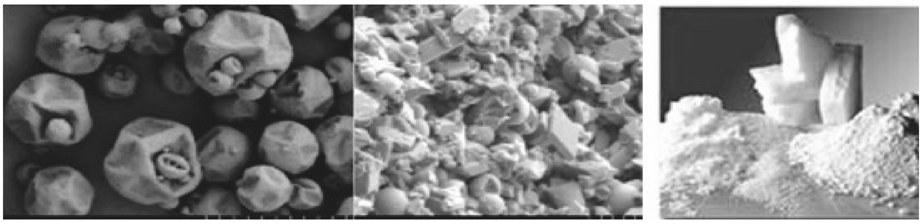
IMPROVING THE ENERGY PERFORMANCE OF THE BUILDING ENVELOPE USING PHASE CHANGE MATERIALS



Hassan First University of Settat, Ecole Nationale des Sciences Appliquées, LISA Laboratory, Berrechid 26100, Morocco. [1]

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"Architecture is a wonderful expression of the discovery process. It's like a scientist who doesn't know the answer, but knows the path to it. That's what drives me: the joy of the path, the discovery."
Glenn Murcutt Architect, winner of the 2002 Pritzker Architecture Prize.

Chapter introductory

"Science is looking for perpetual motion. It has found it: it is itself. **Victor HUGO**

{Cogeneration is much more efficient than separate production of heat and power}

IEA 2009

Our commitment to the development of an efficient and decarbonized energy model for the benefit of the well-being and prosperity of our citizens is based primarily on the increase in renewable energies and the strengthening of energy efficiency. Energy efficiency constitutes, today with renewable energies, a new revolution in the energy sector due to the technological evolution that ensures a correlation between these two components. They should be integrated and taken into consideration in investment decisions and technological choices in all key energy-consuming sectors, including industry, buildings, transport, public lighting and agriculture.

Excerpt from the Royal Message accepting the Energy Efficiency Visionary Award

"Architecture is a wonderful expression of the discovery process. It's like a scientist who doesn't know the answer, but knows the path to it. That's what makes me act: the joy of the path, the discovery.

Glenn Murcutt Architect, recipient of the 2002 Pritzker Architecture Prize

"The Kingdom of Morocco is constantly working to adapt to future changes in order to ensure its economic and social development and meet its growing energy needs in a sustainable manner. Security of supply, availability of energy, energy efficiency and preservation of the environment are the pillars of its energy strategy.

"Our commitment to the development of an efficient and low-carbon energy model for the benefit of the well-being and prosperity of our citizens is based primarily on increasing the use of renewable energies and strengthening energy efficiency.

″We reiterate, on this occasion, Our constant commitment at the national, regional and continental level, to make every effort to foster a climate of sustainable development of energy efficiency, renewable energy, technological innovation and green jobs in general.″

EXCERPTS FROM THE SPEECH OF HIS MAJESTY KING MOHAMMED VI ON THE OCCASION OF THE ACCEPTANCE OF THE ENERGY EFFICIENCY VISIONARY AWARD IN MAY 2017

{ ABSENCE OF DISCOMFORT (FANGER);ϖ FEELING OF PHYSICAL AND MENTAL WELL-BEING (EUROPEAN PASSIVE SOLAR HANDBOOK)ϖ CONDITIONS IN WHICH THE BODY'S SELF-REGULATING MECHANISMS ARE AT A MINIMUM LEVEL OF ACTIVITY (GIVONI)}.

1.Introduction

Global warming and climate change are mainly caused by the high emission of greenhouse gases in the atmosphere. The energy sector being the most important emitter of these gases worldwide, several countries have reinforced the priority given to energy efficiency and the use of renewable energies through the implementation of policies adapted to their economic, social and climatic specificities. Architectural design is a fundamental step in the creation and production of the building envelope; it is also a very complex step due to its hyper-interested aspects. Upstream, this phase has a considerable influence on several parameters: electrical, thermal, energetic and more globally environmental. Is it possible to create environmentally friendly buildings from the drawing board? The answer is "yes", using what is called bioclimatic architecture with organic and local materials. This type of design takes into account local climatic conditions - sun, wind, rain, heat, air flow etc. - to reduce the environmental impact of a building. - to reduce the environmental impact of a building. Another key aspect is energy efficiency, which is a crucial weapon in the fight against climate change. The building sector is among the most energy intensive sectors in Morocco with an energy consumption of up to 33% divided into 7% for tertiary buildings and 26% for residential buildings. This consumption is subject to increase given the population growth, the creation of new cities and the sustained use of air conditioning and heating and ventilation systems that Morocco knows. The building sector alone represents an energy saving potential of 40%.this policy of Energy Efficiency in Morocco has been concretized by the adoption of Law 47-09 in 2009 on bioclimatic architecture which defined as is a way of designing building envelopes according to the local climate, with the aim of ensuring thermal comfort by using environmental resources. They must also blend into their natural environment. This is not new, as it is fair to say that traditional architecture is inherently bioclimatic. All you have to do is look at the shapes of the roofs and the sizes of the windows in different countries and regions.The main objectives of bioclimatic architecture are to create healthy and comfortable homes for the inhabitants of these buildings, while respecting the environment. To do this, it is essential to avoid using polluting materials, to ensure the well-being of local biodiversity and to use energy, building materials, water and other resources efficiently. Bioclimatic buildings rely on design and daily use strategies that help reduce their energy consumption. These are the most common: Bioclimatic and efficient design. Designing buildings that adapt to the local climate to minimize energy expenses and resources used, avoiding leakage and waste. Control and intelligent use of space. Buildings and their rooms should be appropriately sized to optimize energy use. Sustainable materials such as wood, stone, natural fibers and recycled materials minimize the impact of the building. Use of renewable energy. Bioclimatic buildings use different types of renewable energies - solar, geothermal, wind powere . it requires the study and evaluation of choices and alternatives to better meet the various requirements and solve problems that may arise later (Hall, 2010). This evaluation covers all the components of the building including the envelope, which is considered a crucial element in order to achieve an efficient architectural design (Kontoleon et al., 2007). Indeed, the overarching design goal is to provide occupants with comfortable indoor environments regardless of the nature of the external conditions (Lavoye et al., 2015), and it would be wrong to restrict the environmental dimension of the building to the sole concern of reducing the energy bill (Arnal, 2013; Zemella et al., 2014). Over time, architectural bioclimatic design has undergone great changes under the influence of several parameters(the evolution of lifestyles, the emergence of new trends, the development of new materials and construction techniques, etc.). Inevitably, the bio-architectural project has been negatively influenced by these upheavals. Thus, the modern movement contributed to the production of an architecture that was perfectly indifferent to the climate by overestimating the technological possibilities and by considering them suitable to replace the teaching of the "ancients". With the modern movement, the very notion of architecture had been profoundly modified, it was no longer the art of building as originally defined, it had become a plastic exercise where environmental and contextual parameters no longer had a place (international style, rapid production of buildings, iron and glass architecture,...).

The years 2020 and 2021 were marked by an unprecedented crisis of covid 19. Thanks to the enlightened vision of His Majesty King Mohammed VI, may God assist him, Morocco has managed the pandemic with responsibility and solidarity. All components of society have shown commitment and strong mobilization. At the Moroccan Agency for Energy Efficiency, we have adopted the same state of mind to ensure a green and sustainable recovery post covid. The government has decided, with a department dedicated to the green economy, in charge of setting up, within the

framework of the national strategy for sustainable development, the national action program for the transition to a green economy and to ensure its implementation, that the exercise of the State's guardianship over the AMEE is from now on the minister in charge of the green economy, who in the new government is the minister of energy transition and sustainable development. To this end, changing the economic paradigm and moving to a green economy is necessary to succeed in the challenge of energy transition and reducing greenhouse gases, responsible for global warming. The green economy holds a great potential in terms of job creation for the youth in our country and for our entire continent. The green economy has gained importance in the context of the pandemic, where the recovery must focus on areas such as access to renewable energy, sustainable mobility, decarbonization of industry and, of course, energy efficiency. In this respect, energy efficiency is a cross-cutting action that concerns all economic sectors.

