in the diagram) were 105 kWh / m² for heating and hybrid ventilation and 25 kWh / m² for lighting [201].

- It was chosen to be one of the references examples to the case study because this building was concentrated to apply some of the passive cooling techniques to decrease the cooling load and increase the thermal comfort hours inside the building as a way to decrease the usage of the air condition systems in the summer and use natural ventilation. And this will be the main idea for the case study.

4-2 Porta Nuova

A new center for Milan, the redevelopment of Porta Nuova, an area of 290,000 sqm located in the very heart of Milan, has succeeded in recreating a strategic center for the city, and it is Italy's most significant urban redevelopment project to date.

Through the creation of a large area, located near Duomo, between Brera and Piazza della Repubblica, the three historic districts of Garibaldi, Varesine and Isola are finally reconnected and enhanced by a shared pedestrianized zone of over 160,000 sqm, offering 5 km of cycle path, a plethora of urban infrastructures and a large public park, I Giardini di Porta Nuova (Porta Nuova Gardens) which is 90,000 sqm.

The integration of residential apartments, offices, retail spaces and cultural centers - all with the highest quality and energy standards - makes Porta Nuova a unique example of an eco-sustainable, mixed-use urban environment in Italy. Porta Nuova Business District rises in an area where the urbanistic complex of Altra Sede Regione Lombardia is located and it offers 140,000 sqm of office space spread over eight GRADE A office buildings. Porta Nuova is Italy's most innovative urban redevelopment, comparable only with Europe's most advanced business districts.

Business District Varesine was born from a vision created by American architects, Kohn Pedersen Fox Associates (KPF). Located east of the Porta Nuova area, it comprises three buildings with strong and elegant lines, which has already become iconic in Milan. The fluid rhythm of the structures and the increased height has brought to life the unique architecture which blends successfully into the surrounding panorama, both modernizing and enhancing it. The carefully thought-out design, the choice of materials and the technologies used have enabled the development of 60,000 sqm of GRADE A office space, for a new generation of high-performing, efficient and sustainable buildings.

Figure 40: Porta Nuova Distract (Source: [202])

4-2.1 Maximum accessibility and a central location

Business District Varesine is located on an important crossroads in the city.
Linate and Malpensa airports, located 10 and 52 km from the area respectively, provide efficient links with Europe and the rest of Italy. Centrale and Garibaldi railway stations, both served by High Speed services, are just 500 metres away. On top of all of that, 4 underground lines, the local railway line and a large number of above ground public transport links are also available within walking distance. The three office blocks benefit from 300 allocated parking spaces, and a further 500 spaces have been created for public use. All parking areas have been designed to meet the development's parking needs without interfering with the pedestrian zones. Vehicle access has been facilitated by a carefully designed road system and the creation of a dedicated service road. As Business District Varesine is located outside of the city's vehicle toll area, visitors are not subject to toll payment.

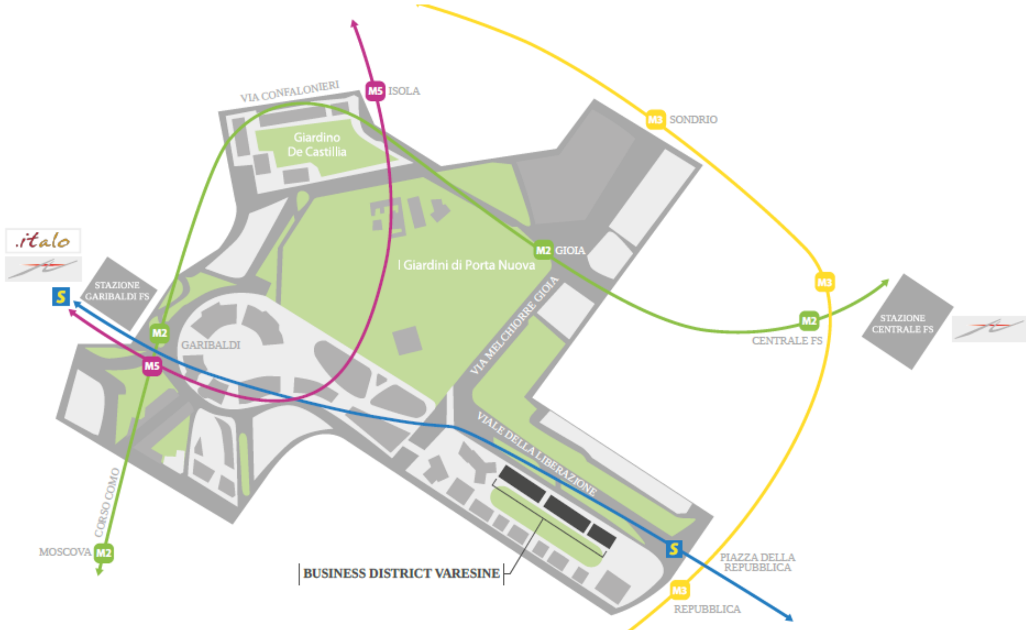


Figure 41: The accessibility to Porta Nuova District (Source: [202])

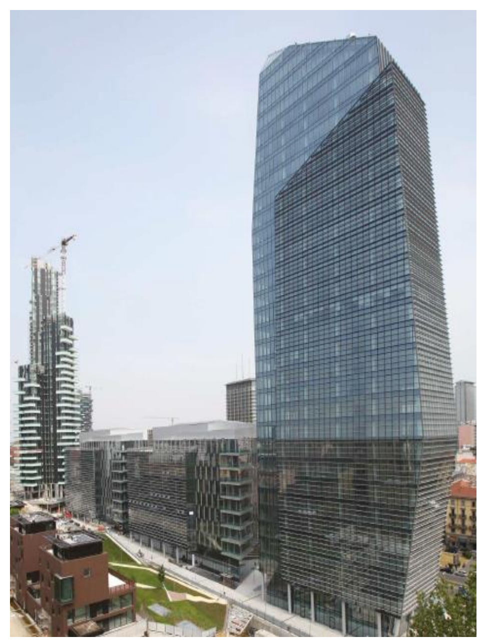


Figure 42: Varesine Business District (Source: [202])

4-2.2 General Information

Porta Nuova Varesine, Milan, Italy.
Architect: Kohn Pedersen Fox Associates.
Building: 30 floors above ground (the last 3 are technical rooms), 4 basement floors.
Available office space: approximately 32,500 sqm.
Underground parking: 155 car spaces.
Archives: 2.258 sqm.
Retail: 271 sqm.
Office height: 300 cm, without drops.
Certification LEED: pre-certified Gold.

4-2.3 Aesthetics and innovation

Business District Varesine was designed by the team of architects of Kohn Pedersen Fox Associates, and stands out for its powerful and, at the same time, harmonious structures. Characterized by modern lines and spectacular glass surfaces, this business district has a strong visual impact. Next to the two 9-floors buildings stands the unmistakable diamond-shaped tower which dominates over the city, with its 30 floors and its137 meters height, a new symbol of technology and innovation in Italy.

4-2.4 Sun Protection

State-of-the-art bruise soleil elements have been integrated into the building surfaces, adding personality and offering protection from sun rays.

Figure 43: Sunshades on Varesine Office Building (Source: [202])

4-2.5 Efficiency serving business

The buildings of Business District Varesine are the stars of the show, both outside and in. The double-height lobbies, elegant and welcoming, offer all the character of an international style and are all fitted with modern security and monitoring systems which are connected to designated control rooms. The carefully thought-out design offers a range of layout options - from closed offices to open spaces - ensuring maximum flexibility in the use of space and reducing the square meters requirement for each workspace, as well as the cost of furnishings and environment reconfiguration. Dedicated activity spaces offer ideal environments for meetings and other events, with the added benefit of truly spectacular views.

4-2.6 Facades

- Curtain wall façade with floor to floor ceiling glass and aluminum structure.
- High-performance insulated glass and exterior solar protection with architectural shade elements.
- Window frames made of thermally insulated structural broken aluminum profiles.
- Sound reduction index R’w = 42 dBA.
- Thermal transmission U <= 1,3 W/mqK.
- Solar factor without screening <= 30%.
- Light transmission >= 48%.

Figure 44: Open Terrace in Varesine Office Building (Source: [202])

4-2.7 Materials

Every space has been designed with maximum attention to efficiency, design and finishing's. The materials used embody high quality standards and their long-lasting nature is reflected in the low maintenance costs.
Calcium sulphate raised floor with galvanized steel structure, dimensions: 60 x 60 cm, total (gross) height up to 15 cm. Microperforated metallic suspended ceiling completely accessible panels, dimensions: 60 x 60 cm, sound reduction index R'w is 30 dB. Lighting units integrated in the suspended ceiling, providing anti-glare direct light.
In Lobby: Natural stone floors. Painted plasterboard ceilings. Custom lighting with both embedded and suspended lighting units. Walls clad with natural stone, wood, steel and glass.

4-2.8 Heating

Winter interior air: 20° C ± 1° C - exterior air: -6° C WB, -5° C DB (76%UR).
Summer interior air: 25° C ± 1° C - exterior air: 24° C WB, 34° C DB (48%UR).
Heat pump control center Production of hot and cold water through polyvalent air/water units (heat pumps), capable of producing cold water at +7° C and hot water at 45° C, designed to work at external temperatures of -5° C in wintertime and +34° C in summer.
Distribution of fluids through variable capacity pumps with energy saving inverters.

4-2.9 Cooling

Ceiling-mounted four-pipe fan coil air conditioning system. Air conditioning distributed by linear slot diffusers at the perimeter and by rectangular diffusers in the internal areas. The system is centrally regulated by BMS. Air change rate of 11 liter/sec per person, with one person per 10 sqm of office. Air treatment by variable air volume fan unit with high-efficiency heat recovery system and high-pressure spray humidifier.

4-2.10 Electrical system and power generator

- Dedicated transformer room for building.
- Main switchboard with sections for normal and emergency power networks.
- Generator and UPS power utilities security building life safety and critical systems.
- Power risers are located adjacent to stairways.
- There are two secondary power panels installed on every floor, permitting flexibility for two tenants per floor.
- Interior load: Lighting: 15 W/sqm - power: 20 W/sqm.

4-2.11 New Sustainability Standers

Porta Nuova has achieved excellence in the field of eco-sustainability, thanks to the state-of-the-art technologies which protect and preserve the environment. For this reason, Business District Varesine has been awarded the prestigious international sustainability pre-certification, LEED GOLD, for Leadership in Energy and Environmental Design.
The LEED certification system is based on six key points:
• the regeneration of downgraded areas
• water efficiency

• energy performance
• selection of materials
• interior environment quality
• innovation

LEED GOLD certified buildings are considerably more efficient than average existing buildings, therefore allowing consistent savings on running costs.
The three meters high ceilings, with no lowered sections, the penetration of natural light and the continual air circulation contribute to a comfortable microclimate in all spaces.
There will be more than 1.500 new trees in the park, in the public gardens and along the pedestrian paths.

4-2.12 The Gate of Knowledge

Milan plans for creativity. Porta Nuova will play a pivotal role in the network of cultural landmarks of the city. Through extensive dialogue with the local communities, the operation has been finely tuned to pay the greatest possible attention to the character and the past of the various districts. Libraries, museums, bookshops, artisan's ateliers and educational establishments will help foster the youthful energies that Milan has always attracted successfully. The neighborhood will offer to the people of Milan new spaces to meet and socialize in the center of the city. Porta Nuova will host the Modem, destined to become an educational complex devoted to creativity, a campus with exhibition halls, classrooms and labs; the House of Memory, a museum, dedicated to the Resistance in Milan and to Terrorism victims; the Fondazione Riccardo Catella, studying and promoting the best practices in territorial development; the"Incubatore dell'Arte", an experimental incubator housing the cultural and artistic initiatives that were born in the Isola neighborhood, an exhibition center in the Garibaldi area and a cultural center in Varesine area [202].

- It was chosen to be one of the references examples to the case study because this building located in the line axis of the case study, so it is in the same surrounding, applied some techniques to increase the daylighting, enhance the interior environmental quality, using specific materials to maximize attention to efficiency as the materials used embody high quality standards and their long-lasting nature is reflected in the low maintenance costs and, this building utilized the terrace to be an outdoor space for the employees for relaxation and take a break and the case study already has a terrace that will be utilized to be an outdoor space.

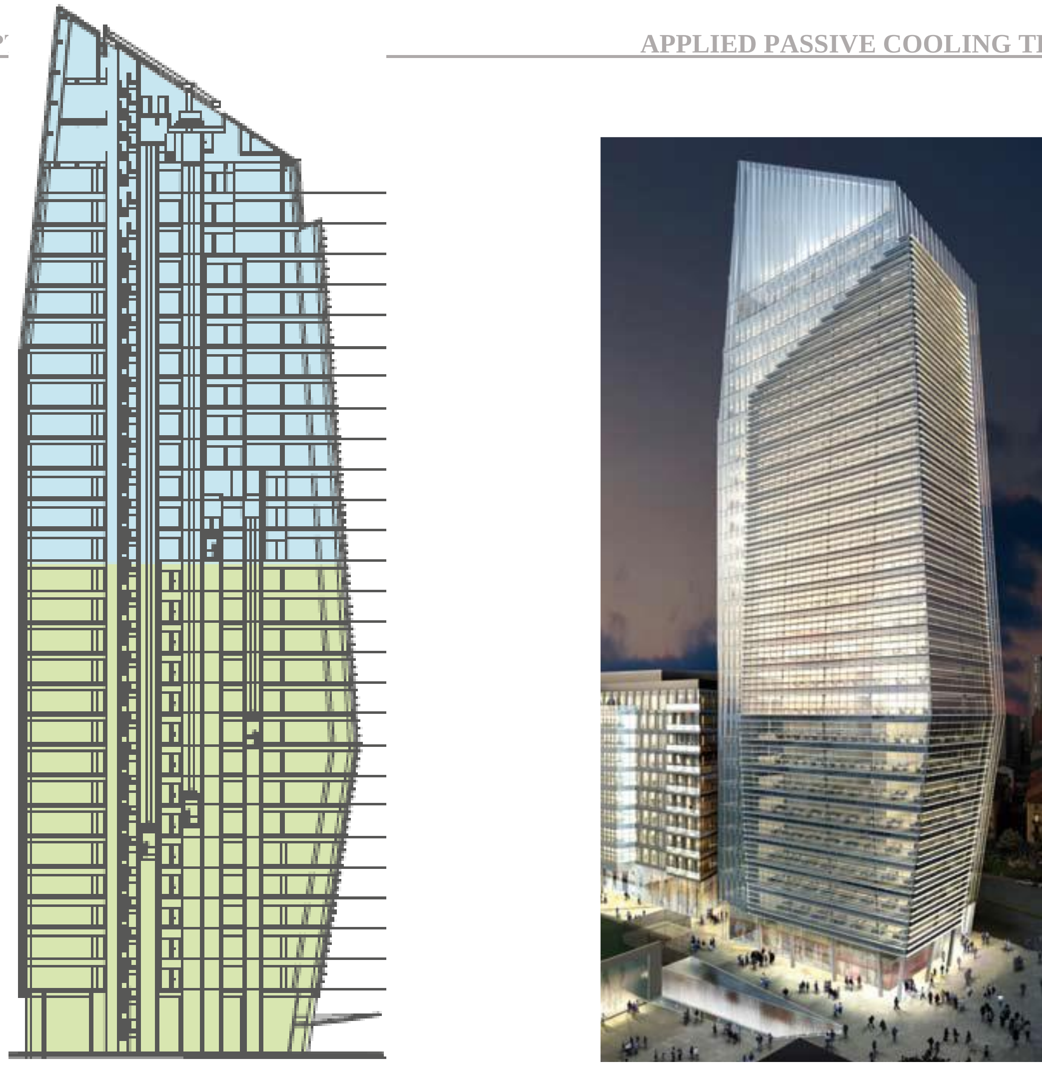


Figure 45: Section and 3D Shot for Varesine Office Building (Source: [202])

Figure 46: Repeated Floor Plans for Varesine Office Building (Source: [202])

4-3 Green Life: The Credit Agricole Headquarters in Parma

"Minimal, simple and green" is the energy strategy that the design studio Frigerio Design Group has adopted for Green Life, the new Crédit Agricole headquarters in Parma, Cavagnari area. The Crédit Agricole di Parma complex, characterized by 12 thousand square meters of built and over 70 thousand square meters of park, was created to host workplaces in step with the times and contain innovative technologies for the benefit of the environment and workers.

The new volumes that make up the Crédit Agricole headquarters in Parma are three, two office buildings and a multi-purpose Forum. The car parks, technical rooms and warehouses are underground in favor of the vast green area. These are architectural forms that arise from the context to recall the pre-existing ones with the aim of enhancing the territory both from the point of view of the memory of the past epochs and in favor of the new environmental awareness towards the future.

Figure 47: The Credit Agricole headquarters (Source: [203]).

4-3.1 General Information

Team: Politecnica Ingegneria e Architettura, Frigerio Design Group, Policreo S.r.l.
Project: ‘Green Life’ Crédit-Agricole Italia Bank New Headquarter, (20.500 m2).
Location: Parma, Italy
Dates of services: 2013-2015.
Dates of Construction: 2016-2018.
Credit: Enrico Cano, Mario Carrieri.

4-3.2 Building Form

The two Green Life buildings that house the offices have a compact shape to reduce heat loss and a linear plan to optimize space. According to the principles of bioclimatic design.

4-3.3 Facades

The main facades of the volumes are arranged to the south and north, the façade elevation and the internal functions vary according to their orientation. The south sides of the two buildings house the open space offices, the facades are mainly glazed and protected by a sunscreen system, while the north sides of the two buildings welcome the closed offices. The north-facing facades are built with high insulation walls, finished with terracotta tiles and have a reduced number of windows compared to the south façade.

4-3.4 Strategies for energy saving

The buildings of the Crédit Agricole headquarters in Parma have been designed with the aim of obtaining the minimum ecological footprint and maximum energy savings, **so much so that the complex has obtained the prestigious international LEED gold certification** .
In addition to the passive design strategies concerning compact volumes, the orientation of the building, the positioning and sizing of the windows and the relative blackout systems and a correct use of materials and construction technologies.

Compact volumes to reduce losses, placed along north-south heliothermic axis to maximize passive solar gains. The Eco-Uffici south facades are fully glazed and protected by a modular shading, while the north facades have reduced windows and outside high-performance walls

Figure 48: Shows the sunshades that prevent sun rays from the glassed facades (Source: [203]).

4-3.5 Energy Production

Green Life uses renewable sources such as geothermal and photovoltaic energy and has a Phyto depuration plant . The roofs of the two office buildings host a series of 428 KW photovoltaic panels, while in the subsoil an 800 KW geothermal system is installed. The Phyto depuration plant causes the gray water to be recovered and used for toilet drains.

Figure 49: Shows the Photovoltaics Panels on the roof (Source: [203]).

4-3.6 Smart working in the Crédit Agricole headquarters

The technologies inside the buildings of the Crédit Agricole headquarters in Parma promote energy savings by minimizing the waste of resources and materials and support the work-life balance policies. Individual printers and baskets disappear, they are replaced with technologies for scanning and remotizing documents and ecological islands in order to discourage the use of paper and therefore avoid waste.

4-3.7 Natural Ventilation

Green Life hosts mostly multifunctional open spaces, abolishing fixed workstations. Natural ventilation and night-time free cooling guarantee sensory comfort for internal workspaces. These are places where people find optimal conditions from an acoustic, hydrothermal and lighting point of view and therefore find themselves working in the best environmental conditions. In the central strip of Green Life's buildings, natural ventilation and visual comfort are favored by a series of double, triple or quadruple height spaces, with an interior garden and pond, made to encourage natural ventilation in spring and autumn, as well as by pools and internal gardens.