2.Objective (state of the art, scientific objectives, problematic):

For several decades, low-income citizens in Moroccan cities have been suffering from thermal inequalities, energy poverty and thermal comfort constraints. They resist indoor temperatures of less than 16°C and more than 32°C, which causes the phenomenon of heat stress. The most vulnerable to climate change are the people who live in the densest environments and have the most limited resources. The removal of all subsidies by 2025 in Morocco will exacerbate the energy disparity. Reducing energy costs is a major challenge in Morocco. This mobilization is justified primarily by the costs associated with energy consumption. Indeed, 10% of Moroccan gross domestic expenditure was in 2014 dedicated to energy expenditure [1]. Similarly, such consumption has disastrous long-term environmental consequences: greenhouse gas emissions, depletion of natural resources, etc. Among the sources of energy consumption, Heating, Ventilation and Air Conditioning (HVAC) systems represent about 50% of the total expenditure in buildings [2]. This considerable proportion can be explained in part by the great variations in temperature recorded in Morocco, which make it essential to provide air conditioning or heating almost at all times. The development of green buildings thus inevitably requires an optimization of the use of HVAC systems. In this perspective, a clear difference between the use of HVAC systems during the day and at night has been observed. Indeed, during the day, the solar irradiation incident on the façade of a building coupled with the various internal gains (occupancy density, lighting, etc.), cause a high demand for air conditioning. Conversely, during the night, internal and solar gains are non-existent and the outside temperature is lower: heating is often required. From this point of view, storing the excess loads emitted during the day and re-emitting them during the night, when heating is required, is an ideal solution in terms of increasing energy efficiency. Indeed, less heat would have to be supplied and extracted by the HVAC system [3]. Most building materials have either a relatively low thermal mass or a high structural mass, such as concrete. The provision of thermal inertia is therefore necessary but comes with significant disadvantages and restrictions in terms of structural design, aesthetics and ecology. However, there is a type of material that combines high thermal inertia with excellent specific properties, which is becoming increasingly important in new building designs: phase change materials (PCM). The high thermal inertia of these materials stems from their ability to change phase at a user-adjustable temperature. This is because the large amount of latent energy absorbed during melting of the PCM is stored in the material and then released at the desired time when the PCM solidifies through an exothermic process. Depending on the properties of the thermal zone, it is therefore possible to integrate PCMs and optimize their parameters in order to advantageously dephase the energy consumption peaks and, by the same token, significantly reduce the use of the CVA system. Consequently, the integration of these PCMs in the envelopes of new buildings or in renovation would contribute to reduce the energy bill in the building sector in Morocco. The envelope of traditional buildings has remained for a long time a passive means of limiting heat loss or heat gain and also of ensuring a certain air conditioning due to its thermal inertia. Indeed, the thermal energy stored in the walls during the hot periods is restored during the cold periods. In the current buildings, in particular in the tertiary field, one endeavours to decrease the thickness of the walls to reduce the costs while respecting the standards to limit the thermal losses. However, such structures do not provide sufficient thermal inertia to absorb fluctuations in outside temperature. One of the ways to reduce the energy needs of a building is therefore the design of an energy efficient envelope, limiting the losses and recovering the maximum passive contributions. To achieve these objectives, there are a number of basic principles, the most important of which are insulation and thermal inertia, as well as the use of solar gain. As far as thermal inertia is concerned, the use of PCMs in the walls themselves allows the substitution of sensible heat storage for latent heat storage which requires much less volume and mass for the same amount of thermal energy. One of the key objectives of low energy building research is to find a way to manage the time differences between energy sources and energy consumption. The main objective here is to model, quantify and optimize the impact of the presence of PCMs in a thermal zone subjected to the climatic conditions of Morocco with the ultimate goal of developing low energy buildings. First, a complete numerical model of the thermal behavior of a zone will be developed using the simulation tool Trnsys, with the possibility of including phase change materials. The realization of this objective will allow to have available a customized code, fully scalable, able to calculate all the thermal variables of interest in a building in interaction with the environment. Such a complex wall technology integrating PCMs must be properly taken into account in order to simulate the energetic behavior of buildings and to evaluate their impact in several domains (environmental, thermal behavior of buildings, etc.). Once the thermal characterization of the building has been performed, the second specific objective will consist in processing all the data obtained in order to measure the impact of the presence of PCMs from several perspectives.

On the one hand, the average temperature will be examined after integration of the PCMs in a zone. On the other hand, the effect of the addition of the PCMs on the decrease of the load to be provided by the HVAC system, or even the decrease of the internal temperature variations will also be studied. Different objective functions will be developed in order to study this issue. Furthermore, the selected criteria will be analyzed for two distinct cases, namely a seasonal cyclic regime and a real annual regime. Finally, knowing under which aspects the integration of MCP is most beneficial, a third sub-objective is to optimize the overall material properties. Thus, at the end of this project, we should know the characteristics, the quantity and the position at which the inclusion of PCM in a zone influences most significantly the energy efficiency of this zone. Many types of materials and layouts are being investigated. The choice of a PCM depends mainly on the intended application and the user's needs. Thus, it is necessary to define criteria that facilitate the selection of a PCM for a given application [4]. The processing temperature and the melting range remain important criteria in the choice of the type of PCM to be used. Their melting range can be determined according to the desired application (building, transportation, food, textile, etc.). On the other hand, these materials must have a high latent heat of fusion. Other criteria are also to be considered such as thermal properties, physico-chemical properties and economic aspect. In this project, we are mainly interested in the case of organic PCMs because of their numerous advantages. Indeed, organic PCMs are available in a wide temperature range (between 0°C and 150°C) and are compatible with conventional building materials, they are chemically stable and do not require the use of nucleating agents. They are non-corrosive, they are not affected by supercooling most of the time and they are recyclable. Nevertheless, they have some disadvantages: they have a lower conductivity in the solid and liquid state, they have a lower latent heat of fusion, they have a high volume in the liquid state, and they are flammable [5,6]. The most commonly used organic PCMs are mainly based on kerosene, fatty acids and sugar alcohols. This project involves a co-tutored thesis between the two partners.