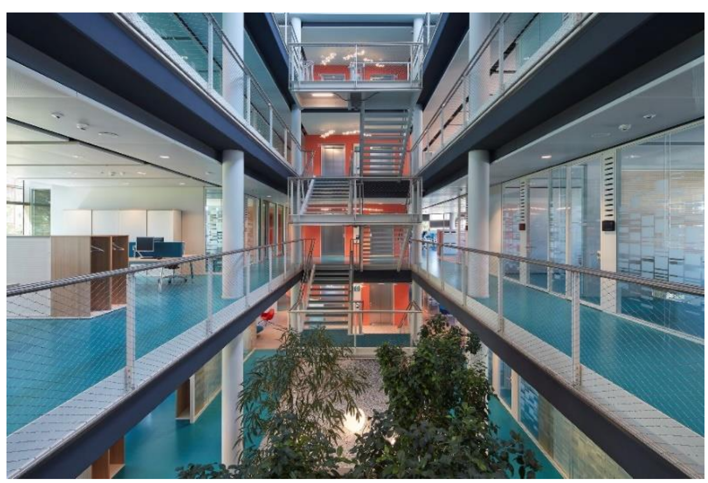


Figure 50: Shows the green atrium inside the building that help in refreshing the air (Source: [203]).

Figure 51: Shows the green atrium inside the building that help in refreshing the air, (Source: [203]).

4-3.8 Offices

These measures allow a new vision of the workplace by the employees and place the workers and their well-being at the center of attention. Employees go to the office no longer by obligation but for a pleasant choice, using laptops and modern communication technologies to work occasionally from home by adopting a highly international working mentality and in step with the times [203].

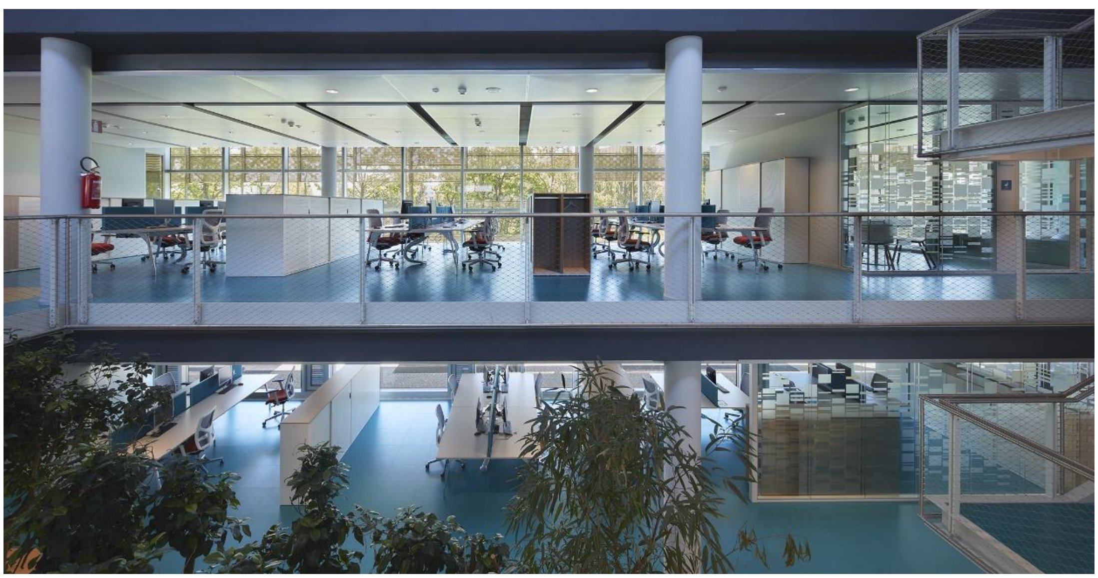


Figure 52: Shows the Open workspaces that helps in natural ventilation inside the building and the glassing faced that helping in daylighting to reduce the artificial lighting, (Source: [203]).

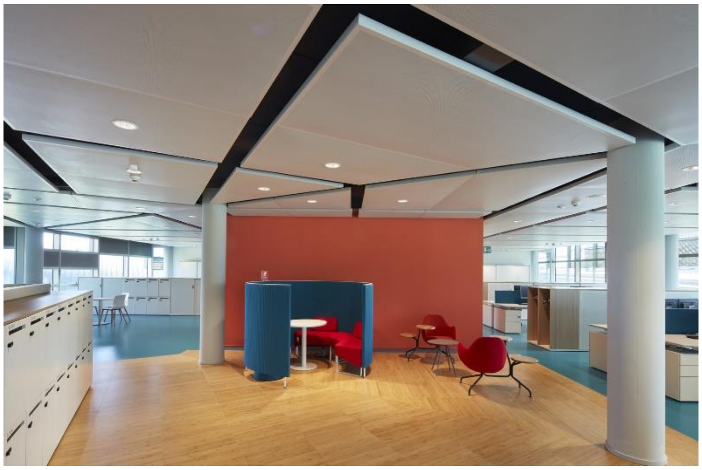


Figure 53: Shows the Open workspaces that helps in natural ventilation inside the building and the glassing faced that helping in daylighting to reduce the artificial lighting, (Source: [203]).

- It was chosen to be one of the references examples to the case study because this building was concentrated to apply green life inside the building with an interior garden and pond, made to encourage natural ventilation to decrease the cooling load and increase the thermal comfort hours inside the building and make the employees feel that they are working in a pleasant place and also, the positioning and sizing of the windows for air movement inside the building. And all of that will be applied for the case study.

4-4 Conclusion

As it shown some examples of office buildings that located in Italy, applied some passive techniques to increase the daylighting, to enhance the interior environmental quality, like using specific materials as the materials used embody high quality standards and their long-lasting nature is reflected in the low maintenance costs and apply green life inside the building with a green atrium (encourage natural ventilation to decrease the cooling load and increase the thermal comfort hours inside the building) also, the positioning and sizing of the windows for air movement inside the building. As all that decrease the usage of the air condition systems in the summer as result of increasing the thermal comfort hours and using the natural ventilation techniques.

As a result of what showing above, the using of the passive cooling techniques in the office buildings decreased the total cooling energy demand for it, and that relies to decrease the total energy consumption of the office buildings in general. Simultaneously that will help in decreasing the economic crisis in the world and increase the utilization of Passive techniques in the whole construction sector.

CHAPTER FIVE

Lampedusa Office Building

(Milan, Italy) Case Study

5-1 Data Collection for The Building

The first and important thing for any project is the data collection as it is the process of gathering and measuring information on targeted variables in an established system for the analysis, which then enables one to answer relevant questions and evaluate outcomes.

5-1.1 Site Analysis

5-1.1.1 Location

Milan is a city in northern Italy, capital of Lombardy, and the second-most populous city in Italy after Rome, with the city proper having a population of 1,372,075 while its province-level municipality has a population of 3,242,420. Its continuously built-up urban area (that stretches beyond the boundaries of the Metropolitan City of Milan) has a population estimated to be about 527 over 1,891 square kilometers (730 square miles). The wider Milan metropolitan area, known as Greater Milan, is a polycentric metropolitan region that extends over central Lombardy and eastern Piedmont and which counts an estimated total population of 7.5 million, making it by far the largest metropolitan area in Italy and the 54th largest in the world. Milan served as capital of the Western Roman Empire from 386 to 402 and the Duchy of Milan during the medieval period and early modern age.

Figure 54: Italy map, (Source: [204]).

Milan is considered a leading alpha global city, with strengths in the field of the art, commerce, design, education, entertainment, fashion, finance, healthcare, media, services, research and touri sm. Its business district hosts Italy's stock exchange and the headquarters of national and international banks and companies. In terms of GDP, it has the third-largest economy among European cities after Paris and London, but the fastest in growth among the three, and is the wealthiest among European non-capital cities. Milan is considered part of the Blue Banana and one of the "Four Motors for Europe".

Lampedusa Office Building is located in Milan, Italy.at latitude 45°26'04.42" N and longitude 9°11'26.49" E.

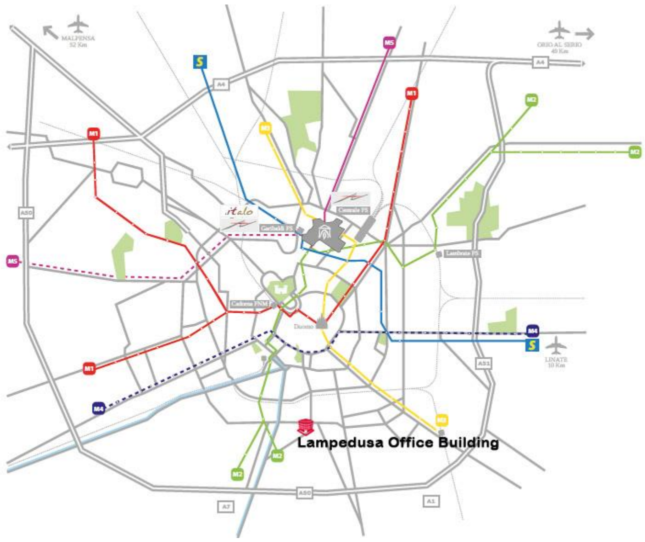


Figure 55: Analysis map for the building location in Milan, (Source: Author, 2019).

Located in the linear axis with Duomo (Milan City Center) and Porta Nuova (The Big Commercial District)

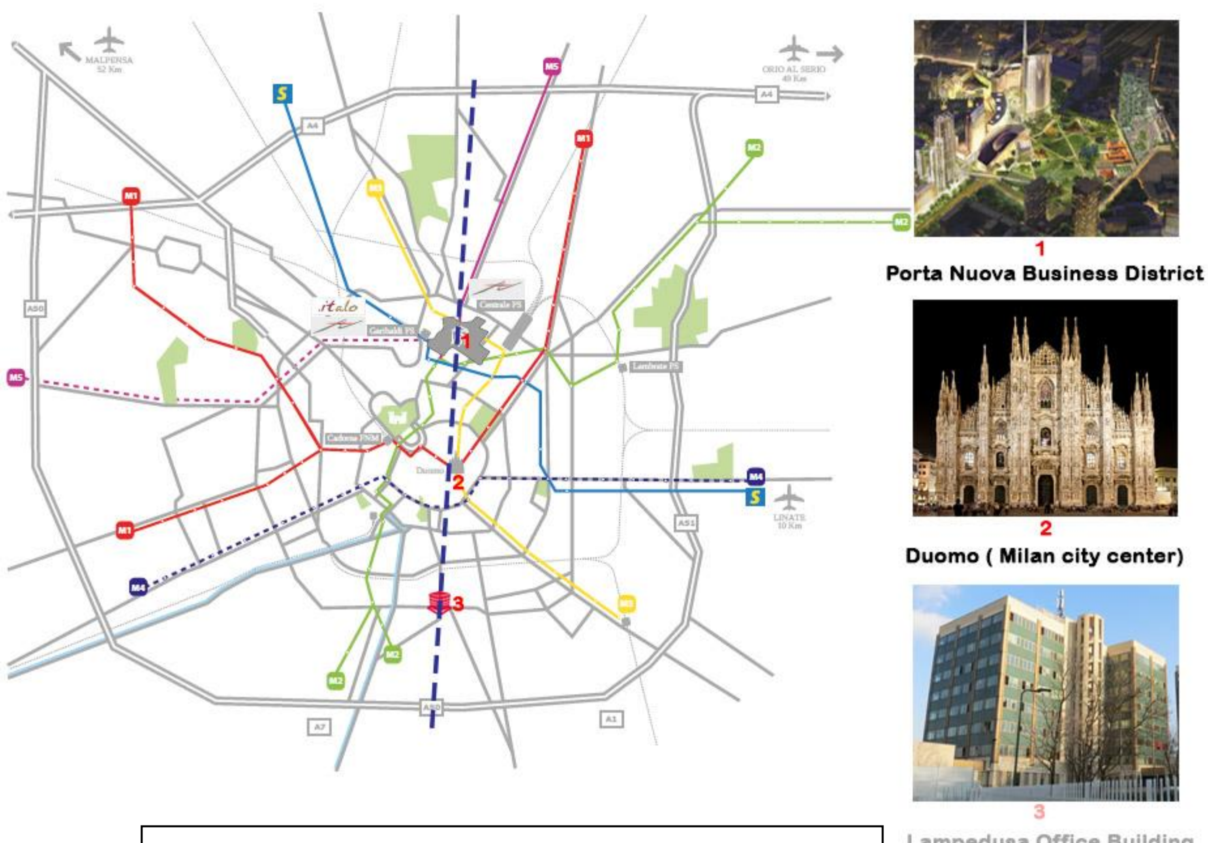


Figure 56: Analysis map for the building location from Milan city center, (Source: Author, 2019).

Figure 57: Analysis map shows the public transportation around the building location, (Source: Author, 2019).

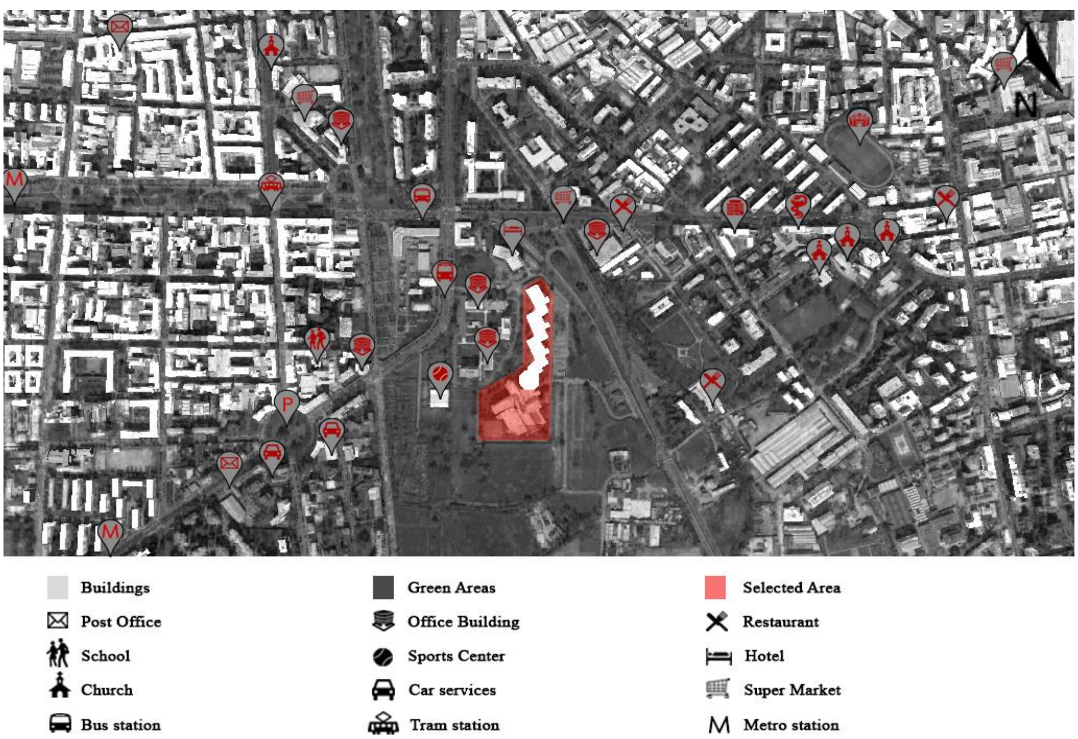


Figure 58: Analysis map shows the function of surrounding buildings, (Source: Author, 2019).

5-1.2 Climatic Analysis

5-1.2.1 Climate

Milan has a humid subtropical climate , according to the Köppen climate classification, or a temperate oceanic climate, according to the Trewartha climate classification. Milan's climate is similar to much of Northern Italy's inland plains, with warm, sultry summers and cold, foggy winters. However, the mean number of days with precipitation per year is one of the lowest in Europe. The Alps and Apennine Mountains form a natural barrier that protects the city from the major circulations coming from northern Europe and the sea.

5-1.2.2 Air Temperature

Winter, from December to February, is cold, wet and gray. Temperatures often remain around freezing (0 °C or 32 °F) also in the daytime, and the sky remains overcast for long periods. **Fog**, once very common, has become quite rare within the city, where the so-called urban heat island effect also makes the temperature less cold, especially at night.
The wind is usually weak or absent, a warm and dry wind that comes down from the Alps and is able to bring clear skies and good visibility (a sign of its presence, in addition to mild air, is the possibility to see the snow-capped Alps).
There is a moderate amount of rainy days, even though the winter is relatively dry when compared with the other seasons. **Snow** usually falls at least once every year, and sometimes can be abundant, but tends to melt soon enough. In the city, because of the heat island, snow accumulates with more difficulty than in the surrounding countryside and in the hinterland towns.
Every now and then, cold air masses from Eastern Europe can bring fairly intense frosts, though the temperature rarely drops below -10 °C (14 °F).
Typically, from the second half of February, the temperature tends to increase, and highs exceed quite often 10 °C (50 °F).

Spring in Milan is initially unstable, and gradually becomes a pleasant season, especially from mid-April to late May, when there are many sunny days, with mild or pleasantly warm temperatures during the day. In March, the first mild days alternate with cold days; in April it can still be quite cold, especially in the first half of the month. Atlantic depressions, which cause rainfall, are quite frequent. In May, the first afternoon thunderstorms may occur.

Summer, from June to August, is hot and muggy, and generally sunny. The heat is felt due to high humidity and low or no wind, which are conditions typical of the Po Valley, but also to the fact that in the city the heat is trapped between buildings. Sometimes an Atlantic front, able to bring cool and rainy weather, can pass also in summer; more often, on sunny days, thunderstorms can erupt in the afternoon and in the evening.

Autumn offers several nice days in September, and sometimes on early October, then quickly becomes cloudy and rainy. The first cold days typically occur in November. Overall, autumn is the rainiest season of the year. Although the number of rainy days is not too high, when it rains, the rain tends to last several hours, even the whole day.

Milan - Average temperatures

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min (°C)	-1	0	4	7	12	15	18	18	14	9	4	0
Max (°C)	6	9	14	17	22	26	29	29	24	18	11	6
Min (°F)	30	32	39	45	54	59	64	64	57	48	39	32
Max (°F)	43	48	57	63	72	79	84	84	75	64	52	43

Milan - Average precipitation

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Prec.(mm)	65	65	80	80	95	65	70	95	70	100	100	60	945
Prec.(in)	2.6	2.6	3.1	3.1	3.7	2.6	2.8	3.7	2.8	3.9	3.9	2.4	37.2
Days	7	7	8	8	8	8	6	7	5	7	9	6	86

Table 4: Monthly comparison to show average temperature and average precipitation for Milan climate, (Source: Climates to travel, 2019).

5-1.2.3 Humidity

Relative humidity typically ranges between 45% (comfortable) and 95% (very humid) throughout the year, rarely dropping below 27% (dry) and reaching as high as 100%Wind is generally absent: over the course of the year typical wind speeds vary from 0 to 14 km/h (0 to 9 mph) (calm to gentle breeze), rarely exceeding 29 km/h (18 mph) (fresh breeze), except during summer thunderstorms when winds can blow strong. In the spring, gale-force windstorms may happen, generated either by Tramontane blowing from the Alps or by Bora-like winds from the

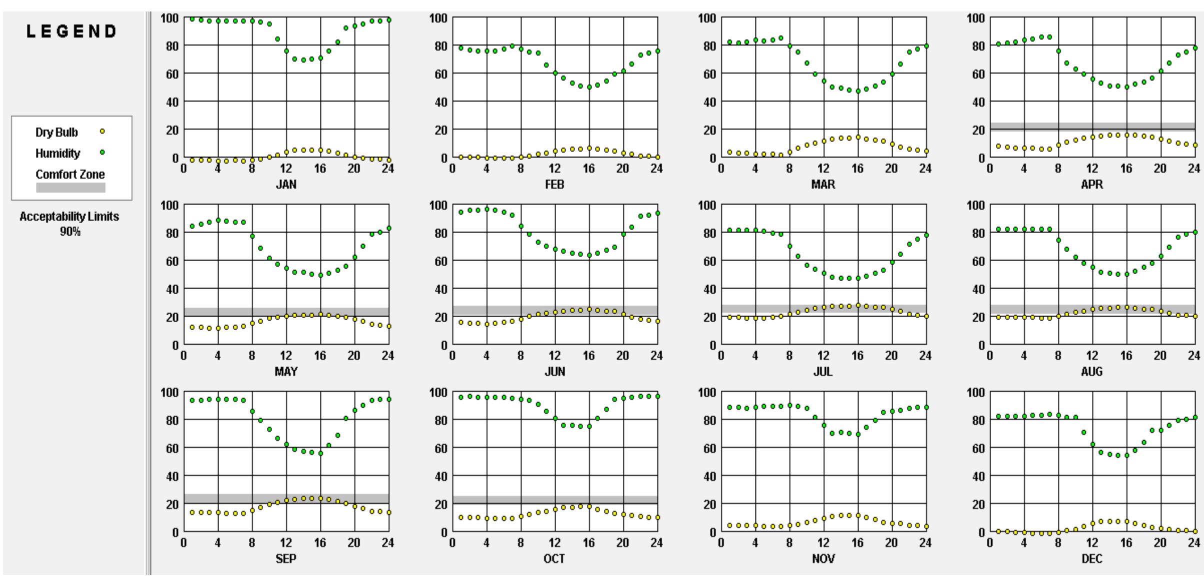


Figure 59: Dry bulb and relative humidity, (Source: Climate consultant, 2019).