3 .Description and methodology: The **overall objective of the project is to improve the living conditions of the local population, through welfare and the fight against poverty and social inequalities. The specific objective is to set up a pilot unit using local building materials, with low environmental impact, provided with organic materials with phase change to be able to study the improvement of the energy efficiency of residential and tertiary buildings. The valorization of local materials is a priority for this project. Clay bricks are the basic matrix into which organic PCMs made from biobased materials will be incorporated. One of the envisaged tracks is the use of MCP in the form of fatty acids extracted from the waste of pomace resulting from the transformation of the olive into oil, thus allowing the valorization and the treatment of these waste and consequently the protection of the environment. The research work will bring innovation, through the combination of local materials and biosourced PCM, and will allow the building materials companies to develop by making their products evolve. Indeed, the analysis of the environmental performance and the economic feasibility of these materials constitutes an important new field of scientific research. The benefits, energy consumption, and environmental indicator for all stages of the PCM life cycle must be evaluated in detail to configure an appropriate energy balance perspective of the material life cycle. Our research strategy aims to examine in detail the topic of PCM use as thermal energy storage materials for the building sector. The goal will therefore be to verify the feasibility and technical performance of PCM as a new means to stabilize indoor air temperature. The study includes a numerical modelling and simulation part and an experimental part. To carry out this project, a model will be developed taking into account the physico-chemical properties of the PCM to be integrated in the building envelope and the local climatic conditions in relation to the thermal comfort. A test chamber equipped with a set of sensors and recorders will be built in Morocco to create a local model based on empirical data. Simulations will be done using the EnergyPlus and Trnsys calculation tools by studying a large set of parametric analysis to be able to calibrate the proposed model. The modeling of this system is essential to define the material specifications and to determine how these PCMs can be integrated into the building envelope.**

4 .National and international context: **The construction sector, both residential and tertiary, is undergoing a major expansion in Morocco. At present, there is an extraordinary boom in construction activity. A significant increase in the housing stock is therefore expected, based on the State's short- and medium-term construction programs and the projections of the Statistics Directorate of the Haut-Commissariat au Plan. The new housing stock, which will be built over the next twenty years, is estimated at about three million units. In addition, users of existing buildings suffer from serious problems due to the form and materiality of the building material. This is because incoming shortwave solar radiation is mainly stored in building materials such as concrete, stone and asphalt and is then radiated as longwave heat into the urban atmosphere. This leads to the well-known "urban heat islands" and "heat stresses". Urban heat causes many problems: infrastructure deterioration or failure (road melting, breakdowns), thermal discomfort and low productivity, hygiene (reduced physical and cognitive performance) and health and safety problems (respiratory, heart and kidney problems) and additional deaths [7-9]. In Morocco, heat problems are also expected to be exacerbated by climate change-induced temperature increases [10,11]. Similarly, energy use has become a central issue in the operation and development of the building sector in Morocco. The growth in energy consumption is associated with a significant increase in population and a rapid evolution of the housing stock. In 2015, the installed electrical capacity in Morocco amounted to 8500 MW, compared to 3700 MW in 1999.**

Expected results and implementation plan **In this project, the innovation lies, on the one hand, in the combination of local building materials and phase change materials and, on the other hand, in the use of biosourced materials, such as fatty acids derived from the valorization of olive oil pomace waste. This association will have the double advantage of reducing energy consumption in the building sector in the different climatic zones of Morocco and of ensuring a better respect of the environment. The study of the effect of the quantity of PCM to be incorporated in the building envelope will allow to determine the reduction and the delay of the thermal load through such an envelope in the climatic conditions of Morocco. The expected outcome is the identification of the type and quantity of PCM to be incorporated into the building envelope and the determination of the location where this material should be incorporated into such a composite wall. This project will provide evidence of the value of incorporating phase change materials into building envelopes. This result will be provided in the form of energy efficiency gains by decreasing energy consumption in heating and cooling systems, and in the form of thermal comfort gains. The use of biobased materials will provide a sustainable gain respectful of the environment. The economic benefits will be important for low and middle income citizens, and by the creation of jobs and businesses associated with this sector. Morocco: In terms of research, the project will evaluate the potential of phase change materials. It will provide scientific data on the merits of integrating these materials and their impact on the thermal comfort of buildings. The impact on the stability of the daily temperature fluctuation inside the building is a win-win scenario for energy efficiency in the building and for the environment. The project will train a junior researcher. It will benefit senior researchers to acquire knowledge in modeling and simulation of heat transfers in the building. The results of the project will be presented in the form of a series of conferences. This seminar will be open to students, teacher-researchers and industrialists. Finally, this medium and long term project will allow the incorporation of new phase change materials in building envelopes.**

CHAPTER I: BIBLIOGRAPHICAL STUDY AND STATE OF THE ART

The National Agency for the Development of Renewable Energy and Energy Efficiency (ADEREE) has launched an energy efficiency program in the building sector, the main objective of which is to reduce the energy consumption of this sector. Quantitatively, the program aims at an estimated energy saving of 1.4Mtoe/year by 2030 and a reduction of greenhouse gases of about 4.5 $MteCO_2$.

1.Introduction

At the global level, the building sector alone represents around 28% of final energy consumption and contributes to about one third of CO2 emissions, as shown in the following graph: For thousands of years, the thermal within the building has aroused the interest and ingenuity of Man, in the sense that, from a social point of view, the habitat represents the shelter, the protection against the hazards of nature, the physical integrity and lately the comfort of its occupants. Thus, over the years, Man has used his genius to improve the thermal conditions in his home, starting with the simplest techniques, even artisanal, to the advanced measures of energy efficiency and thermal comfort as they are known today. Significant heating and cooling energy savings and improved thermal comfort within the building can be achieved through appropriate passive and/or semi-passive techniques, including better orientation, optimal window sizing, thermal insulation, natural or mechanical ventilation... (Al-Sallal 1998; Al-ajmi and Hanby 2008; Krüger et al. 2010; Jaber and Ajib 2011; Ebrahimpour and Maerefat 2011; Givoni 2011; Hester et al. 2012; Yaşar and Kalfa 2012; Byrne et al. 2013; Stazi et al.

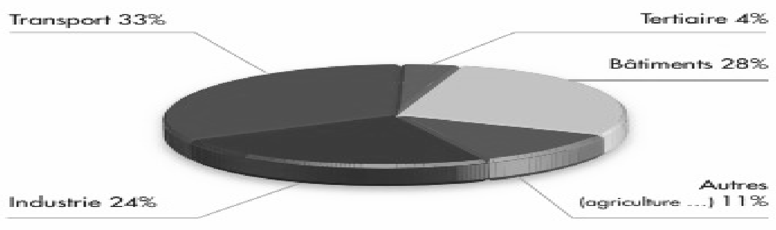


Figure 1: Final energy consumption of the building sector in the world 2010

Moreover, it is estimated that the potential for energy savings in this sector worldwide is in the order of 40%, and this largely through economically profitable measures. It is also an eminently strategic sector because of the long life span of buildings: today's constructions will have a lasting effect on tomorrow's consumption and a building that is well thought out at the time of its conception will always be more efficient and less costly than a building that is renovated afterwards. If the thermal sector: A thermal regulation is, in general, a text framing the thermal of new and / or existing buildings. It sets maximum energy consumption in several areas: heating / cooling, hot water, ventilation and lighting ... for each type of building; residential, administrative, commercial etc., the thermal regulations have emerged in different developed countries after the middle of the last century to increase towards 1974 following the first oil shock to cope with the sharp rise in the price of hydrocarbons and reduce the energy bill. In Morocco, the first thermal regulation was developed by the Moroccan Agency for Energy Efficiency and came into being on November 06, 2014 under the name of: "General Construction Regulation Setting the Rules of Energy Performance of Constructions" (RTCM 2014). However, despite its entry into force in November 2015, the (RTCM 2014) remains almost inapplicable for reasons so far unknown. On the other hand, the Thermal Regulation of Constructions in Morocco (RTCM 2014) is presented in the form of two approaches: one is called prescriptive approach and the other performancial. The first offers a technical description of the regulatory limit requirements of the thermal characteristics of the envelopes of residential buildings. The second one explains the thermal performance limits of residential buildings by climate zone. However, the RTCM is limited to the thermal aspect of the building and does not deal with other types of electrical consumption (e.g., lighting), although it is indicated in Article 3 of the RTCM: - development of the technical specifications of the thermal regulation, then implementation of the regulatory and normative framework; - implementation of a strategic plan and adequate communication tools for the mobilization and awareness of stakeholders, including administrations, companies, energy efficiency in buildings; - Support and technical assistance to professionals and administrations in charge of monitoring the application of thermal performance requirements, in order to strengthen their capacities in this field; - Creation of a favourable climate for investments in the field of energy efficiency; - Development and implementation of a portfolio of demonstration projects integrating advanced technological innovations.