5.1.2.4 Solar Radiation and Sun Path

The amount of **sunshine** in Milan is low from mid-October to February, when sunshine is rare, and even when the sun comes out, it is often weak and veiled in mist. On the contrary, there is a moderate amount of sunshine in spring, while it is quite frequent in summer, except for the albeit rare rainy days and the more frequent afternoon thunderstorms.

Milan - Sunshine

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours	2	3	5	6	7	8	9	8	6	4	2	2

Table 5: Monthly comparison to show sunshine hours per year, (Source: Climates to travel, 2019).

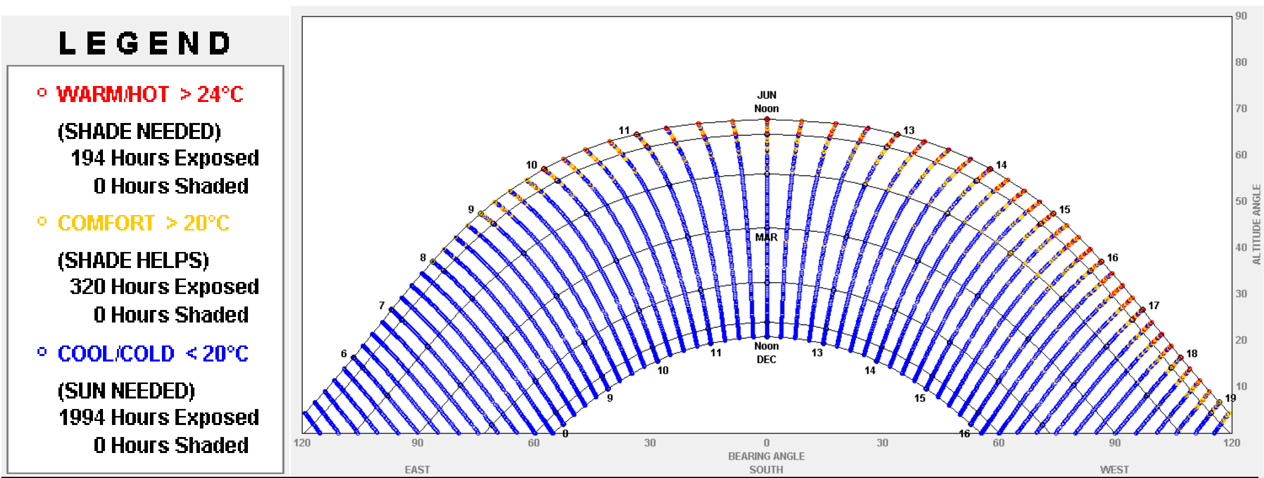


Figure 60: Sun path chart (21 December to 21 June), (Source: Climate consultant, 2019).

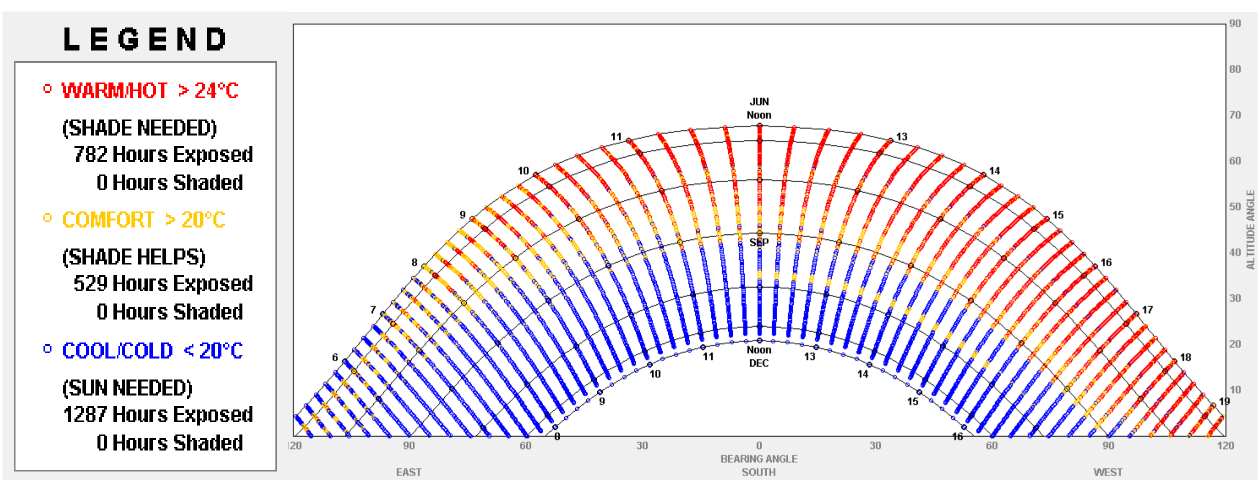


Figure 61: Sun path chart (21 June to 21 December), (Source: Climate consultant, 2019).

5-1.1.5 Wind Velocity and Direction

As you can see on the wind rose of Milan the privilege wind direction is almost from **W**est **S**outh **W**est, **S**outh **W**est, **E**ast **S**outh **E**ast and **E**ast, but this is not all the yearlong for example the **E**ast and **E**ast **S**outh **E**ast wind is blowing through summer and shoulder season but for **W**est **S**outh **W**est, **S**outh **W**est is almost all the year and this will affect directly on the passive design strategy that will use the wind direction like cross-ventilation or cooling the external envelope. The average yearly wind speed is 4 m/ sec, which is enough for natural ventilation.

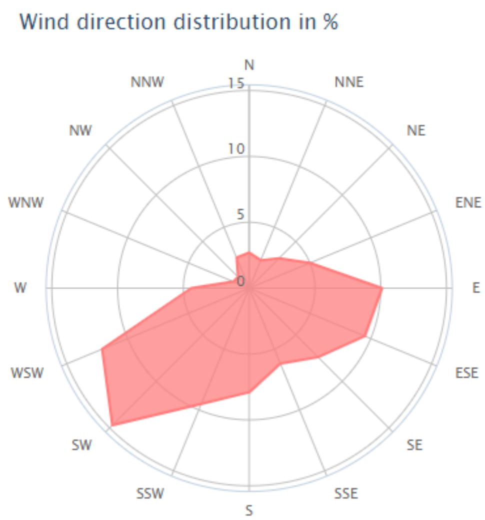


Figure 62: Wind rose for Milan shows the wind velocity, (Source: Climates to travel, 2019).

Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Year 1-12
Dominant wind direction													
Wind probability >= 4 Beaufort (%)	2	2	5	5	4	2	2	2	2	3	2	2	2
Average Wind speed (kts)	4	4	5	6	5	5	5	5	4	4	4	4	4

Table 6: Monthly comparison shows the average wind speed and average temperature, (Source: Climate to travels, 2019).

5-1.3 Building Description

The Lampedusa Office Building is a tower in Milan, Italy, located in Via Lampedusa 11, beside the Metro Stop. Regarding to the location of the tower, its facades looking on Via Lampedusa, the name of this street was a driver to the name “Lampedusa Office Building”. The building area is 71390m2 and 8 floors high with height 3.60 m for each floor, with 3 more underground floors.

The overall design of the tower is mainly based on the International Style architecture. The building is a simple form, the ground and underground floors are larger than the main body. The main structure is reinforced concrete (columns and beams) with asbestos cladding walls with single glass, half of it transparent and half of it opaque. The main function of the building is offices. Spaces that are used least are to be left unconditioned (e.g. storage areas, toilets, lifts or garages). The last floor is not used as it is empty.

Figure 63: Several views for the existing office building, (Source: Author, 2019).

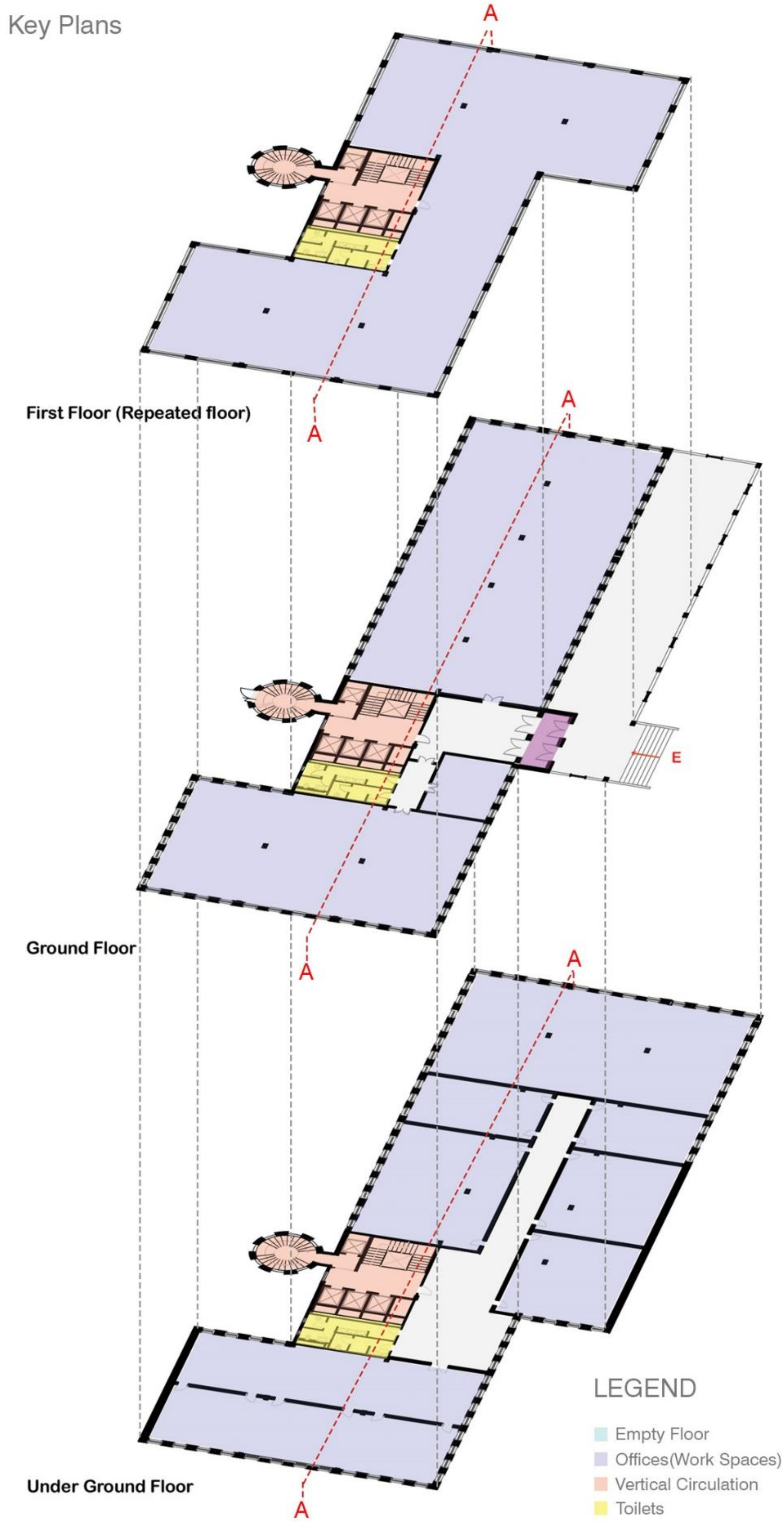


Figure 64: Floor plans (under ground floor, ground floor, repeated floor) for the existing office building, (Source: Author, 2019).

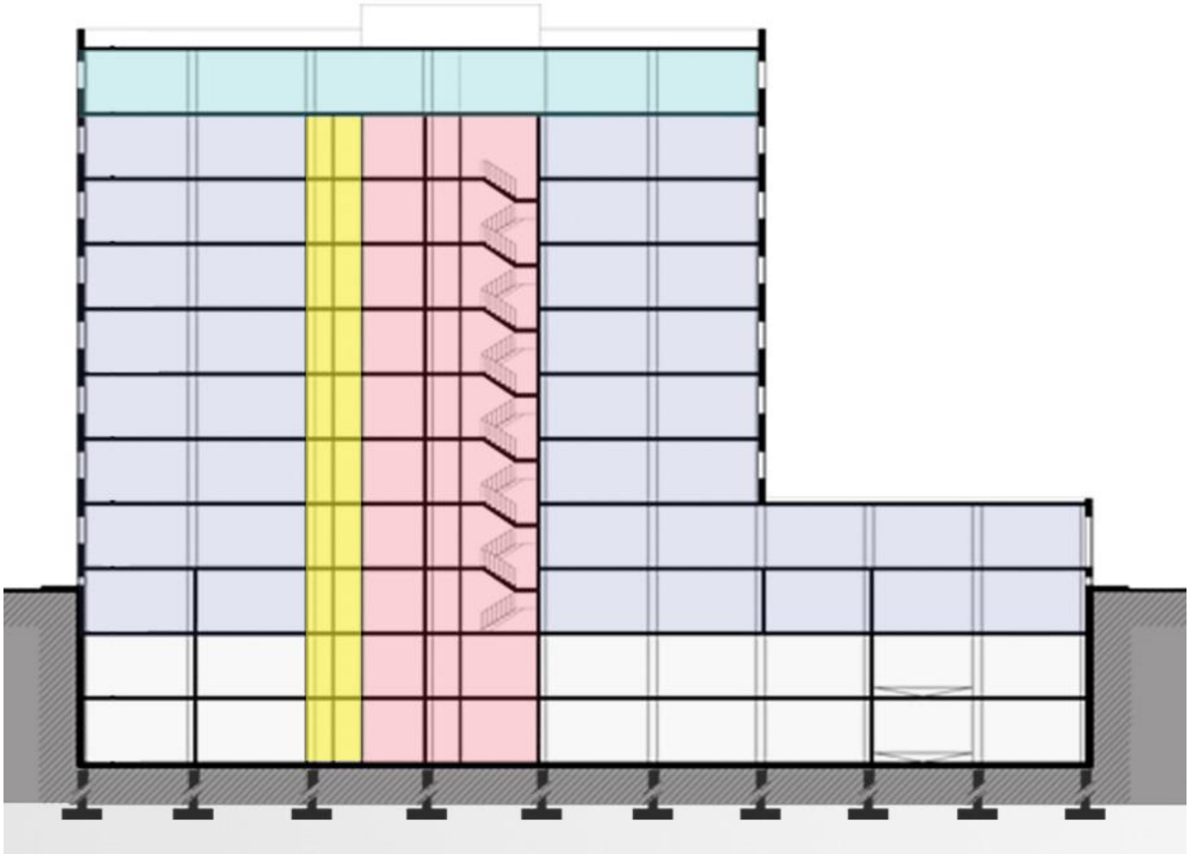


Figure 65: Section (A-A) for the existing office building, (Source: Author, 2019).

- **Operating Hours:** From 9:00 am to 6:00 pm (8 hours per day, 5 days per week).
- **Started Operating:** 1970.
- **Total Gross Floor Area:** 7139m2.
- **Building Envelope:** Used Asbestos cladding for walls and Single glazing curtain wall in north, south, east and west facades. Asphalt tiles for roof.
- **Type of Air Condition:** Fan Coil unit (4 pipe), water cooled chiller, water side economizer.
- **Occupant density:** 1-3 Occupants/Office.
- **Number of Occupants:** 180 Occupants.
- **Total Energy Consumption:** 296 kwh/m2 per year.

5-2 Strategy

Improving Energy Performance for the building, reduce the cooling load and increase the thermal comfort in summer and all of that was determined by two methods:

- Calculation that was taken from the existing building.
- Simulation that created by different simulation programs.

The calculations for annual energy use were done using the data sheets with each energy consumption system utilized in the building based on operating hours. The appropriate simulation tools are required to be efficiently and accurately to show the performance of proposed building design systems.

Simulation is based on energy plus simulation engine. DB creates a virtual environment where HVAC and lighting systems of the building are evaluated without compromising thermal comfort. DB has been used to predict the building annual energy use considering building design, building materials and optimization of thermal comfort, lighting, weather data and activity in the case study building. Simulink, THERM, ISOLPARMA and LBNL WINDOW software's to calculate the cooling load of the building, thermal comfort and thermal transmutation.

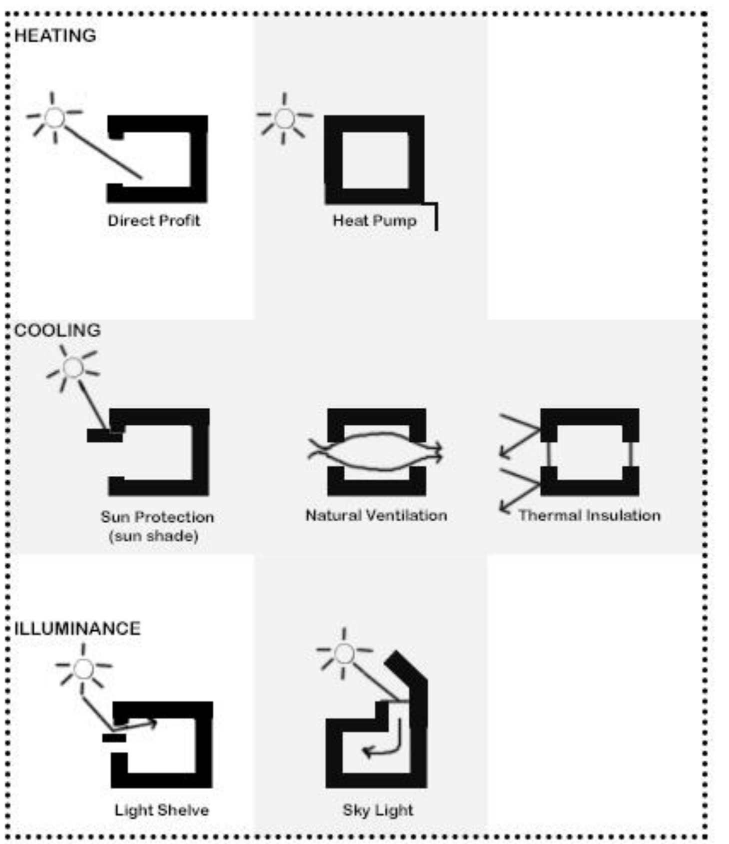


Figure 66: Main strategy for the proposal design, (Source: Author, 2019).

5-3 The Proposal

The proposed design building is based on improving the energy performance of the existing building for (lighting, equipment and total energy consumption). Also, to decrease the total cooling load by using natural ventilation techniques for passive cooling system and increase the thermal comfort.

5-3.1 Curtain Wall (Glassing Types)

Glassing type has a significant impact on cooling, heating and lighting energy demands. Also, effect on the indoor thermal comfort and it provide a convenient work environment as a result of the effect of daylighting.

- (Existing Building), Single glazed U value = 5.06 W/m2 K.
- (Proposed Building), Double glazed low E (0.1), U value = 1.1 W/m2 K.