Energy Efficiency and Renewable Energy Regulations Framework Law No. 99-12 on the National Charter for the Environment and Sustainable Development, 2014 - Sets forth the rights and duties inherent in the environment and sustainable development. - Strengthens the legal protection of resources and ecosystems. - Establishes sustainable development as a fundamental value shared by all components of society. - Defines the responsibilities and commitments of the parties involved - the State, local authorities, public institutions and companies, private companies, civil society associations and citizens. - Provides for institutional, economic and financial measures in order to establish a system of environmental governance. Law No. 47-09 on energy efficiency, 2011 Institutes the concept of energy performance for all economic sectors. It provides for the establishment of: - Building Energy Code: with a view to setting the rules for the energy performance of buildings by climatic zones by addressing, in particular, orientation, lighting, insulation and heat flows, as well as renewable energy contributions; - Minimum energy performance of equipment: Appliances and equipment running on electricity, natural gas, liquid or gaseous petroleum products, coal and renewable energy, offered for sale on the national territory must comply with minimum energy performance set by regulation; - Mandatory energy impact study for any urban development program project or any building construction program project; - Mandatory energy audit for establishments, companies and natural persons whose

Energy Efficiency and Renewable Energy Regulations Framework Law No. 99-12 on the National Charter for the Environment and Sustainable Development, 2014 - Sets forth the rights and duties inherent in the environment and sustainable development. - Strengthens the legal protection of resources and ecosystems. - Establishes sustainable development as a fundamental value shared by all components of society. - Defines the responsibilities and commitments of the parties involved - the State, local authorities, public institutions and companies, private companies, civil society associations and citizens. - Provides for institutional, economic and financial measures in order to establish a system of environmental governance. Law No. 47-09 on energy efficiency, 2011 Institutes the concept of energy performance for all economic sectors. It provides for the establishment of: - Building Energy Code: with a view to setting the rules for the energy performance of buildings by climatic zones by addressing, in particular, orientation, lighting, insulation and heat flows, as well as renewable energy contributions; - Minimum energy performance of equipment: Appliances and equipment running on electricity, natural gas, liquid or gaseous petroleum products, coal and renewable energy, offered for sale on the national territory must comply with minimum energy performances set by regulation; - Mandatory energy impact study for any urban development program project or any building construction program project; - Mandatory energy audit for establishments, companies and individuals whose annual thermal and/or electrical energy consumption exceeds a specific threshold. Enforcement Decree of Law No. 47-09, General Building Regulations setting the energy performance of buildings, 2015 The purpose of this regulation is to reduce heating and cooling requirements for all new residential and tertiary buildings. It adopts a prescriptive approach for buildings with opening rates (ratio of the surface of glazed openings to the total surface of the facades) of less than 45% and a performance-based approach for other buildings. The technical requirements concern the heat transfer coefficients of the building walls. In order to obtain a building permit, the project owner is required to submit a technical file on the thermal performance of the building in question, proving compliance with the regulations. Draft implementing decree of Law No. 47-09, Mandatory energy audits The decree provides for : - Mandatory and periodic energy audits from an annual consumption of 1,500 TOE for the industrial sector and 500 TOE for the tertiary sector, including also establishments and enterprises of production, transport and distribution of energy; - Accreditation of auditors, periodicity and control of energy audits - Energy efficiency classes; - The draft decrees will specify the effective dates of entry into force of the mandatory requirement and will specify the conformity assessment process in accordance with the provisions of the aforementioned Law 12-06

2.1) Climate zoning: For the purposes of thermal regulation, a climate zoning was carried out by analyzing the annual hourly climate data recorded by 37 weather stations over the period 1999-2008 (10 years), based on the results of simulations of annual thermal needs for heating and cooling of buildings in eleven representative Moroccan cities. The elaboration of the climatic zoning was carried out according to the criterion of the number of degree days of winter and the number of degree days of summer. Two types of zoning were established: - Zoning based on heating degree days at 18°C; - Zoning based on cooling degree days at 21°C. Heating degree days: Measure of the difference between the average temperature of a given day in relation to a reference temperature and which expresses the domestic heating needs. The reference temperature used is 18°C since, on average, when the outside temperature falls below this level, the interior must be heated to maintain a comfortable temperature. When the outdoor temperature is 18°C, internal gains can raise the indoor temperature above 20°C and heating is not required. Cooling Degree Days: Same as Heating Degree Days but measures the need for home cooling during the hot summer months relative to a reference temperature. The reference temperature used is 21°C. When the outdoor temperature is 21°C, internal gains can increase the indoor temperature above 24°C/26°C and imply air conditioning needs. The Moroccan territory has been subdivided into six homogeneous and circumscribed climate zones: Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Zone 6. The following map represents the climatic zoning adopted for the thermal regulation in the building in Morocco.

2.2) The performance-based approach: consists in setting the minimum technical specifications in terms of thermal performance of the building. These are evaluated through the annual energy needs of the building, related to thermal comfort. These needs correspond to the heating and/or cooling needs of the building independently of the type of heating and/or cooling systems used. They correspond to the annual sum of the thermal demands that the building imposes on its installations to satisfy the thermal comfort needs of its occupants. The annual heating and/or cooling needs of the building are calculated by building energy simulation software or simplified computer tools, using reference temperatures for heating and cooling: 20°C in winter and 26°C in summer. The annual specific energy needs of the building, related to thermal comfort (BECTh) are determined according to the following formula:

BECTh = BECh + BERef We understand by : - BECTh: annual energy requirements for thermal comfort of a building expressed in kWh/ (m2 .year) - BECh: Annual energy needs for heating expressed in kWh/year and calculated over the winter period for a basic indoor temperature Tch = 20 ° C; - BERef: Annual energy needs for cooling expressed in kWh/year and calculated over the summer period for a basic indoor temperature Tref

= 26 ° C; - STC: Total living space conventionally conditioned expressed in m2 and equal to the sum of floor areas excluding work.

Occupant needs n Comfort: General state of well-being. n Air quality: Absence of pollution. n Ventilation: Ensure a comfortable indoor environment. Comfort depends on the following parameters: - Thermal conditions: Air temperature, radiation sources, temperature of surrounding surfaces, thermal permeability of surfaces in contact with the body. - Air quality: Relative air velocity in relation to the subject, relative air humidity, air purity or pollution, odors. - Acoustics: Noise level, acoustic nuisance, reverberation time.

Comfort is a physiological sensation involving more than one parameter. Thermal comfort only takes into account the following parameters: - Factors related to the individual: - His activity and the performance of that activity. - His clothing. - Factors related to the environment: - Temperatures of the air and surrounding surfaces. - Relative air speed and degree of turbulence. - Water vapor pressure or relative humidity. Air quality: Good air quality does not contain impurities in quantities that are annoying or dangerous to the occupants. Ventilation: The purpose of ventilation is to provide a comfortable indoor environment, keeping the occupants healthy.

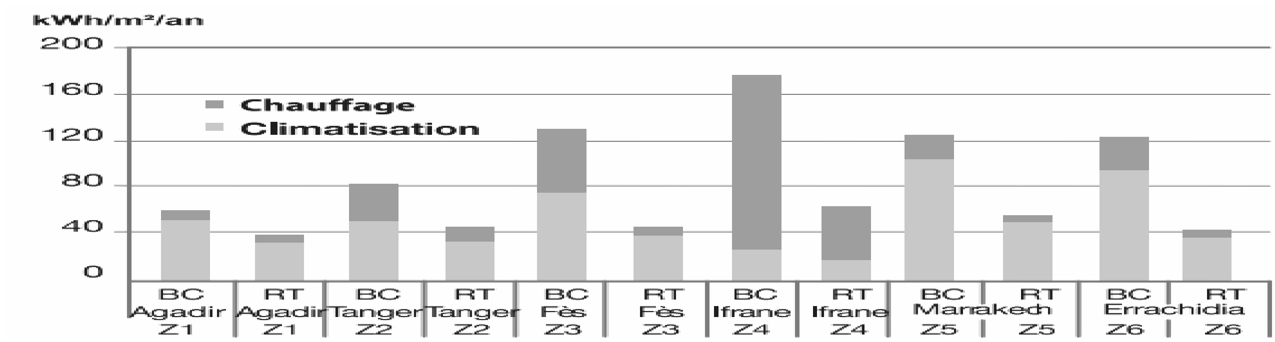
Quality of thermal insulation: - Fire resistance. - Mechanical resistance (traction and compression). - Airtightness. - Resistance to water vapor diffusion. - Low water absorption by immersion, by flotation and by diffusion. - Dimensional stability and heat behavior. - Acoustic qualities. - Price.

- Expected socio-economic, energy and environmental impacts of the thermal regulation

- Impact on the final consumer: The feasibility and effectiveness of the implementation of the regulation depends to a large extent on the economic interest of the recommended measures on the envelope for the final consumer. It is therefore necessary to analyze the advantages and disadvantages of these provisions for the final consumer.

Impact on heating and cooling requirements: Compliance with the requirements of the thermal regulations for residential buildings should result in a significant reduction in heating and cooling requirements compared to the baseline situation, as shown in the graph below.

Figure.2. Comparison of base case and thermal regulation Residential building (Ti = 26°C in summer) according to climate zone.



-Impact on final energy consumption The requirements of the thermal regulations allow final energy savings for the consumer of approximately 22 kWh per year per m2 of covered building1 . These savings vary from 8 kWh/m2 /year (zone Z1) to 75 kWh/m2/year (zone Z4) depending on the climate zone.

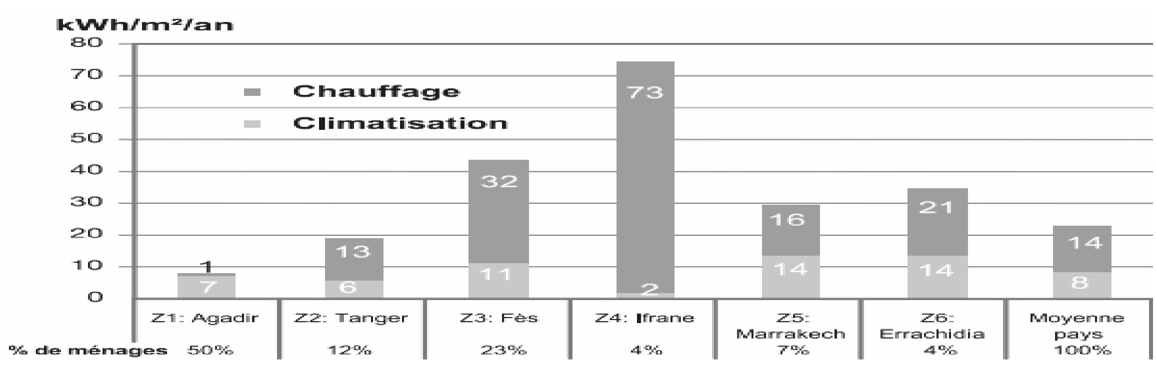


Figure .3.Final energy savings for heating and cooling by climate zone

-Additional costs linked to compliance with the thermal regulations: Compliance with the technical specifications of the regulations implies an average additional investment cost of around Dh112/m2, i.e. on average 3.2% of the average construction cost1. This additional cost is more or less high depending on the zone and the type of habitat, given the difference in the measures to be implemented. It varies from Dh43/m2 in the Agadir zone for luxury apartments to Dh315/m2 for low-cost villas in the Ifrane and Fez zones. In relative terms, this additional cost represents a particularly high percentage of the construction cost for the low-cost housing category, especially outside the coastal areas (Z1 and Z2).