Choosing the type of glassing depending on the impact on energy consumption for cooling, heating and lighting. The South West and the North East zones have the operable windows.

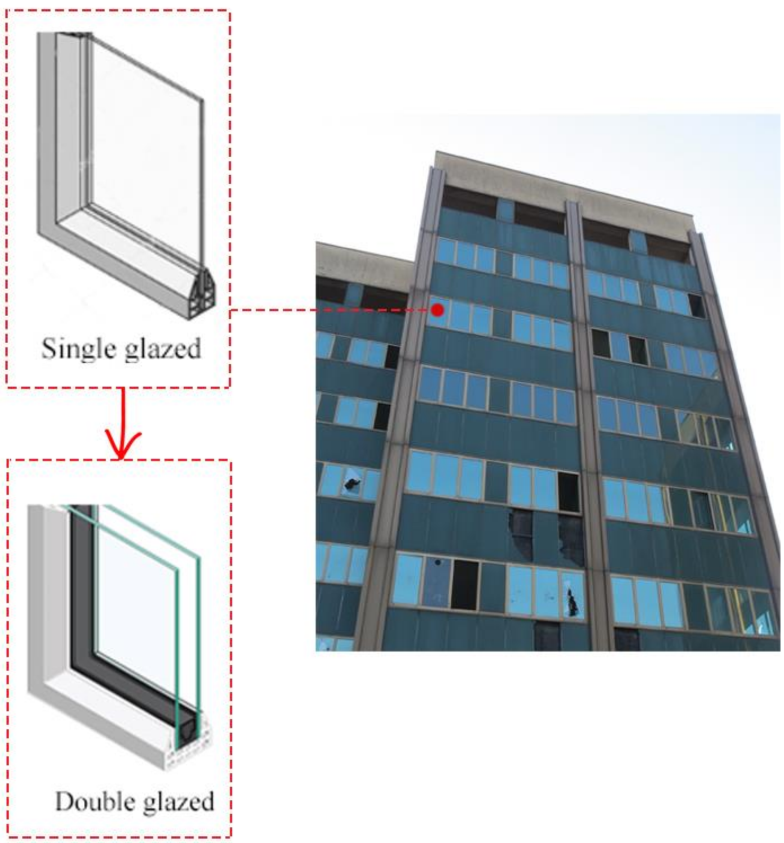


Figure 67: Using double glazing curtain wall rather than single glazing curtain wall for the new proposal of the office building, (Source: Author, 2019).

5-3.2 Operable Window “Cross Ventilation”

Knowing how the fresh air circulates within a structure around the people inside, and through its openings is crucial to determining how to optimize cooling and improve air quality. You can find this by looking at the building’s inlets and outlets. Wind Effect Ventilation controls the air quality inside of a building environmentally and cost-effectively.

When wind flows into the side of the building, each side of the building is hit with different amounts of pressure. The pressure changes force the air toward the lower pressure side of the building in the attempt to reach equilibrium. Ideally, having an opening on the lower pressure side allows the interior air to circulate out to the side with the lower pressure.

Wind Effect Ventilation relies on natural elements to provide a beneficial and comforting atmosphere within commercial and industrial buildings. This kind of ventilation is excellent in almost any climate and is an inexpensive method of cooling. There aren’t any operating costs, carbon emissions, nor energy consumption. So, there are openings (operable windows) in South West and North East to work as inlet and outlet for the prevailing wind to enter the building.

Figure 68: Using Operable windows rather than fixed windows in the new proposal of the office building, (Source: Author, 2019).

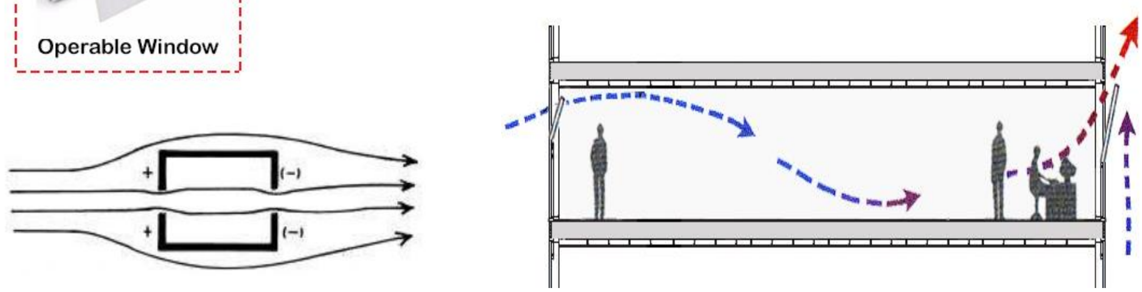


Figure 69: Sketches showing the air movement inside the office building, (Source: Author, 2019).

5-3.3 Solar Chimney "Stack Ventilation" in South East Façade

Changing in the services stairs in the building to act as solar chimney for the building to improving air flow inside the building. As Warm air is 'lighter' than cold air, so it naturally rises. Cold air naturally sinks. In buildings, where this air is trapped, you end up with a pressurization effect. Warm air gathers at the top of the building, creating relatively high or "positive" pressure that pushes the air out of the building. When warm air rises to the top, we're left with relatively low or negative pressure near the bottom of the building. The lower levels then act like a vacuum that sucks air inside through lower-level doors, windows and walls to balance the negative pressure. This drastic temperature difference causes a much more extreme stack effect, with intense positive pressure near the top of buildings and acute negative pressures near the bottom. Of course, cold air rushing in through ground-level doors and windows only multiplies the effect.

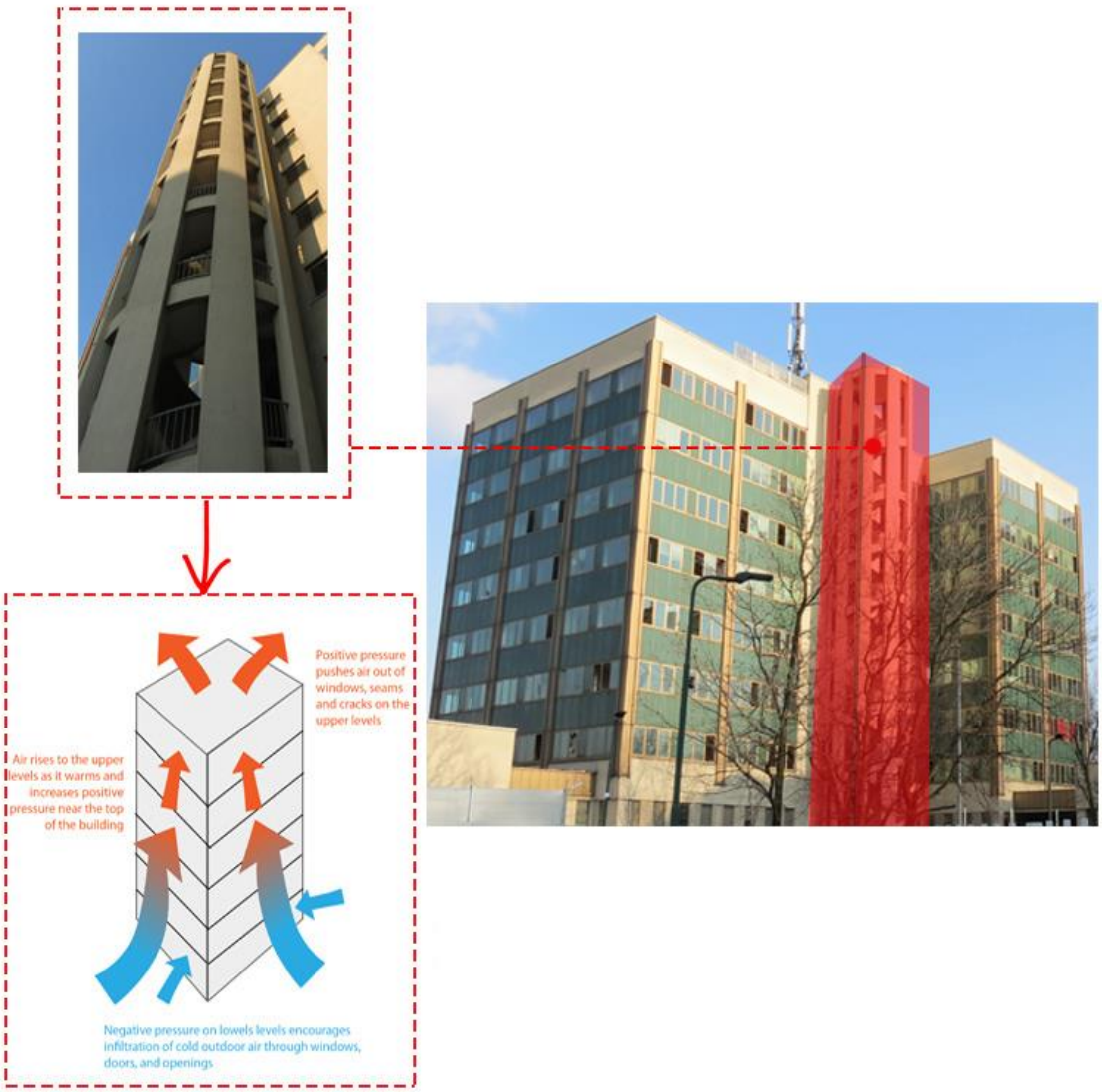


Figure 70: Changing the old service stairs to new mass that will act as solar chimney in the South facade in the new proposal of the office building, (Source: Author, 2019).

In Summer

Air is down naturaly through operable windows then solar chimeny as stack effect and draws used air up and exhauset it out of the building

Figure 71: The mechanism of the solar chimney in the summer season, (Source: Author, 2019).

5-3.4 Green Atrium in North East Facade

Atrium is a large open air or skylight covered space surrounded by a building. Atria were a common feature in Ancient Roman dwellings, providing light and ventilation to the interior. Modern atria, are often several stories high and having a glazed roof or large windows, and often located immediately beyond the main entrance doors (in the lobby).

Atria are a popular design feature because they give their buildings a "feeling of space and light." The atrium has become a key feature of many buildings in recent years. Atria are popular with building users, building designers and building developers. Users like atria because they create a dynamic and stimulating interior that provides shelter from the external environment while maintaining a visual link with that environment. That will create new types of spaces in the building, can increase commercial value and appeal, can enhance the performance of the building and adding a natural view inside the building.

Figure 72: Add a new mass to the existing building that will act as Green atrium in the North facade in the new proposal of the office building, (Source: Author, 2019).

5-3.5 Sun Shading Devices (Sun Protection)

Using optimized shading systems play a significant role in reducing the solar radiation effect on building which will reduce cooling demands and enhance indoor thermal comfort. There is a big effect of facades sunshades on energy consumption, as it dropped the energy consumption down. And that shows the best results with respect to both cooling and lighting energy in South West and South East.

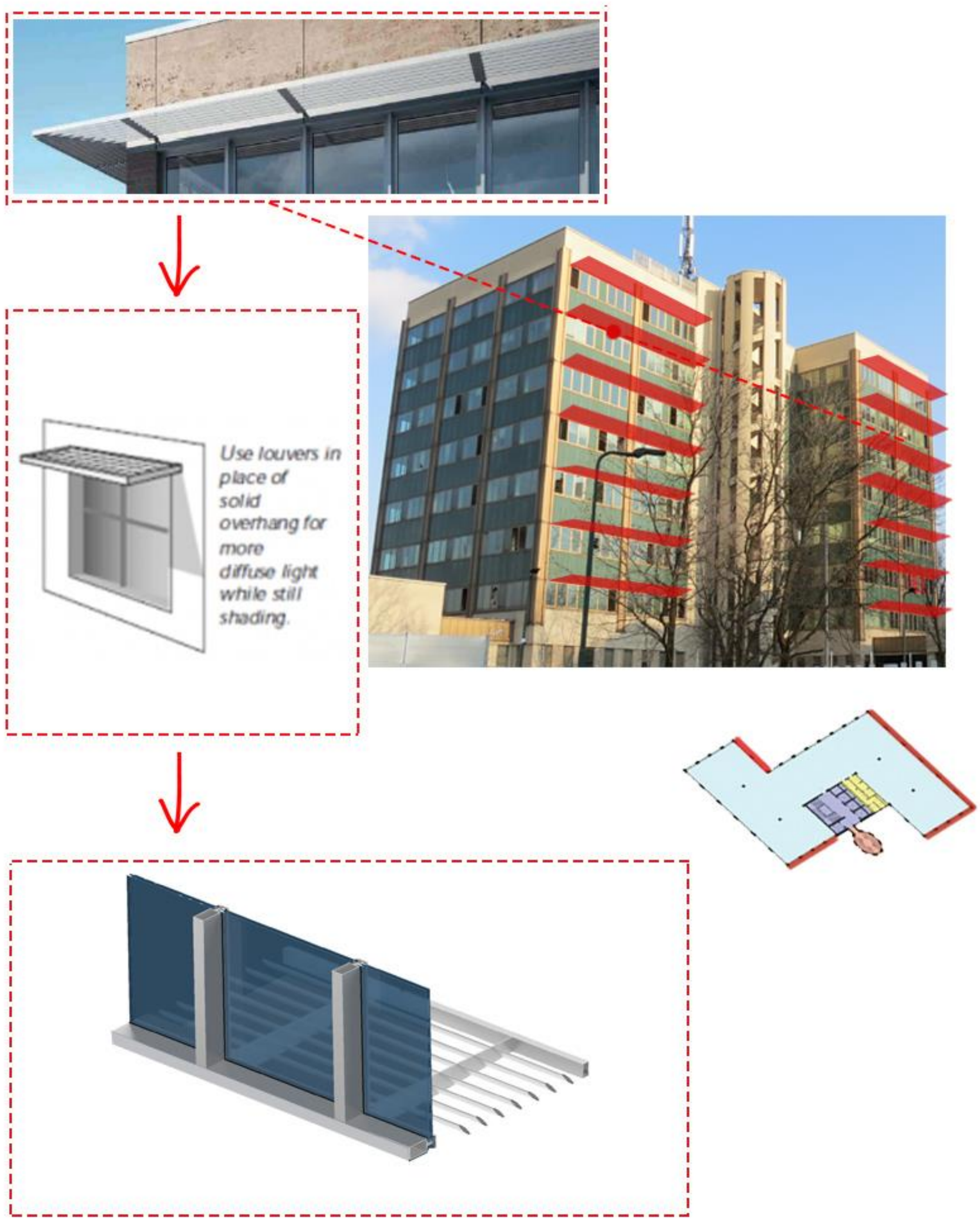


Figure 73: Adding sunshades in South facades in the new proposal of the office building, (Source: Author, 2019).

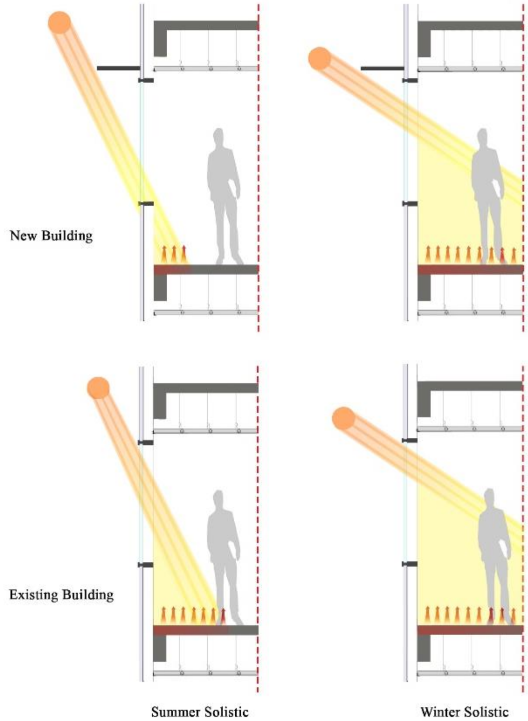


Figure 74: Sketch for the comparison between using sunshades in Winter and in Summer in the existing building and in the new proposal, (Source: Author, 2019).

5-3.6 Artificial Lighting

The design of the building with its transparent North and South facades allows the use of natural light in the offices. The shading system ensures an adapted, good daylight supply. In addition, light is brought into the building through the glazed atrium. In the open office space, an artificial lighting is installed that will be LED lighting with lighting control. Lighting depending on the occupancy schedule and the lighting power density was set to 6 W/m2. The default illuminances range is from 100 - 500 lux depending on the space type, also as the function of the building is office building.

The glazed atrium brings natural light to the building and allows the offices to naturally air. The building, including the atrium, meets the market standard for office buildings. Above the atrium, which also contains an internal garden, there are skylight, with a view to a natural ventilation system and a corresponding daylight strategy with adjustable ventilation grilles that are opened or closed according to the required air flow.

LED vs CFL vs Incandescent Cost	Incandescent	CFL	LED (Viribright)
Watts used (Office Building 400-500 Lumens)	40W	12W	6W
Average cost per bulb	$1	$2	$4 or less
Average lifespan	1,200 hours	8,000 hours	25,000 hours
Bulbs needed for 25,000 hours	21	3	1
Total purchase price of bulbs over 20 years	$21	$6	$4
Cost of electricity (25,000 hours at $0.15 per kWh)	$169	$52	$30
Total estimated cost over 20 years	$211	$54	$34

Table 7: Comparison between several types of artificial lights, (Source: Researcher, 2019).

5-3.7 Thermal Transmittance for Materials (U. value)

U-value is the most common measure and it incorporates the thermal conductance of a structure along with heat transfer due to convection and radiation. For all building constructions there is a maximal admissible thermal transmittance, which indicates the amount of heat flow in watts per square meter of construction with the temperature difference of 1 Kelvin (W/m²K).So, the proposed materials shows a very low U.value to reduce the heat transfer cross the building and improve the thermal comfort inside the building. By knowing the thickness and the thermal conductivity for each layer we can calculate the thermal transmittance.

ELEMENT	MATERIAL	HERMAL CONDUCTIVITY (W/mK)
Frame Detail	Aluminium Anodized	λ= 160
Gaskets	EPDM	λ= 0.25
Glazing	Laminated Glass Thermal Glass Float Glass	λ= 0.75 λ= 1 λ= 1
Spacer	Polysulphide Butyl Rubber Silica Gel Bulk Aluminium Anodized	λ= 0.4 λ= 0.24 λ= 0.13 λ= 160
Insulation	Polyamide 6.6 with 25% Glass Fiber	λ= 0.3
Insulation (Filling)	Polyurethane Foam	λ= 0.05
Gasket (Internal)	Silicon Foam	λ= 0.17
Sub Frame	PVC(rigid)	λ= 0.17
Fake Frame	Galvanized Steel	λ= 0.2
Sealant	Silicon	λ= 0.35
Insulation Panel		λ= 0.035

Table 8: The materials that will be used for the windows in the proposal design and its thermal conductivity, (Source: Researcher, 2019).

ELEMENT	MATERIAL	HERMAL CONDUCTIVITY (W/mK)
Frame Detail	Aluminium Anodized	λ= 160
Sealant	Silicon	λ= 0.35
Gaskets	EPDM	λ= 0.25
Glazing	Glass Toughened	λ= 1
Insulation	Polyamide 6.6 with 25% glass fibre	λ= 0.3
Spandrel Insulation	Rock Wool	λ= 0.038
Plasterboard		λ=0.285
Spacer	Polysulphide Butyl Rubber Silica Gel Bulk Aluminium Anodized	λ= 0.4 λ= 0.24 λ= 0.13 λ= 160
Slab	Gypsum Board Aluminium Painted	λ= 0.2 λ= 160
Roof Joint	Gravel Polyethylene HD Polyethylene LD Polypropylene Polyolefin Insulation Fiber Cement Concrete Galvanized Plate Steel Polyurethane Foam Polyurethane Foam Sprayed	λ= 0.7 λ= 0.5 λ= 0.33 λ= 0.22 λ= 0.18 λ= 0.031 λ= 0.6 λ= 0.85 λ= 62 λ= 17 λ= 0.05 λ= 0.024

Table 9: The materials that will be used for the wall in the proposal design and its thermal conductivity, (Source: Researcher, 2019).

5-3.8 Thermal Energy Storage (TES)

Use Phase Change Materials (PCMs) in the celling as it is ideal product for thermal management solutions. This is because they store and release thermal energy during the process of melting & freezing (changing from one phase to another). When such a material freezes, it releases large amounts of energy in the form of latent heat of fusion, or energy. Conversely, when the material is melted, an equal amount of energy is absorbed from the immediate environment as it changes from solid to liquid.

This property of PCMs can be used in several ways, such as thermal energy storage whereby heats, or coolness can be stored from one process or period and used later or different location. PCMs are also very useful in providing thermal barriers or insulation, for example in temperature-controlled transport.

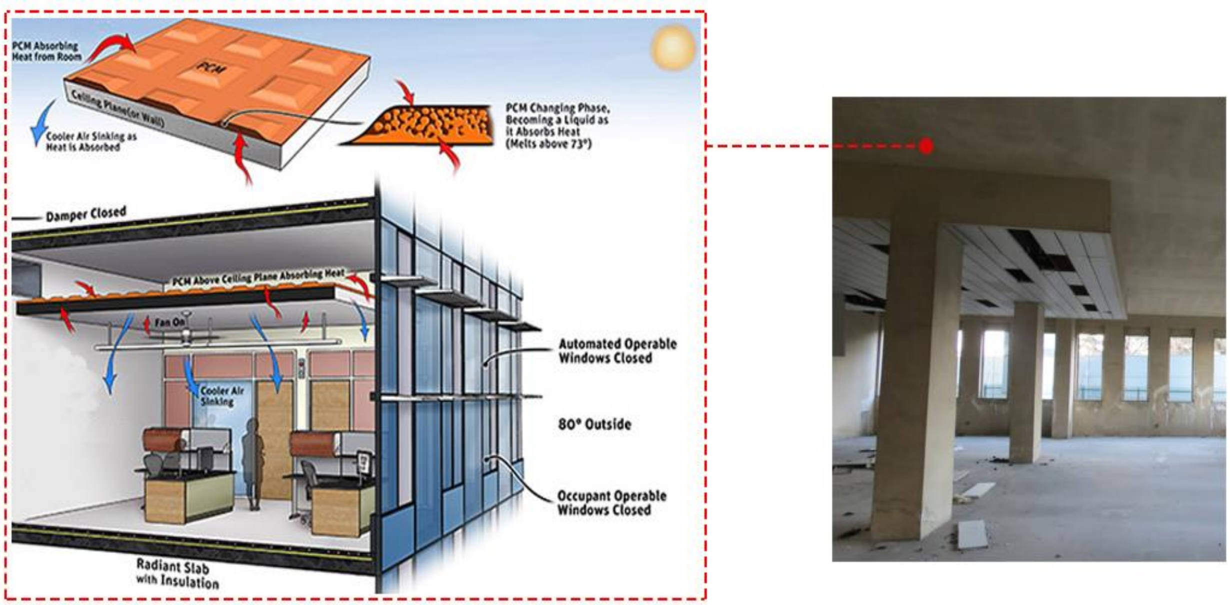


Figure 75: The PCM that will be used in the ceiling in the proposal design for the thermal management, (Source: Author, 2019).

5-3.9 HVAC

In the existing building the HVAC system that used is the fan coil unit 4 pipe, water cooled chiller. In the proposed building the HVAC system used is Heat Pump system. The Heat Pump will be connected to the solar chimney in the building, as in winter convert the cold air to warm air and in the summer convert warm air to cold air. Toilets, storage and basement floors are unconditioned areas. Temperature set point in offices and lobby is 26 ˚C for cooling and 18 ˚C for heating.

Figure 76: The mechanism for the heat pump in the summer season and the winter season, (Source: Author, 2019).

5-4 Results

5-4.1 Thermal Performance Calculations

At constrains conditions for Milan region:

- T external = -5 °C.
- T internal = 20 °C.
- Relative humidity = 50 %.
- External convective heat transfer coefficient he = 25 W/m2K.
- Internal convective heat transfer coefficient hi = 7,7 W/m2K.
- Internal resistance Rsi= 0,13 m2K/W.
- External resistance Rse=0,04 m2K/W.

By using ASHRAE chart, the Dew Point temperature is 9.5 °C

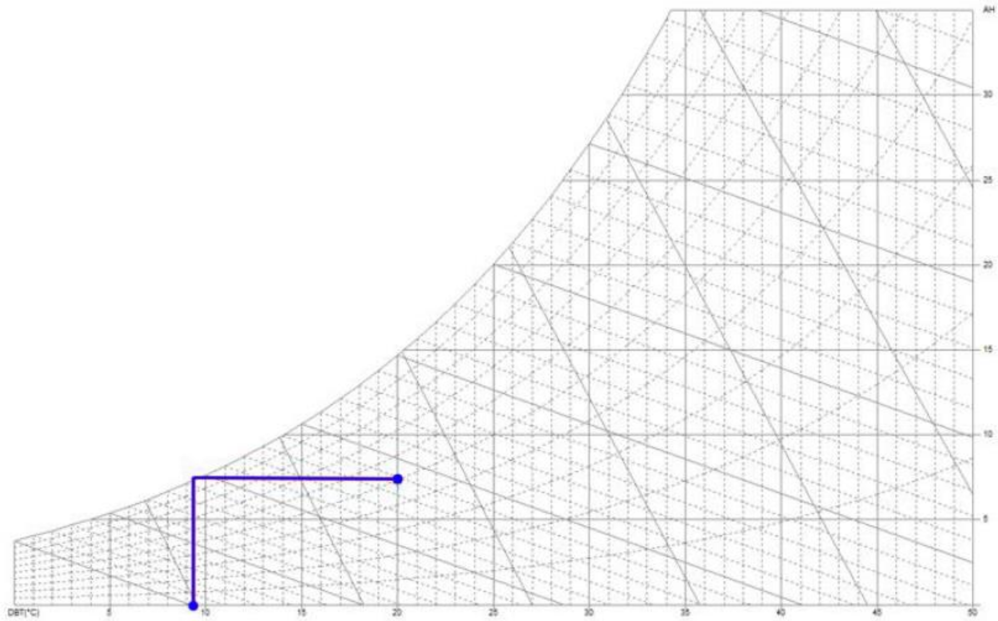


Figure 77: The Psychrometric chart to show the Dew point temperature, (Source: ASHRAE, 2019).

5-4.2.1 Curtain Wall

The dimensions are referred just to the glazing part. It's an insulated glass unit: the external pane is a toughened glass, with thickness of 8 mm; the internal one is laminated, made by float glass (8 mm) and PVB the interlayer of 0,38mm. The cavity between these two panes is filled with Argon 90% and is 18 mm thick.

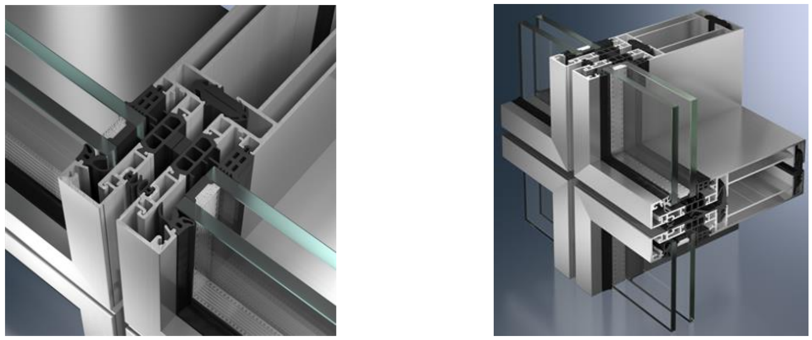


Figure 78: The type of the curtain wall that will be used in the new proposal from SCHUCO company, (Source: SCHUCO products, 2019).

This study is developed through the thermal and hygrometric analyses. The thermal analysis consists in the calculation of linear thermal transmittance, so thermal bridges, and U-value, that must be verified lower than the one set by normative UNI EN 13830:2015 for transparent closures, so Umax = 1.4 W/m2K. To calculate U-value it's used the component assessment method, that divides the representative element into areas of different thermal properties (e.g. glazing units, opaque panels and frames); by area weighting the U-values of these elements, with additional correction terms that describe the thermal interaction between these elements (Ψ-values), the overall façade U-value can be calculated. The hygrometric analysis checks the surface condensation: there is no condensation if the minimum temperature is higher than the dew point temperature (9.5 °C).

5-4.2.1 .1 Thermal Transmittance Calculations

The LBNL window software has been used to calculate the double glazing according to the right characteristics of the glazing and materials in between and then assigned to LBNL THERM to be evaluated. Knowing that the U.glass is 1.0 W/m2K given by the producer. Then from THERM we got the U.frame ,U.edge.

I. Mullion Analysis

- Mullion (glazing – glazing)

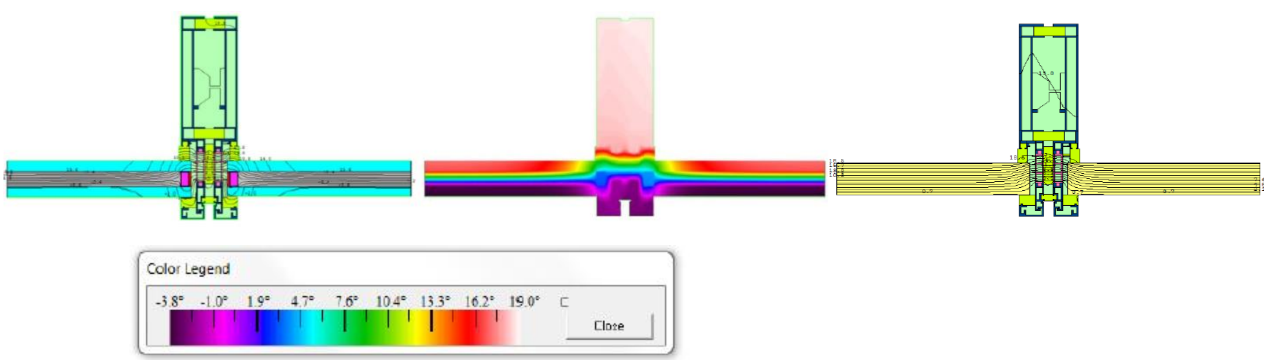


Figure 79: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the mullion curtain wall, (Source: THERM simulation program, 2019).

Frame + Glass Total Length		
	FRAME	EDGE
U	0.83	1.54
b	0.47	0.55

Frame + Insulation Panel Projected (X)		
	FRAME	EDGE
U	2.86	0.86
b	0.05	0.46

L_{Ψ}^{2D}	Ψ
0.944	0.398

Table 10: Showing the calculations for the U. Value for frame and edger for the double-glazed curtain wall for transparent part, (Source: THERM simulation program, 2019).

- Mullion (spandrel – spandrel)

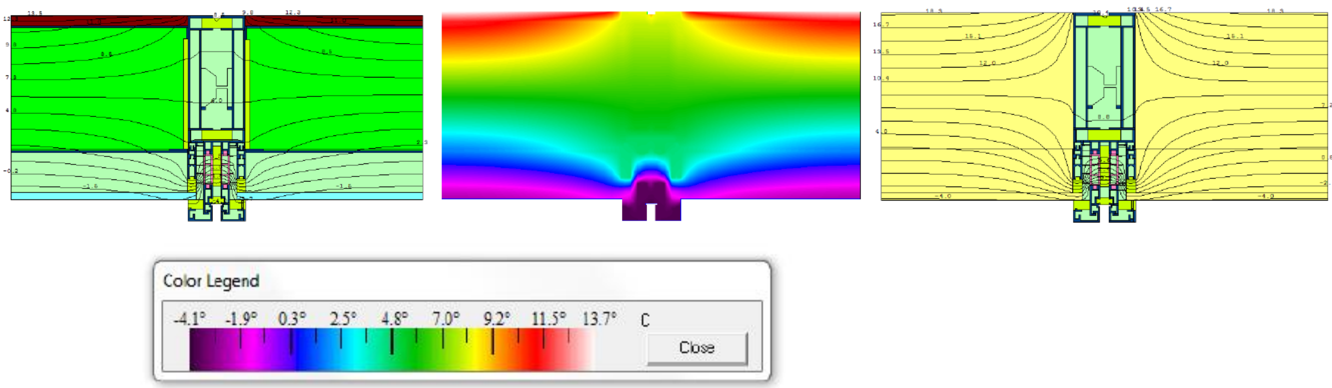


Figure 80: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the mullion curtain wall, (Source: THERM simulation program, 2019).

Frame + Insulation Panel Projected (X)		
	FRAME	EDGE
U	3.61	1.15
b	0.54	0.53

Frame + Glass Total Length		
	FRAME	EDGE
U	3.5	2.9
b	0.06	0.50

L_{Ψ}^{2D}	Ψ
1.251	-0.788

Table 11: Showing the calculations for the U. Value for frame and edger for the double-glazed curtain wall for opaque part, (Source: THERM simulation program, 2019).

II. Transom Analysis

- Transom (spandrel – glazing)

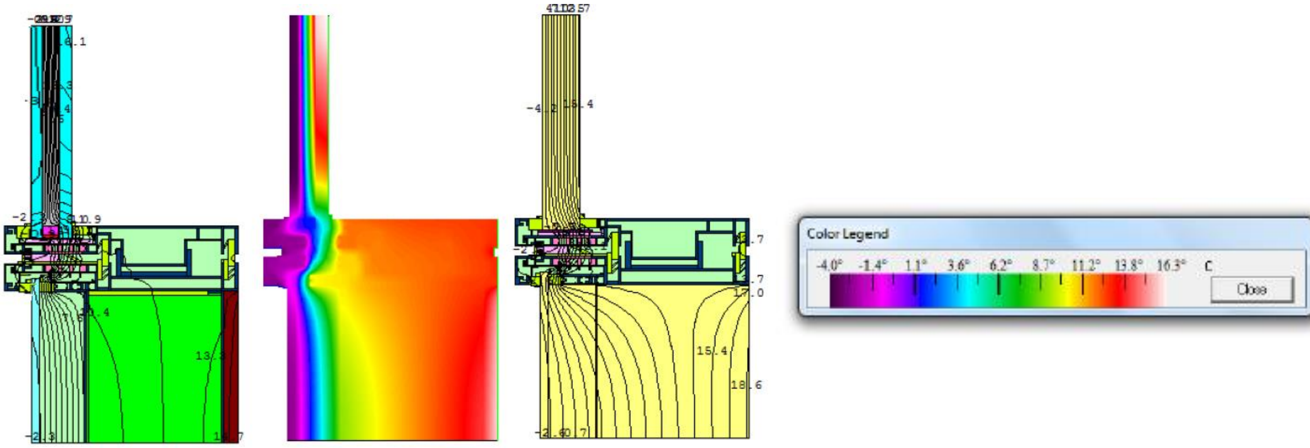


Figure 81: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the transom curtain wall, (Source: THERM simulation program, 2019).

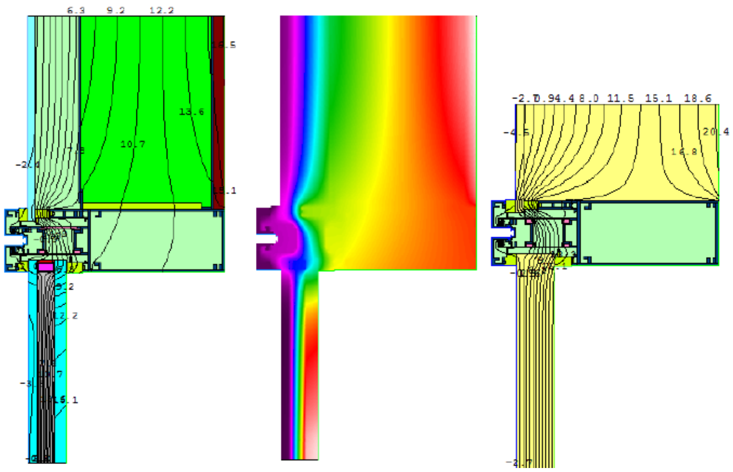
Frame + Glass Total Length		
	FRAME	EDGE
U	1.75	1.57
b	0.22	0.35

Frame + Insulation Panel Projected (Y)		
	FRAME	EDGE
U	5.7	0.88
b	0.07	0.30

L_{Ψ}^{2D}	Ψ
0.943	0.434

Table 12: Showing the calculations for the U. Value for frame and edger for the double-glazed curtain wall for transom, (Source: THERM simulation program, 2019).

- Transom (glazing - spandrel)



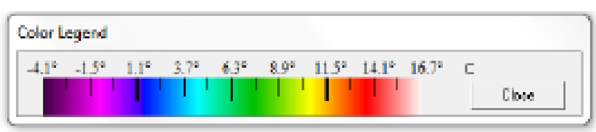


Figure 82: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the transom curtain wall, (Source: THERM simulation program, 2019).

Frame + Glass Total Length		
	FRAME	EDGE
U	1.9	1.5
b	0.211	0.4

Frame + Insulation Panel Projected (Y)		
	FRAME	EDGE
U	4.35	0.14
b	0.06	0.33

L_{Ψ}^{2D}	Ψ
0.949	0.466

Table 13: Showing the calculations for the U. Value for frame and edger for the double-glazed curtain wall for transom, (Source: THERM simulation program, 2019).

The data has been gathered according to the standards calculations, where the areas are referred to the analysis of the one unit. The following data are used to calculate the overall thermal transmittance of the unitized unit:

Area m^2	U-value W/m^2K
$A_g = 3.2$	$U_g = 1$
$A_p = 1.16$	$U_p = 0.241$
$A_m = 0.23$	$U_m = 1.93$
$A_t = 0.17$	$U_t = 1.93$
$A_{cw} = 4.76$	

	Mullion-Glazing	Mullion-Spandrel	Transom Middle (Glass- Spandrel)	Transom Edge (Glass- Spandrel)
Length (m)	Lmg = 2.57	Lmp = 0.93 m	Ltg = 1.25 m	Lp = 1.2 m
Linear Thermal Transmittance (W/mK)	$\Psi mg = 1.16$	$\Psi mp = -0.78$	$\Psi tg = 0.46$	$\Psi tg = 0.43$

Table 14: Table showing the area and U. Values for the curtain wall that already exist in the data sheet and the results from THERM, (Source: Standard data sheet and THERM simulation program, 2019).

The total Ucw value calculated from the previous data as following;

$$U_{cw} = \frac{A_g U_g + A_p U_p + A_m U_m + A_t U_t + L_{mg} \Psi_{mg} + L_{mp} \Psi_{mp} + L_{tg} \Psi_{tg} + L_p \Psi_p}{A_{cw}}$$

The Ucw= 1,184148 W/m2K which is < 1,4 the limit assigned by UNI EN 13830:2015, so the unit of the curtain wall verified the standard limit values.

5-4.2.1.2 Thermal Bridge in the Connections between Curtain Wall and wall

I. Roof Joint

In this joint the insulation of the roof stratigraphy helps in reducing the thermal bridge. The inner temperatures are in between green and red on the infrared diagram. Lower temperature on the interior side in the green region is equal to 10.2 °C which is > 9.5 °C, so no condensation occurs.

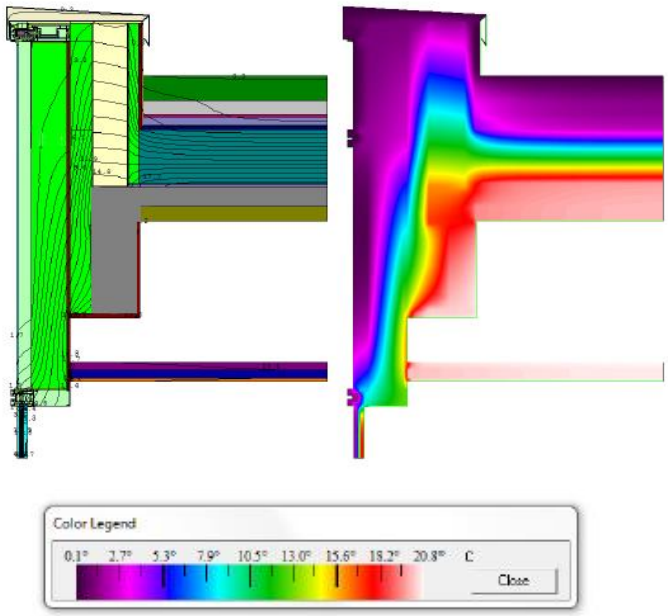


Figure 83: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the roof joint, (Source: THERM simulation program, 2019).