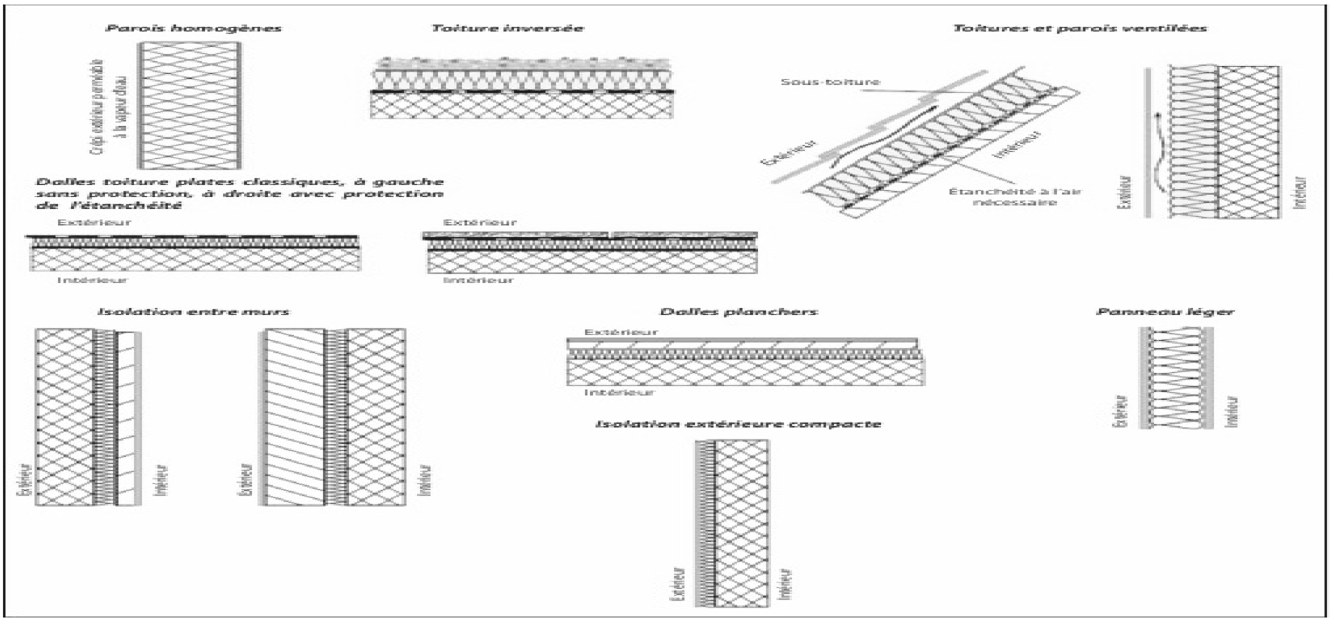


Figure.4.Thermal bridges

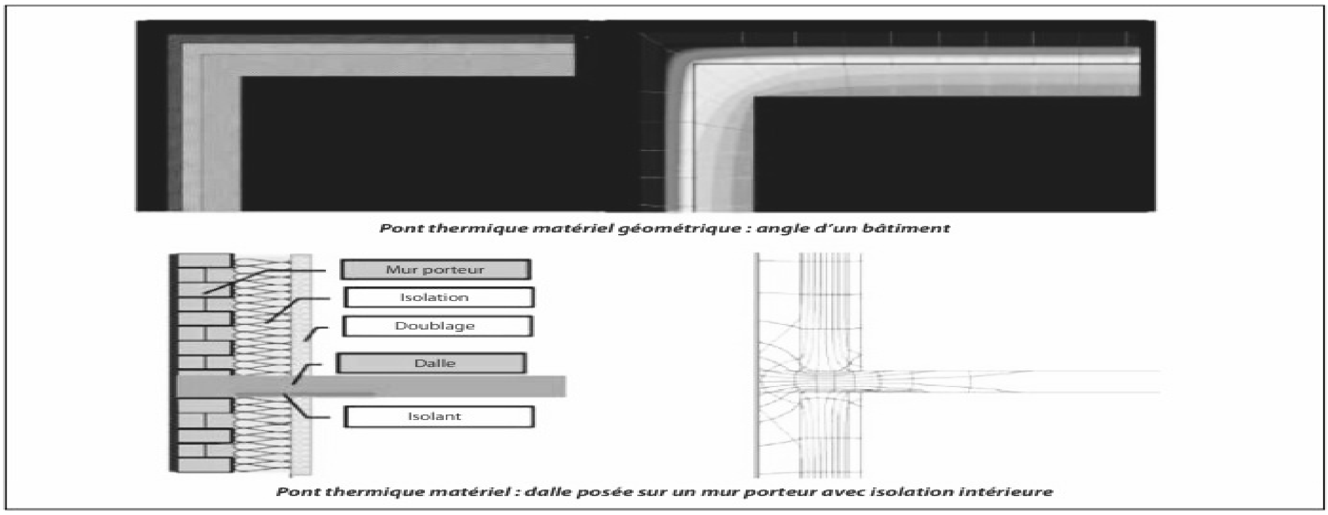


Figure .5. INFRARED CAMERA

Figure .6: Thermography

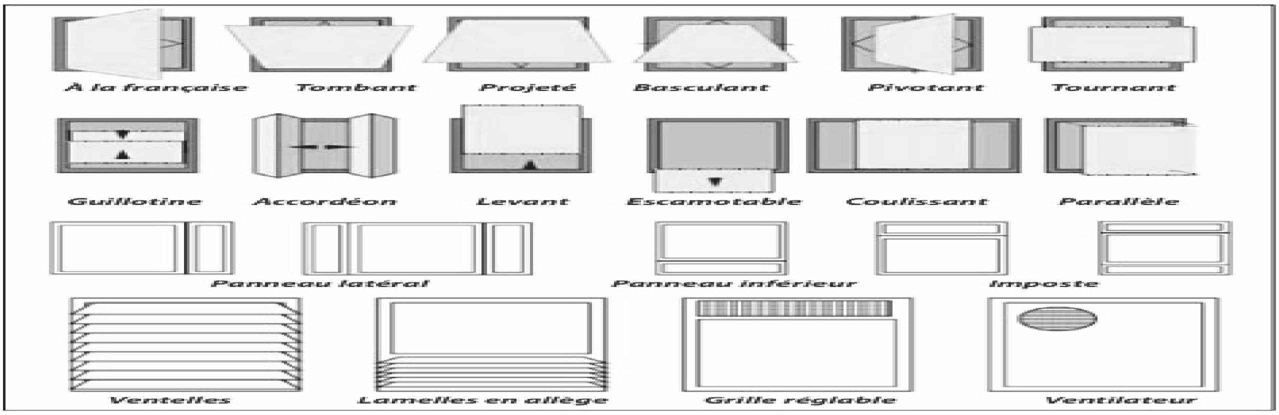


Figure 7: Ventilation openings and vents

-Ventilation influences at least four areas of building physics: - Air quality and consequently the health of the occupants; - Heat loss, hence energy consumption; - Internal and surface condensation problems, hence the durability of the building; - Thermal comfort, particularly draughts.

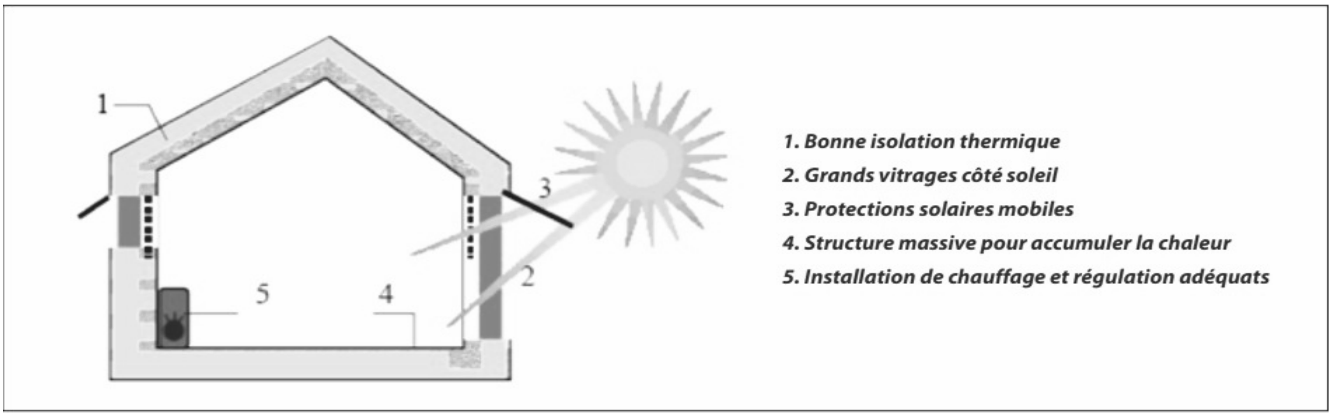


Figure 8: Principles of passive solar heating

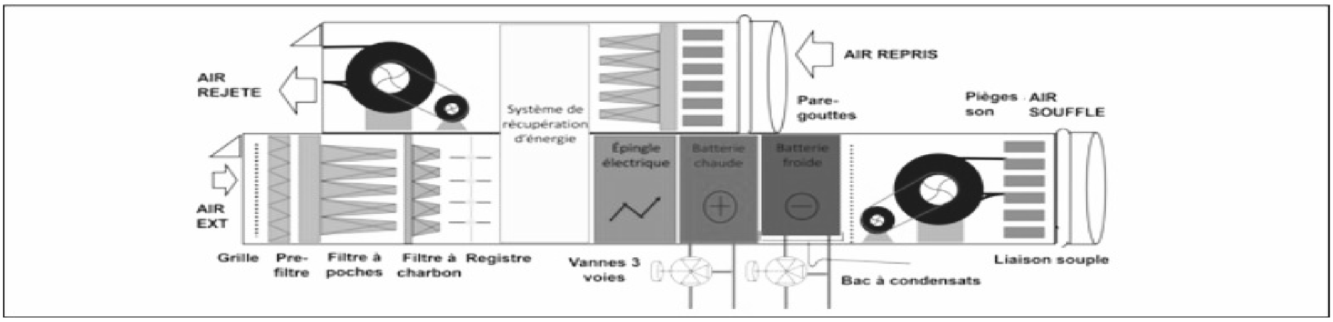


Figure 9: Air handling unit (double flow)

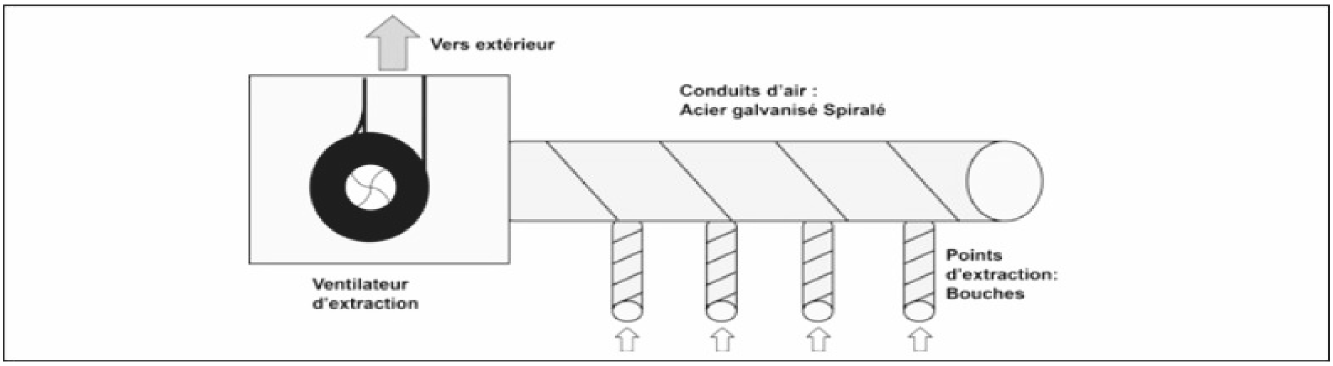


Figure 10: Air extraction Solar thermal

Thermal solar panels: The thermal solar panel consists in capturing the heat of the sun to produce hot water or heating. These panels are more widespread, because they are more basic. The thermal solar panel consists of a heat collector, this heat captured will be transmitted to the heat transfer fluid located in tubes. These tubes direct the fluid to a system of management and distribution of solar thermal energy.

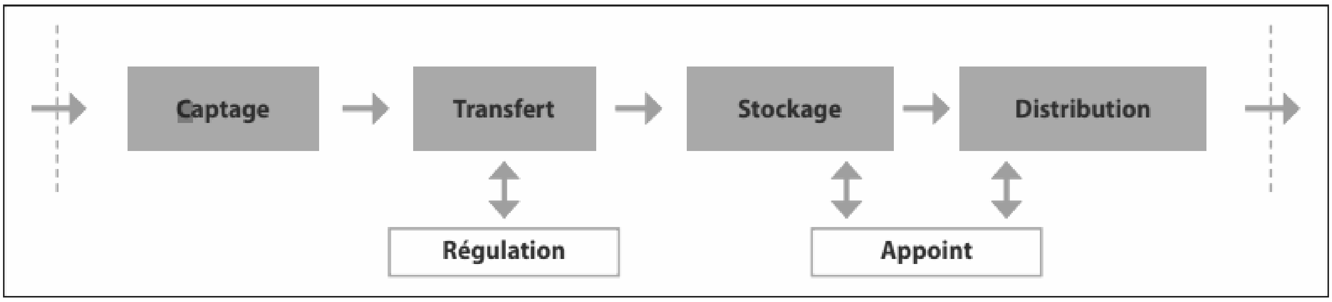


Figure 11: Principles of solar thermal

- Building shape - The more compact a building is, the easier it is to achieve high energy performance. - Exterior walls have a significant economic and ecological cost. Reducing the surface area of exterior walls reduces heat loss, cost and the impact of buildings on the environment.

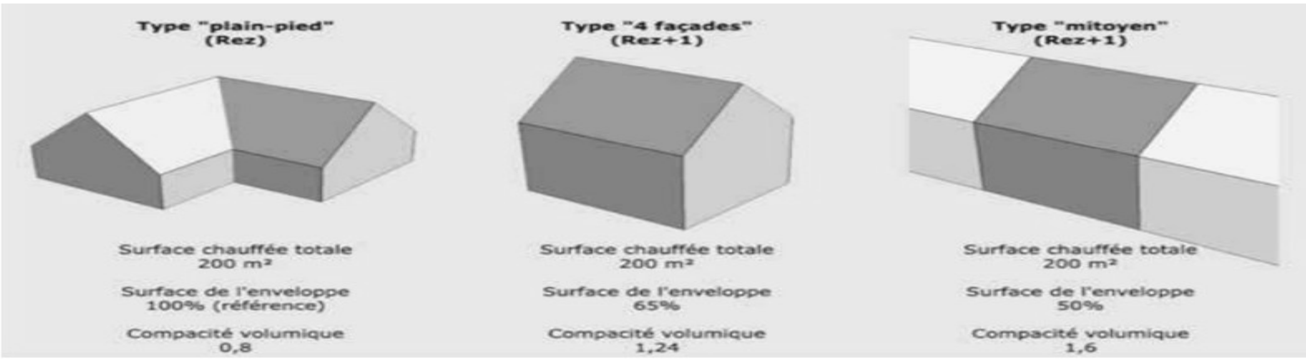


Figure .12. Impact of the compactness of the building.

-Natural summer ventilation Openings on opposite facades of the dwellings with free circulation of air in the dwelling will have a positive impact on ventilation. To allow natural ventilation through the dwelling, the creation of interior courtyards or specific ventilation ducts will be encouraged if necessary.

-Compliance with the Thermal Regulation in force The building must meet the requirements of the Thermal Regulation of Construction in Morocco (RTCM) in force, either by : - The prescriptive approach (if the General Rate of Glazed Bays TGBV.

-Choice of building materials - Give preference to local building materials; - Give preference to construction processes and materials that limit environmental impacts (minimize grey energy); - Give preference to insulation made from : - Organic materials; - Naturally formed minerals in large quantities; - Recycling with a very low grey energy balance. -Reducing heat transfer by insulating the roof is an effective measure for several reasons: n Reduction of the building's energy consumption: The savings compared to an uninsulated roof depend on the thickness and type of insulation, the occupancy of the building and the efficiency of the heating system. The savings from roof insulation can reduce envelope heat transfer by up to 30%. n Improved occupant comfort: In winter, the temperature of the ceiling under the roof increases due to the insulation. This has an immediate impact on occupant comfort by eliminating the cold radiation effect of the ceiling. In the summer, the insulation protects the roof space from overheating caused by the sunlight from the roof. n Reduction of condensation risks: The increase of the interior surface temperature reduces the risks of condensation at the level of the roof space. n Protection of the roof structure: Insulation reduces the impact of daily and seasonal temperature variations on the roof structure. Insulating the roof from the inside is generally not recommended. In this case, the roof slab absorbs solar radiation but cannot diffuse it because of the insulation. This overheating of the structure can lead to waterproofing failures and premature cracking. The extra cost of roof insulation varies from 60 to 300 dhs per m2 depending on : - Nature of the insulation used: noble materials such as cork are more expensive than synthetic materials such as polystyrene; - The thickness of the insulation put in place: the greater the thickness, the higher the price; - The location of the project: the further the project is from the supplier, the higher the price. For roof insulation, expect a payback period of about 5 years.

-Wall insulation Thermal regulations impose acceptable limit values for heat transfer through walls. In general, regardless of the climatic zone concerned and the type of roofing used, the installation of insulation is necessary to meet the regulatory requirements. There are four methods of insulating walls which are classified according to the position of the insulation in relation to the composition of the walls: Low floor insulation The thermal regulations impose acceptable limit values for the resistance to heat transfer through low floors, in areas where the climate is contrasting. In temperate climatic zones (Z1 and Z2), heat transfer through low floors does not

significantly affect heat loss; the regulation does not impose a heat transfer value for low floors. The low floors are the seat of ascending or descending heat transfers depending on the season; depending on the context of implementation, the low floor is directly located on a ground floor, or on a crawl space.