II. Slab Joint

The inner temperature values are in between green and red on the infrared diagram. Lower temperature on the interior side in the green region is equal to 10.6 °C which is > 9.5 °C, so no condensation occurs.

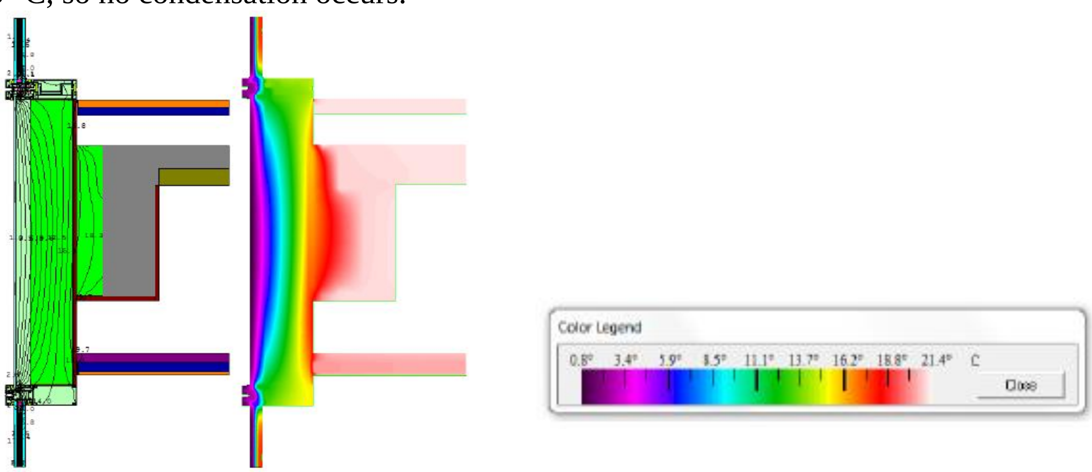


Figure 84: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the slab joint, (Source: THERM simulation program, 2019).

5-4.2.2 Operable Windows Calculation

The window analyzed is composed by an operable shutter and a fixed frame; the glass is composed (from inside) by a laminated glass 4mm + 0,78mm of PVB + 4mm, cavity 12mm filled with Argon, high performance low-e coated glass 4mm, cavity 12mm filled with Argon, clear float glass 8mm; the frame is done in aluminum. Dimensions: 140 mm x 114 mm.
Both window and wall have good thermal performances, the U values from data sheet are quiet low – glass 0.9 W/m2K, frame 1 W/m2K, wall 0.13 W/m2K; this analysis must check if the connection between the two is performant as well.

The thermal analysis consists in the calculation of linear thermal transmittance, so thermal bridges; it must be checked that the U value of window is lower than the one set by normative to UNI EN 13830:2015, so U.max = 1.4 W/m2K. The hygrometric analysis checks the surface condensation: there is no condensation if the minimum temperature is higher than the dew point temperature (9.5 °C).

The software THERM uses a finite-element method to model two-dimensional heat-transfer effects in building components (in this case connection between window and wall) to evaluate a product's energy efficiency and local temperature patterns. The outputs will be linear thermal transmittance and transmittance for the thermal analysis, isotherm diagram for the hygrometric analysis.

5-4.2.3.1 Thermal Transmittance Calculations

According to the normative UNI EN ISO 10077-2 to determine final linear thermal transmittance and U value of frame and window it has to be performed a double calculation: the first with the frame and glazing (FG) and the second with frame and an insulation panel (FP) with thermal conductivity λ= 0.035W/mK. Both length of panel and glass should be greater than 19 cm (in this analysis it is used length of 20cm).

I. Vertical Section for the Window

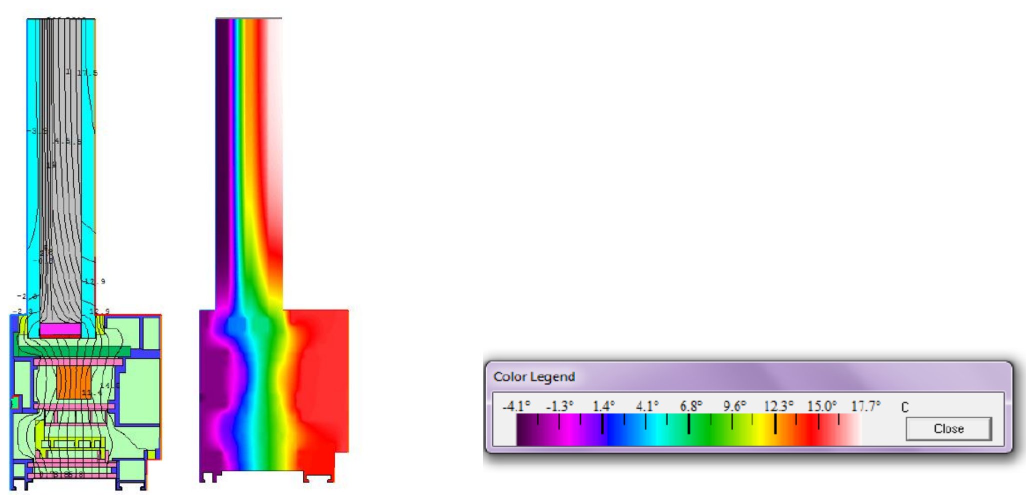


Figure 85: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the vertical section of the window, (Source: THERM simulation program, 2019).

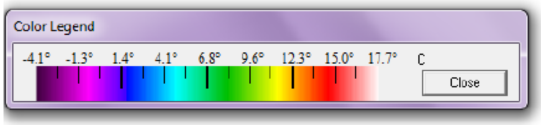
Frame + Glass (Total Length)	FRAME	EDGE
U	1,48	1,22
b	0,17	0,29

Frame + Insulation Panel (Projected (X))	FRAME	EDGE
U	1,51	0,77
b	0,18	0,11

L_Ψ^{2D}	Ψ
0,518	0,129

Table 15: Showing the calculations for the U. Value for frame and edger for the window, (Source: THERM simulation program, 2019).

II. Horizontal Section for the Window



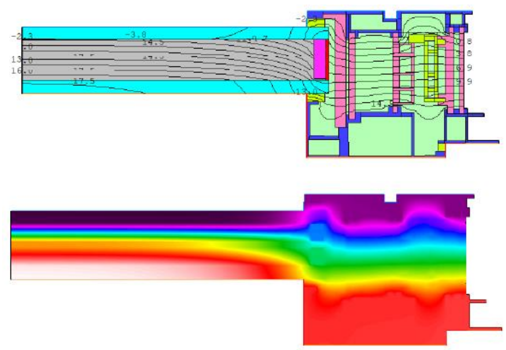


Figure 86: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the horizontal section of the window, (Source: THERM simulation program, 2019).

Frame + Glass (Total Length)	FRAME	EDGE
U	1,4	1,1
b	0,12	0,2

Frame + Insulation Panel (Projected (X))	FRAME	EDGE
U	1,4	0,75
b	0,1	0,2

L_Ψ^{2D}	Ψ
0,477	0,111

Table 16: Showing the calculations for the U. Value for frame and edger for the window, (Source: THERM simulation program, 2019).

These pictures show that the temperatures are uniformly distributed along the window: there is no preferential way for heat to go out, so there is no evident thermal bridge.

where:

- Uglass = 0,9 W/m2K (from data sheet)
- Uframe = 1 W/m2K (from data sheet)

• Ψi = linear thermal transmittance.
• ATOT = total area of the window, obtained as sum of the area of all the element of the window
• UW = total thermal transmittance of the window

$$U_W = \frac{U_{glass}A_{glass+}U_{frame}A_{frame} + \sum_i \Psi_i L_i}{A_{TOT}}$$

A_G m²	U_G W/m²K	A_F m²	U_F W/m²K	L_V m	Ψ_V W/mK	L_H m	Ψ_H W/mK	A_{TOT} m²	U_W W/m²K	$U_{W(Max)}$ W/m²K
0.98	0.9	0.62	1	1.4	0.11	1.14	0.13	1.6	1.14	1.4

Table 17: Table showing the area and U. Values for the operable window that already exist in the data sheet and the results from THERM, (Source: Standard data sheet and THERM simulation program, 2019).

Since the U-value of the window is lower than the maximum U-value from the standard, the thermal analysis is verified.

4.2.3.2 Thermal Bridge in the Connections between the Window and the wall

This analysis shows the possible condensation, that occurs when the minimum temperature is lower than the Dew Point temperature, that is found 9.5 °C by using ASHRAE chart at constrains conditions. For the condensation analysis one boundary condition has changed: it has been set 0 °C for the outside temperature, according to the normative requirement.
The analysis of the possible condensation formation will be performed on the stratigraphy of the joints between the window and the wall itself.

I. Vertical Connection

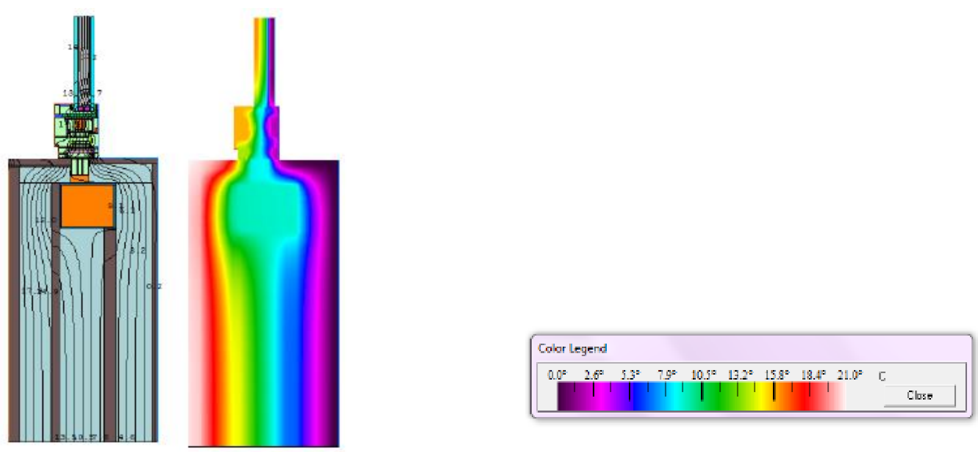


Figure 87: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the horizontal connection between operable window and the wall, (Source: THERM simulation program, 2019).

II. Horizontal Connection

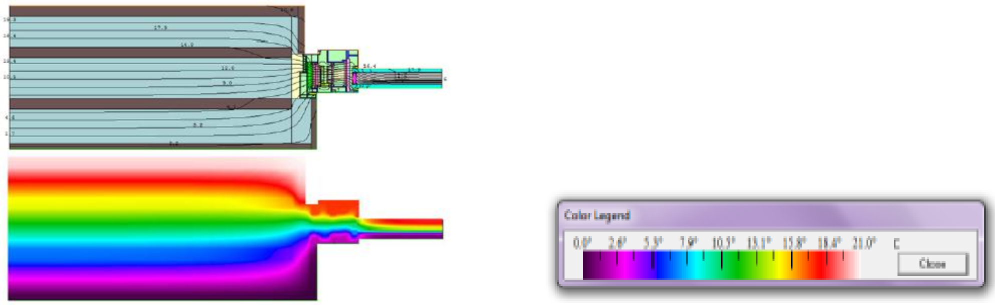


Figure 88: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from the vertical connection between operable window and the wall, (Source: THERM simulation program, 2019).

5-4.2.3 Ventilated Façade

Analyzed the possible formation of condensation. Condensation must to be avoided, because it can damage the façade itself. There can be two types of condensation, the superficial one and the interstitial; the last one is the most dangerous because is impossible to see; that’s why it’s important to perform the thermo-hygrometric analysis.

This method is based on two pressures, the partial pressure and the saturation pressure; when the pressure of a layer reaches the saturation pressure, there’s formation of condensation. This hygrometric analysis has been done with the online software ISOLPARMA, where the inputs have been entered: thickness, water vapor permeability and conductivity of each layer and the external and internal temperatures. The most critical month in Milan is January.

ELEMENT	MATERIAL	THERMAL CONDUCTIVITY (W/mK)
Plasterboard	Plywood (high density)	λ= 0.24
Insultation	Glasswool	λ= 0.038
Insultation (filling)	Polyurethane foam	λ= 0.05
Tubular profile	Galvanized steel	λ= 0.2
Insultation (filling profile)	Foam glass	λ= 0.04

Table 18: The materials that will be used for the ventilated wall in the proposal design and its thermal conductivity, (Source: Researcher, 2019).

Knowing the layers of the vertical closure and their properties, it’s possible to perform the analysis:

The graph shows the result of this analysis: on the x-axis there’s the equivalent air thickness (cm) and on the y-axis the vapor pressure (Pa). The orange line is the saturation pressure profile, while the blue one is the partial pressure profile. Since the partial pressure is always smaller than the saturation pressure, there’s no condensation, not superficial not interstitial.

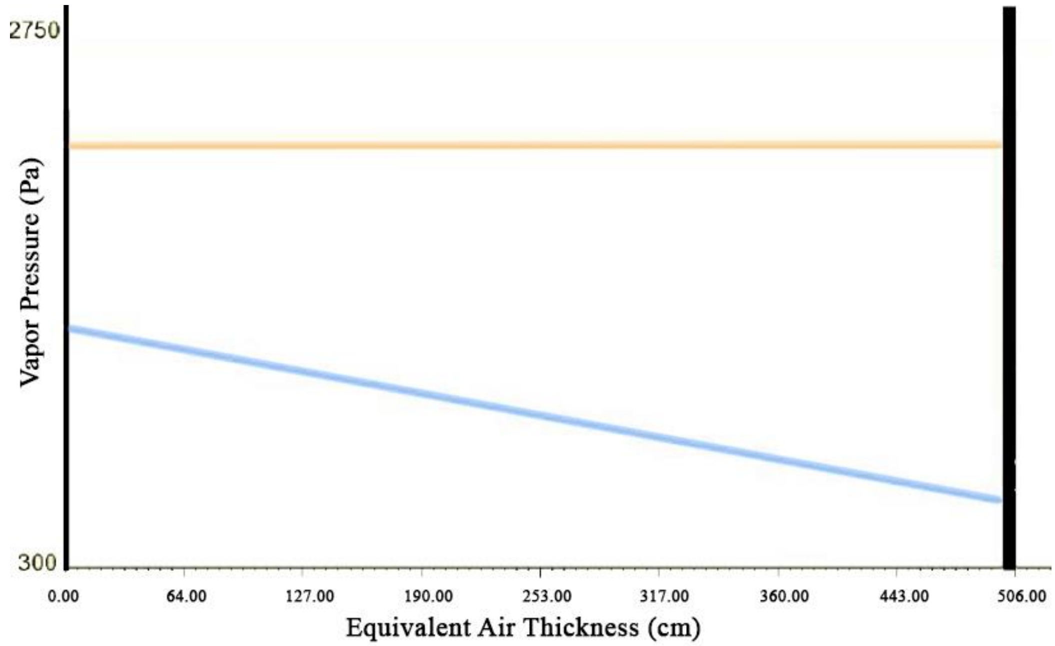


Figure 89: The graph shows that the partial pressure is smaller than the saturation pressure, so there's no condensation in the ventilated wall, (Source: ISOLPARMA simulation program, 2019).

Also, by using THERM to show the thermal bridge for the wall tb be sure that there will not be any condensation across the wall.

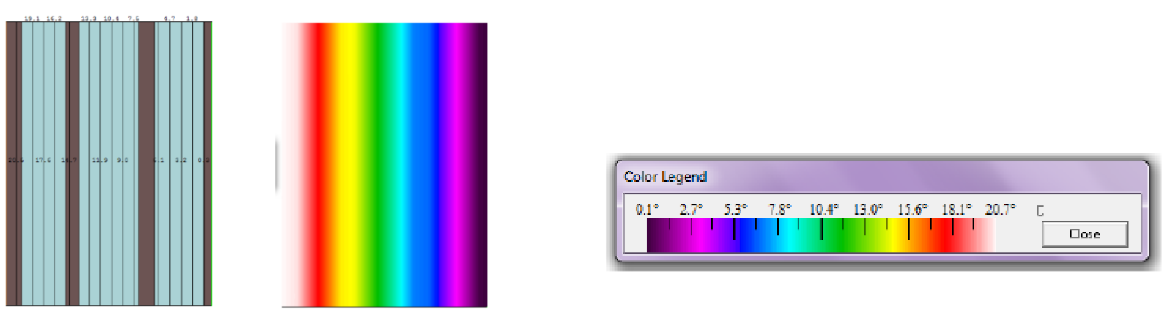


Figure 90: The infrared diagram shows that the inner temperature is between green and red colors and its lower than the Dew point, so there is no condensation from ventilated wall, (Source: THERM simulation program, 2019).

5-4.2 Sunshades Devices Calculations

The shading system has been placed in the South façade, to cover the windows. It’s a horizontal system, made by fixed aluminum lamellas, from SCHUCO. The horizontal solution has been selected due to the orientation of the façade: this shading system let the solar rays go inside the building during winter, while it prevents the passage of solar energy during summer, to avoid overheating inside the building.

During the design, some rules has been followed to have an efficient shading system. First, to have a shadow that covers all the window, then the horizontal lamellas have been selected to allow ventilation through the shading system, that is important during summer because it reduces the external temperature outside the window, and during winter they let the snow passing through, so there are no loads on the shading system.

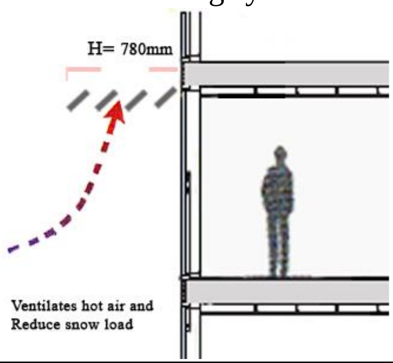
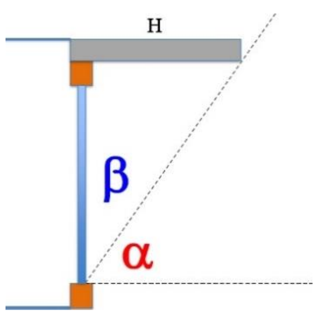


Figure 91: Sketch for the sunshades to show the type that will be used in the new proposal, (Source: Author, 2019).



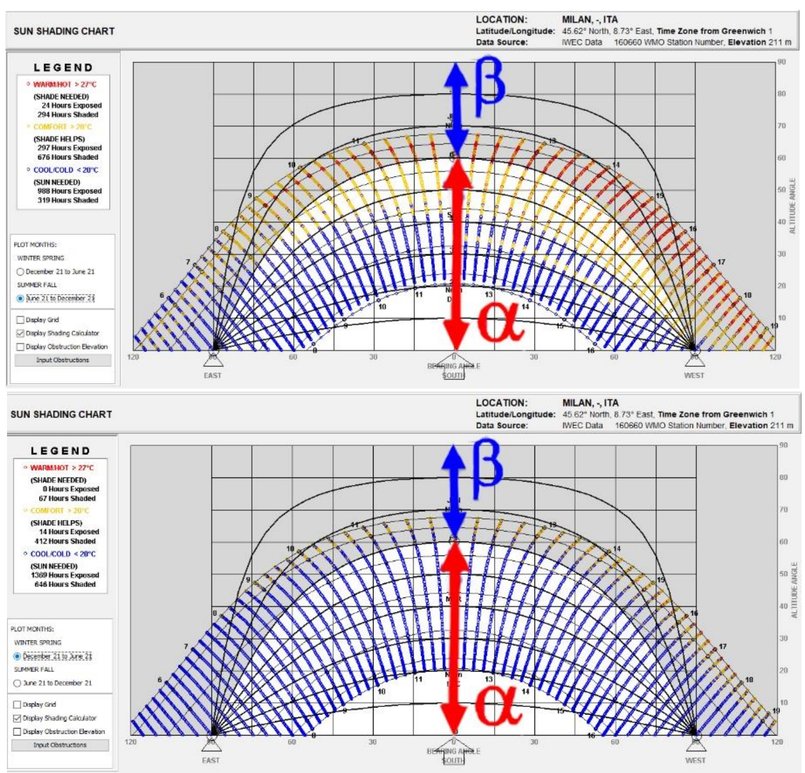


Figure 92: Graph showing how to calculate the width of the sunshades on the ASHARE Graph of the sun path in the Winter and in the Summer (Source: Climate consultant edited by Author, 2019).

The simulation on the shading system has the aim to choose the best angle for the lamellas; for this simulation, the software LBNL WINDOW has been used. To compare different cases, just the tilted angle of the lamellas has been changed along the simulations; the other parameters (materials, glass, boundary conditions) have been the same in all the cases, to get the best comparison.

The results are the following:

U factor	SC	SHGC	Rel Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff	Gap 2 Keff	Layer 3 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K	W/m-K	W/m-K
0.866	0.422	0.367	273	0.356	0.0568	0.7560	0.0579	1.0000	0.0185	1.0000

With shading system (Angel 45)

U factor	SC	SHGC	Rel Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff	Gap 2 Keff	Layer 3 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K	W/m-K	W/m-K
0.871	0.433	0.377	280	0.429	0.0572	0.7560	0.0579	1.0000	0.0185	1.0000

With shading system (Angel 30)

U factor	SC	SHGC	Rel Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff	Gap 2 Keff	Layer 3 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K	W/m-K	W/m-K
0.959	0.462	0.402	298	0.627	0.0512	0.7560	0.0581	1.0000	0.0186	1.0000

Without shading system

Table 19: Table showing the results of the LBNL WINDOW for the sunshades to define which angel is the best choice for the sunshades, (Source: LBNL WINDOW simulation program, 2019).

As seen on the results, the introduction of a shading system changes the technical parameters of the window:

The U-value, the solar factor and the solar heat gain decrease with the closing of the lamellas. From these parameters, the best solution is the third case, lamellas with a 45° angle; since these elements are fixed, this solution is the best one to guarantee thermal performance of the window and daylight standard for the building along the whole year.

5-4.3 Thermal Energy Storage (TES) Effect

Also, using the Phase Change Material (PCM), Thermal energy storage system (TES), that has it is impact on thermal comfort and cooling loads. As it reduces the need to use the air condition as it decreases the total cooling load of the building specially in summer season and increase thermal comfort inside the building.

Simulation results are presented in terms of time profile indoor air temperatures, from which the system behavior is clear in its fundamental aspects, frequency distribution plots, from which a synthetic quantitative analysis is introduced and, analyzed in terms of discomfort indexes. Concerning the discomfort analysis, in order to evaluate the performance in keeping acceptable temperature levels inside the office room, the following indexes are defined:

- Discomfort over-temperature Time Percentage**,** DTP.
- weighted Discomfort temperature Index, I.D.

The DTP index measures the discomfort time during the occupancy period: it is the percentage of time during which the indoor temperature overcomes the fixed temperature upper limit, fixed at 28°C. These indexes, together with the indoor air temperature profiles for the performed simulation, give an appropriate tool to assess the performance of each ventilation system.

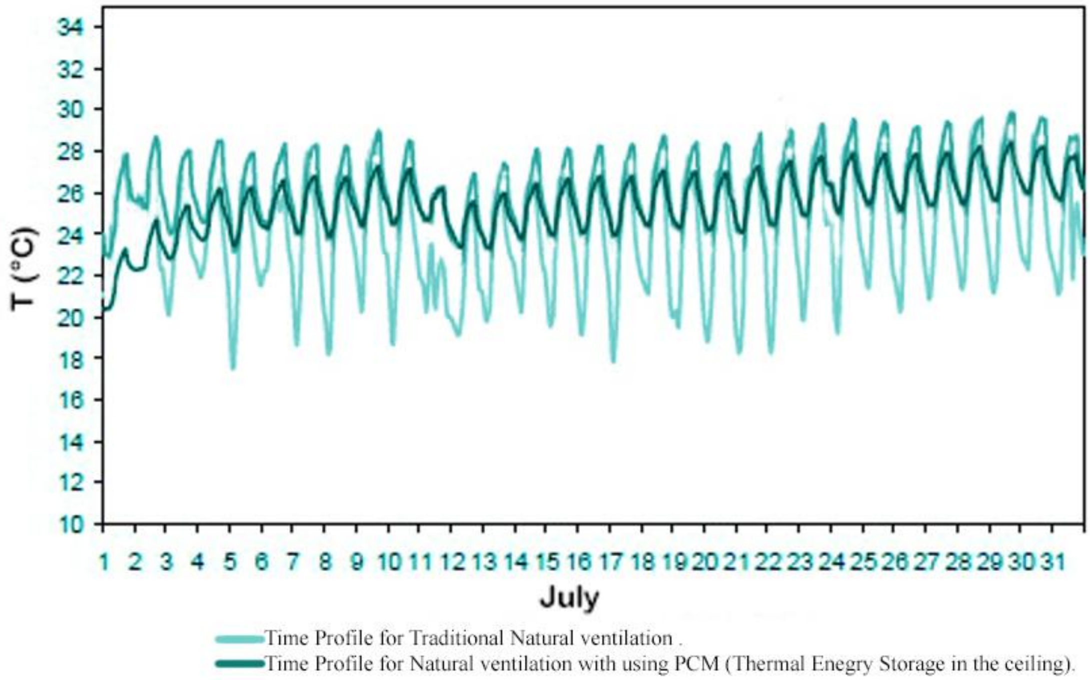


Figure 93: Graph showing the comparison between using the traditional natural ventilation system in the office building and using natural ventilation system with PCM, (Source: Simulink simulation program, 2019).

By comparing the two cases, the of using PCM in celling provides better performance in thermal control of indoor air temperature. With a low level of internal gains. The PCM system can keep satisfactory thermal comfort in the room even with quite hot daily outdoor conditions.

The difference between the two cases is appreciable in all the considered parameters: the mean indoor air temperature is around a 1°C, the DTP reduce to 11%. By examining time profile, the peak cooling loads are reduced for using PCM.

Discomfort Time Percentage Index DTP, weighted Discomfort Index DI, mean indoor air temperature, deviation standard and maximum indoor air temperature for the two cases during occupation period are shown:

City	Ventilation System	DTP (%)	I.D. [°C^2]	M. T. [°C]	Dev. St. [°C]	Max T. [°C]
Milano	NVS	22	149	26,4	2,0	31,0
	NVS+PCM(ceiling)	11	33	25,4	1,9	29,7

Table 20: Table that shows the comparison between the comfort time and the temperature as a result of using PCM (Thermal Energy Storage) in the celling with the natural ventilation system and the traditional natural ventilation system (Source: Simulink simulation program, 2019).

5-5 Proposed Design Drawings

5-5.1 Architectural Drawings

Figure 94: Under Ground Floor, (Source: Author, 2019).

Figure 95: Ground Floor, (Source: Author, 2019).

Figure 96: First Floor, (Source: Author, 2019).

Figure 97: Repeated Floors, (Source: Author, 2019).

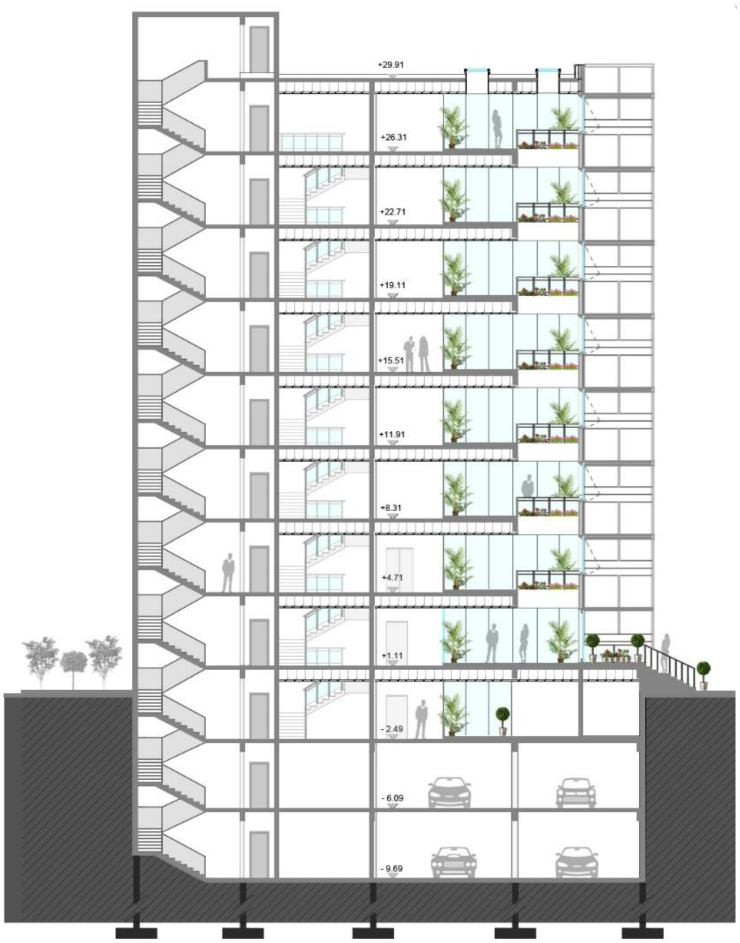


Figure 98: Section B-B and the Section diagram for the Details, (Source: Author, 2019).

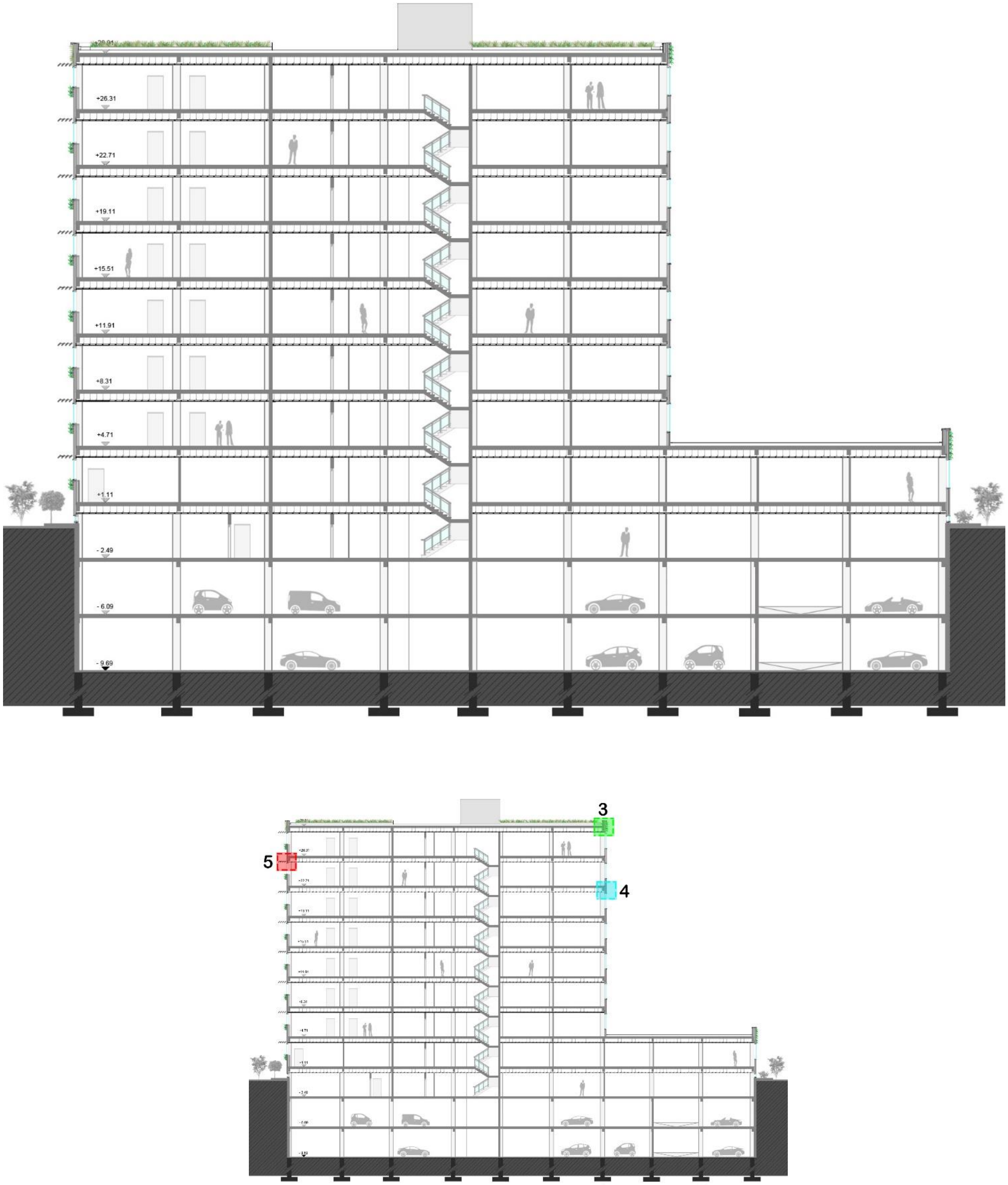


Figure 99: Section A-A and Section diagram for Details, (Source: Author, 2019).

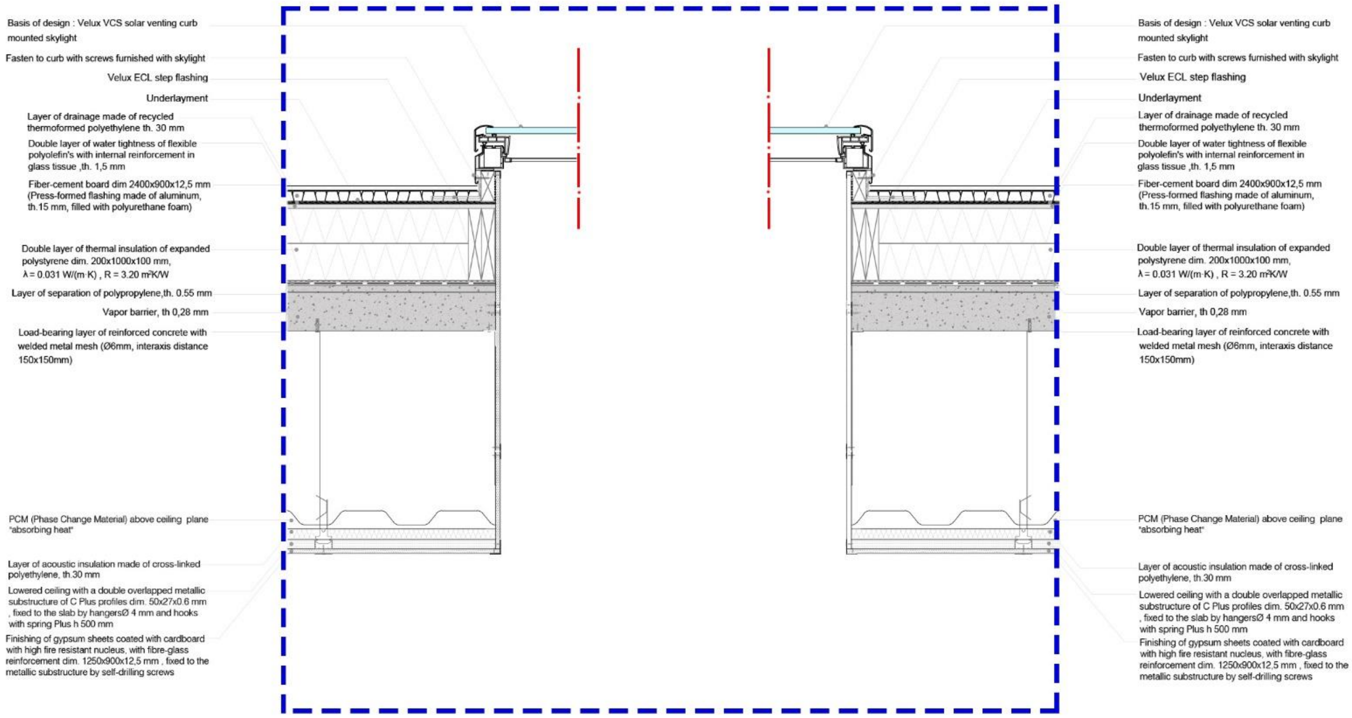


Figure 100: Detail.1 Skylight, (Source: Author, 2019).

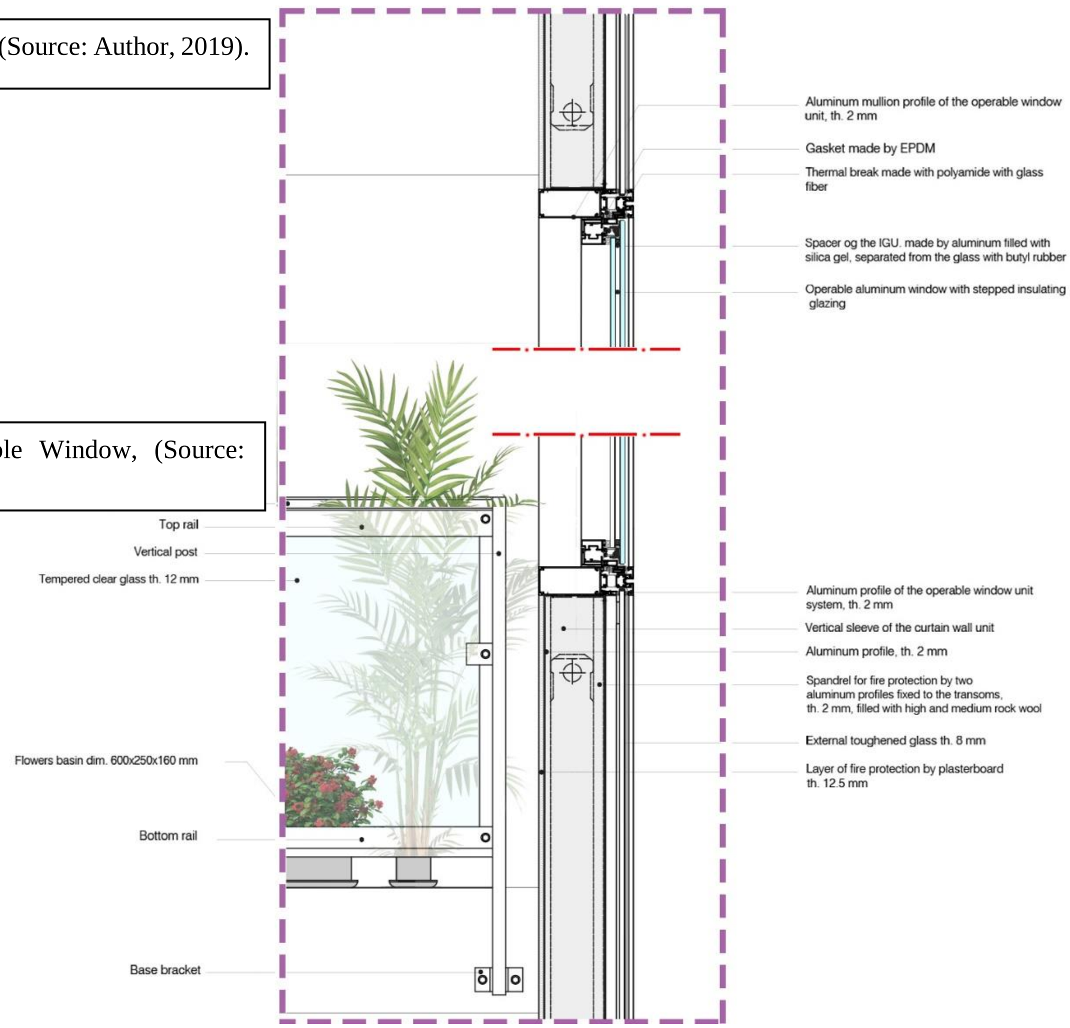


Figure 101: Detail.2 Operable Window, (Source: Author, 2019).

Figure 102: Detail.3 Green Roof, (Source: Author, 2019).

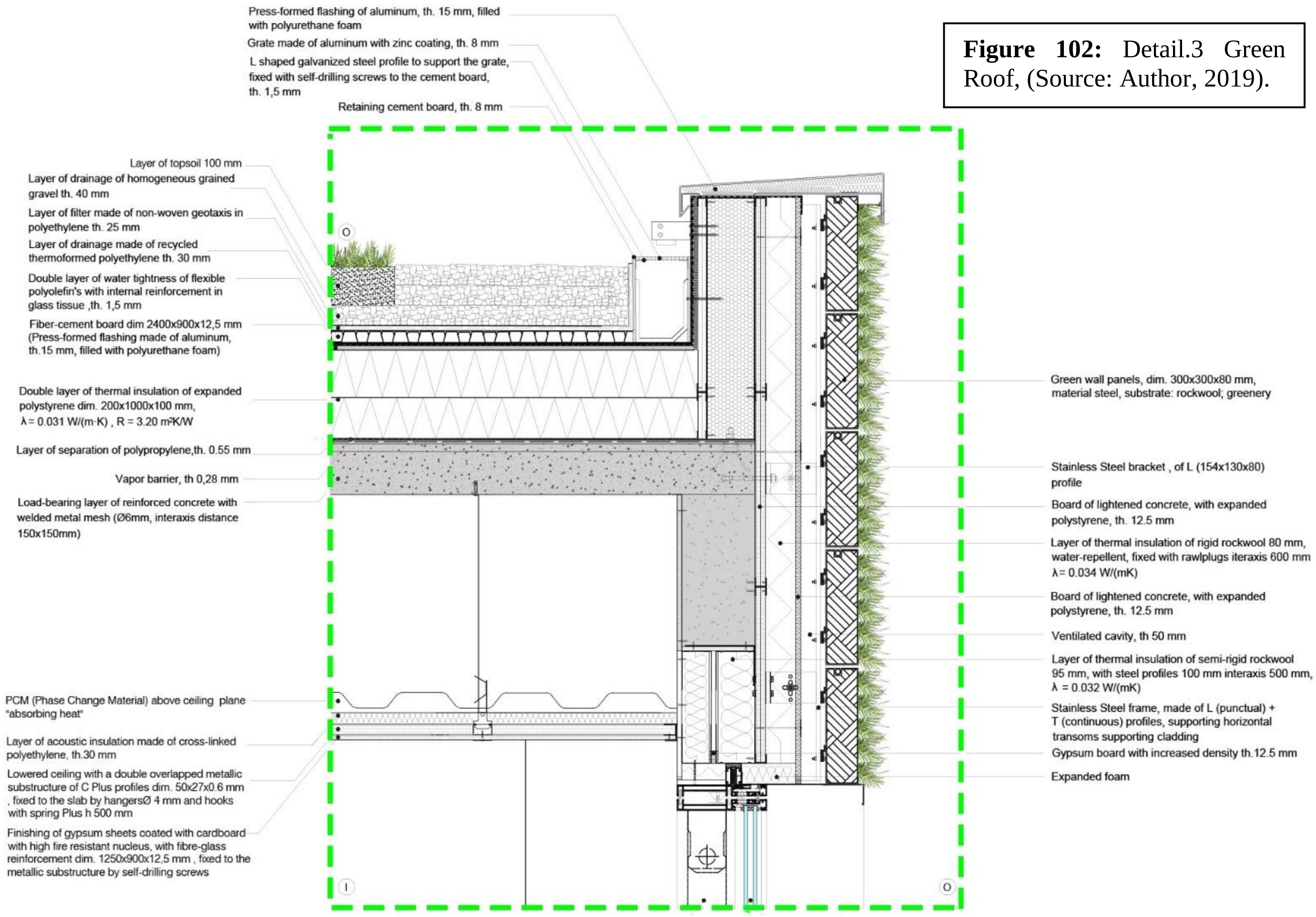
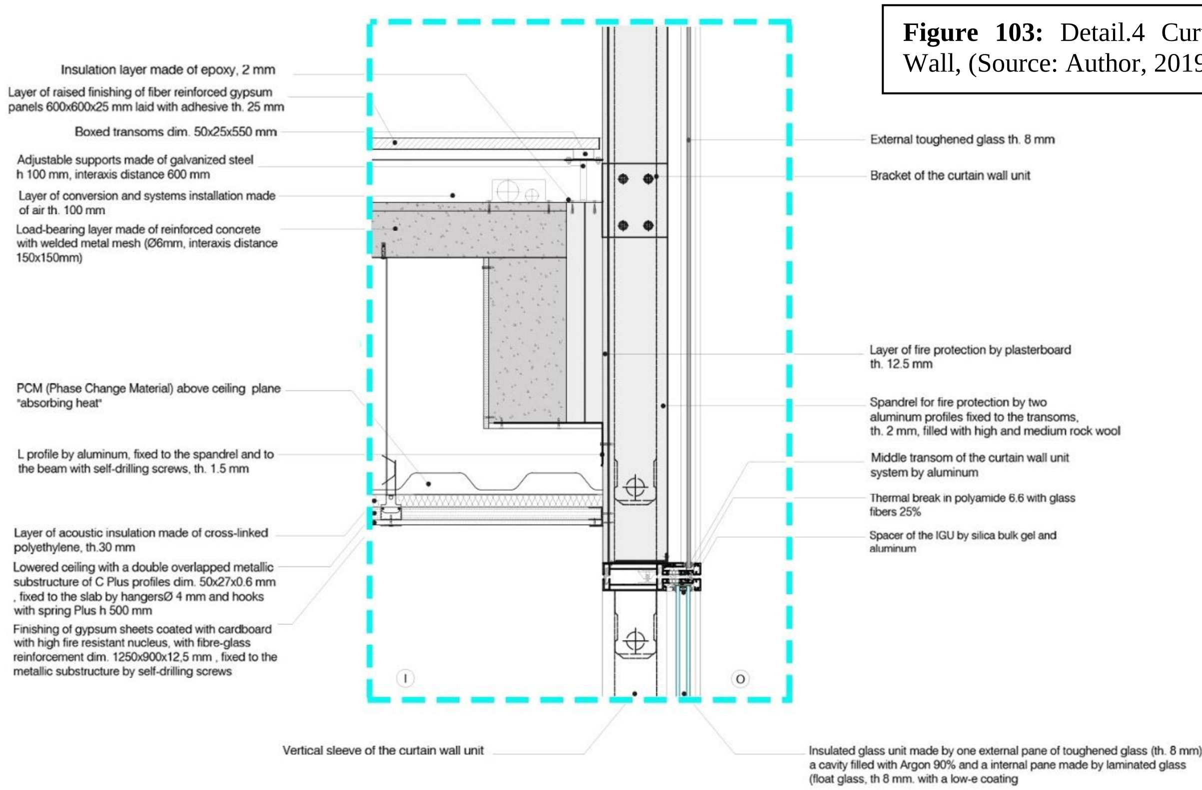


Figure 103: Detail.4 Curtain Wall, (Source: Author, 2019).



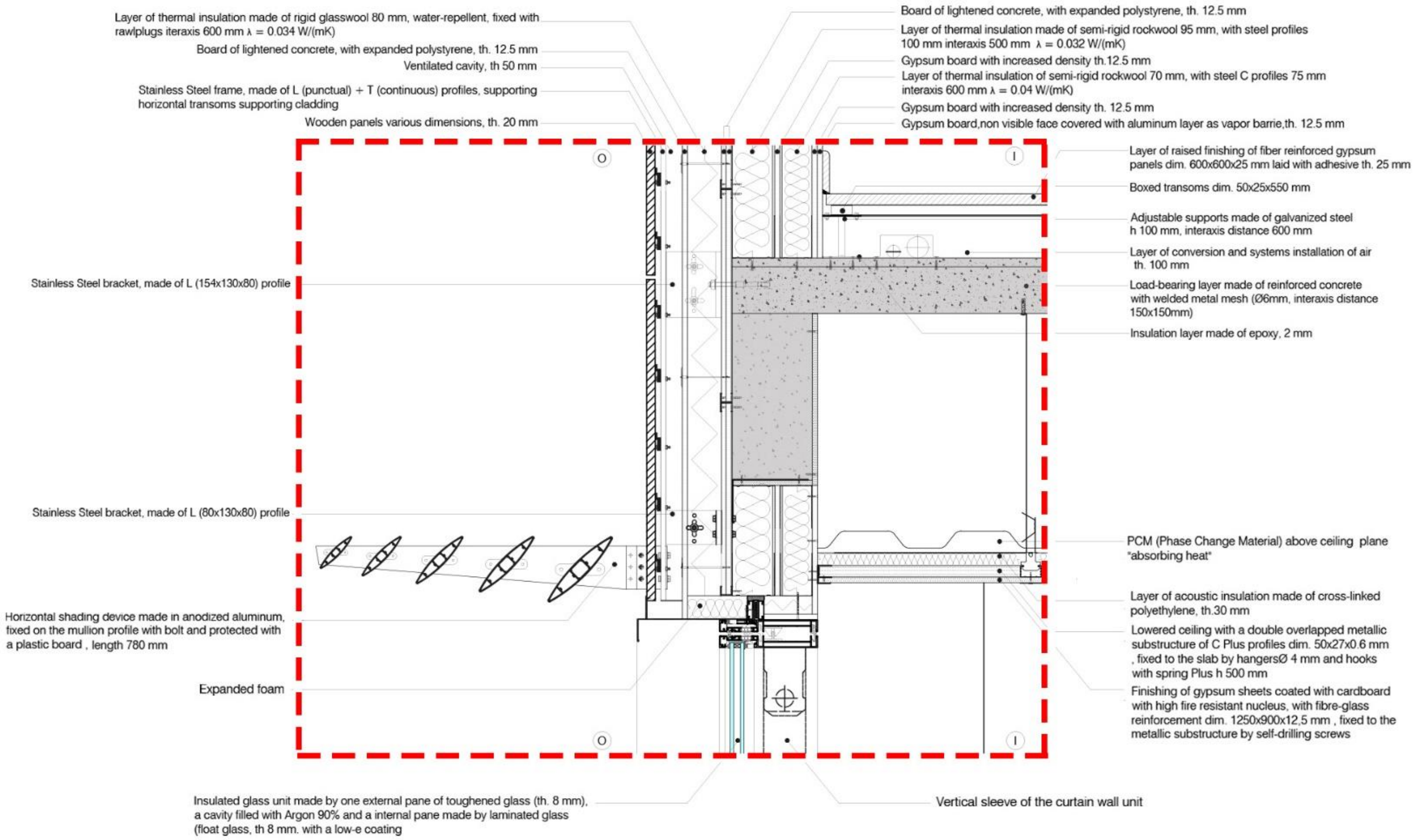


Figure 104: Detail.5 Sun Shading Device, (Source: Author, 2019).

5-5.2 3D Shots for the Building

Figure 105: 3D views for the new Proposal Design Building, (Source: by Author, 2019).

Figure 106 : Overviews for the new Proposal Design Building, (Source: by Author, 2019).

Figure 107: Facades for the new Proposal Design Building, (Source: by Author, 2019).

Figure 108 : Interior Shots for the new Proposal Design Building, (Source: by Author, 2019).

5-6 Conclusion

As shown in the above studies, climatic analysis, architectural drawings and the results of the new proposal, it shows that the using of the natural ventilation techniques and the passive cooling techniques in the building specially in office buildings will have a massive effect in decreasing the cooling and heating load for the buildings , and as a result of that the energy consumption will be decreased ,also the thermal comfort inside the building will be increase, so that the need for the air condition systems will be decreased in summer season and that also will be the result of decrease the cost of the construction field.

All of that confirmed by using the simulation programs like (Casanova, Simulink, THERM, LBNLTHERM, ISOLPARMA, Climate Consultant). The simulation programs are the latest smart tools that helping in make analytical analysis of the environmental impacts and the energy consumption at the beginning of the design phase for the buildings.

As a future vision for the construction, it is important to think first about the sustainable architecture and the green innovations parallel to the smart architecture to save the non-renewable resources and utilize the renewable resources as much as we can.

As a result of the above intervention (The new proposal), the below graphs show that the heating energy demand and cooling energy demand will be decreased per year.

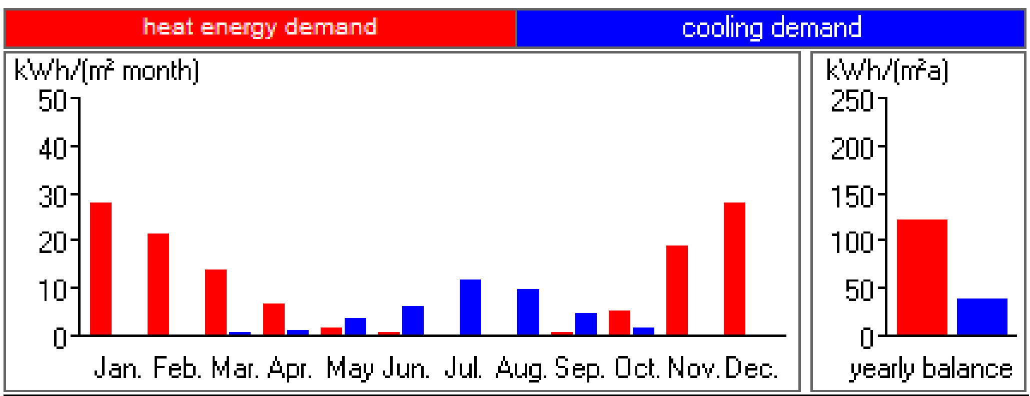


Figure 109: Graph shows the monthly and yearly demand for heating energy and cooling energy for the existing office building, (Source: Casanova simulation program, 2019).

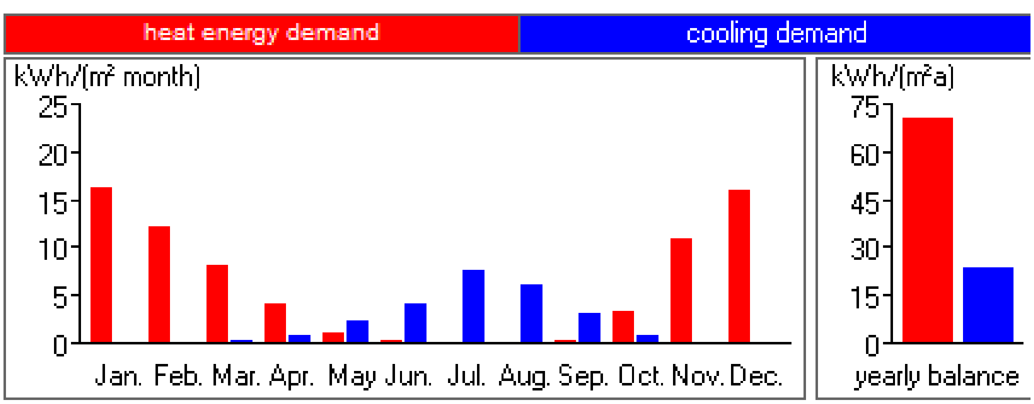


Figure 110 : Graph shows the monthly and yearly demand for heating energy and cooling energy for the new proposal for the office building, (Source: Casanova simulation program, 2019).

CHAPTER SIX

Conclusion & Recommendation

6-1 CONCLUSION

The continued rapid growth of construction industry and demand of energy raises several persistent questions and problems and demands for solution. Passive design responds to local climate and site conditions in order to maximize the comfort and health of building users while minimizing energy use. The key to designing a passive building is to take best advantage of the local climate. Passive cooling refers to a building design approach that focuses on heat gain control and heat dissipation in a building in order to improve the indoor thermal comfort with low energy consumption. Passive cooling systems use non-mechanical methods to maintain a comfortable indoor temperature and are a key factor in extenuating the impact of buildings on the environment. The energy consumption in buildings is very much with the anticipation to further increase because of improving standards of leaving and the increase of world population. Air conditioning use has increasingly penetrated the market during the last few years and quite enough to contribute in the rise of absolute energy consumption.

The issue of sustainability in the building sector is of considerable importance, as this industry from the one point of view causes large impacts on the environment but from the other point of view contributes greatly in socioeconomic perspective of development and growth. In the direction of sustainable construction, several efforts have been initiated to provide a building assessment framework.

During the last few years important basic and industrial research has been carried out that has resulted in the development of new high-efficiency materials, systems, tools and techniques. However, the continuing increase of energy consumption of air conditioning suggests a more profound examination of the urban environment and the impact on buildings as well as to an extended application of passive cooling techniques.

- Theoretical studies have shown that the application of Passive cooling techniques in buildings may decrease their cooling load up to 50% - 70%.

- For southern European and Mediterranean areas, Passive cooling systems can lead to primary energy savings in the range of 40–50%. Related cost of saved primary energy lies at about 0.07 €/kWh for the most promising conditions.

Natural ventilation scenarios include daytime ventilation, night-time ventilation as well as whole-day ventilation: all the solutions investigated allow for an increase in the percentage of hours of comfort on the total of occupied hours.

- The association of night ventilation and phase change material can help in reducing or just shifting peak thermal and, consequently, electric cooling loads in buildings. It can be implemented by a flexible simulation tool on Simulink® environment which guarantees a detailed description and analysis of the simulated PCM ceiling ventilation system located inside an office room.

- Several perceived parameters influence thermal comfort: lighting, draughts, temperature variations, acoustics, olfactory quality, glare and perceived control as well as for air which is perceived as stale and dry. The impact of these parameters depends on the type of ventilation and the perception of the indoor environment temperature (hot or cold).

- ❖ The results show that cooling inside buildings can be enhanced by changing the design of the building to include a solar chimney for natural draft ventilation. By installing solar chimney, evaporative cooler and wall insulation, it is estimated to increase the cost by about 10 per cent of the cost of a conventional room. Therefore, the described passive cooling system with effective modified chimney seems to have very good potential value in terms of economy and, technological point of view.

The study proposes the quantification of decreasing cooling load and thermal comfort improvement obtainable in an office building in Milan using natural ventilation. The building is characterized by overheating from May to October due to high internal loads and solar gains, natural ventilates cooling is a potential solution to improve the thermal comfort of the occupants.

6-2 RECOMMENDATION

In the light of the conclusions, there are several recommendations is made:

- ❖ Raise the awareness of the potential to improve the energy and environmental performance of offices, and to encourage positive management action.
- ❖ Better understanding for micro-climates around buildings, and to understand and describe comfort requirements under transient conditions during the summer period.
- ❖ Find new guidelines for assessing and planning thermal comfort in office buildings are required for both natural ventilation and air-conditioning.
- ❖ Before considering active cooling systems the first step is to reduce the cooling load. This can be done very effectively by intelligent building design. Passive cooling strategies based on “bioclimatic design” (such as orientation and size of windows, reduction of solar gains by sunblind, implementation of thermal mass, night ventilation, the use of energy efficient lighting systems., etc.). Due to this a simplified assessment of cooling loads in early design stages (e. g. architectural competitions) should be done.
- ❖ It is important to improving quality aspects, developing advanced passive and hybrid cooling systems, and finally, developing advanced materials for the building envelope.

Generally, concern for energy consumption is only marginal in most architectural-design practices, even in the developed countries. Passive energy techniques should be the first aim of any building designer, because, in most cases, it is a relatively low-cost exercise that will lead to savings in the capital and operating costs of the air-conditioning plant. Incorporation of these passive cooling techniques would certainly reduce our dependency on artificial means for thermal comfort and minimize the environmental problems due to excessive consumption of energy and other natural resources and hence will evolve a built form, which will be more climate responsive, more sustainable and more environmental friendly of tomorrow.

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