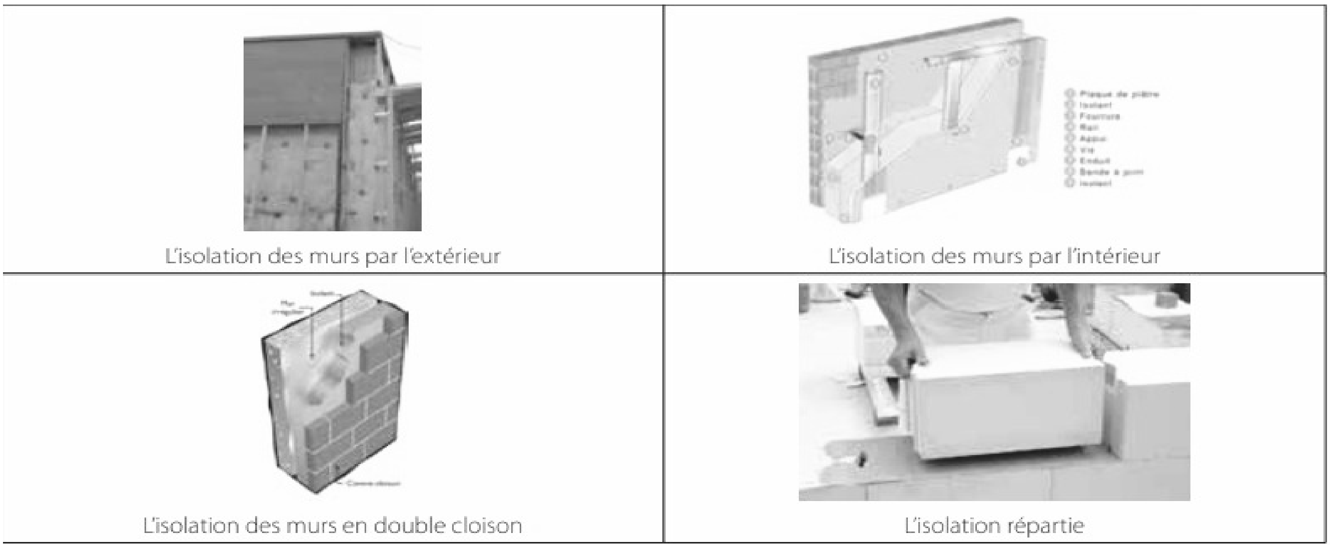


Figure 13: Exterior wall insulation

Exterior walls can be responsible for up to 25% of heat loss or heat gain. They are a source of discomfort due to the presence of cold/hot surfaces and energy consumption for heating and air conditioning. The extra cost of insulating walls varies from 50 to 200 dhs/m² depending on the insulation material and the insulation method chosen. The payback period for wall insulation is generally higher than for roof insulation, except for cold areas. The importance of thermal insulation in reducing the heating/cooling loads of the building has been extensively studied in the literature (Farhanieh & Sattari, 2006; Bolattürk 2008; Kaynakli 2012; Kolaitis et al 2013; Kumar & Suman 2013; Ozel 2013; Fang et al 2014) . In the Netherlands, Van Hooff et al (2014) evaluated the effect of six passive techniques on the number of overheating hours using dynamic thermal simulation of three generic residential buildings namely, a detached house, a semi-detached house with terrace and a top floor apartment. Kaynakli (2012) conducted a literature review on thermal insulation of building exterior walls. This review focused on insulation materials and their economically optimal thickness. The author also examined the effects of envelope thermal insulation and other design parameters on building energy consumption as well as CO2 emissions. This study shows that the optimal thickness of insulation is almost at the intersection of the curves representing the cost of insulation and the cost of energy consumption for the heating/ cooling needs of the building, respectively.

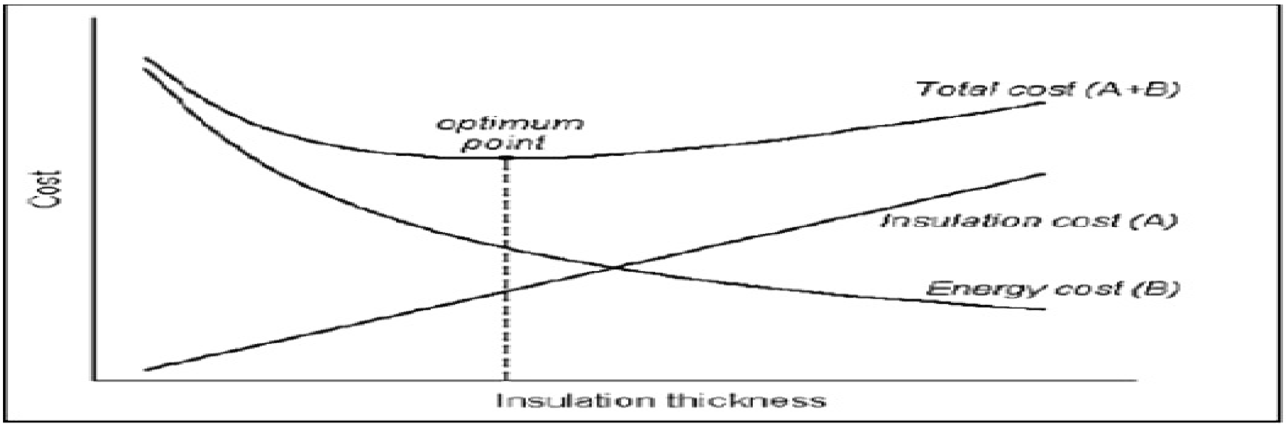


Fig. 14optimal thickness of the insulation

Similarly, in China, Fang et al. (2014) experimentally compared the effect of thermal insulation on the cooling energy consumption of two chambers in the hot climate of Chongqing region. The first chamber, known as the Energy Efficient Chamber, was built with an exterior wall thermal insulation system and the second chamber, known as the Basic Chamber, was built according to the standard design of residential buildings in China. The authors concluded that the first chamber saves 23.5% of energy consumption for cooling compared to the second chamber. However, the summer overheating that can be caused by the thermal insulation of the envelope, the inertia of the floor, the effect of the thermal insulation of the roof are factors that were not taken into account in this research. Also note that the authors' conclusion was based solely on the comparison of temperatures within the two chambers during two typical summer days (July 24 and 25) as shown in Figure 4. Figure 4. Temperature and relative humidity of "Basic chamber" and "energy Efficient Chamber". (Fang et al.

2014) In another study, Stazi et al. (2013) verified the thermal performance of the three envelopes characterized by different traditional wall types adopted in temperate climates. For this purpose, they made experimental comparisons between three buildings located in Italy. All these buildings were built between the 1940s and the 1980s, and have envelopes with different types of walls to cope with external climatic conditions: capacity (high thermal mass), stratification (different layers and a cavity) and resistance (use of an insulation layer). Simulation results by EnergyPlus software show that the behavior of the three envelopes is very different because they interact in different ways depending on the climate changes. In summer, the envelopes with the capacity or resistance strategies have a beneficial effect compared to the stratified envelopes, while in winter, the insulated wall behaves better than the others (due to its low thermal transmittance). On the other hand, a high capacity envelope has a negative effect in summer, as it causes considerable problems of overheating. On the contrary, in winter the insulation placed outside seems to be a good solution. At the end of this research, they concluded that, unlike a traditional external insulation layer that can cause overheating problems in summer, a ventilated external insulation layer is an optimal solution with respect to comfort and energy consumption, both for high thermal mass and for laminated envelopes. A similar study on envelope thermal inertia was done in Argentina by Larsen et al. (2012). They analyzed the influence of a massive and light envelope of a building on the annual energy consumption. They simulated the heating and cooling load of the building by EnergyPlus software, with the use of hourly weather data from Salta, Argentina. After the comparison between light and massive walls, they stated that the latter are preferable to light ones in arid climates. This type of wall gives energy savings of about 25%.

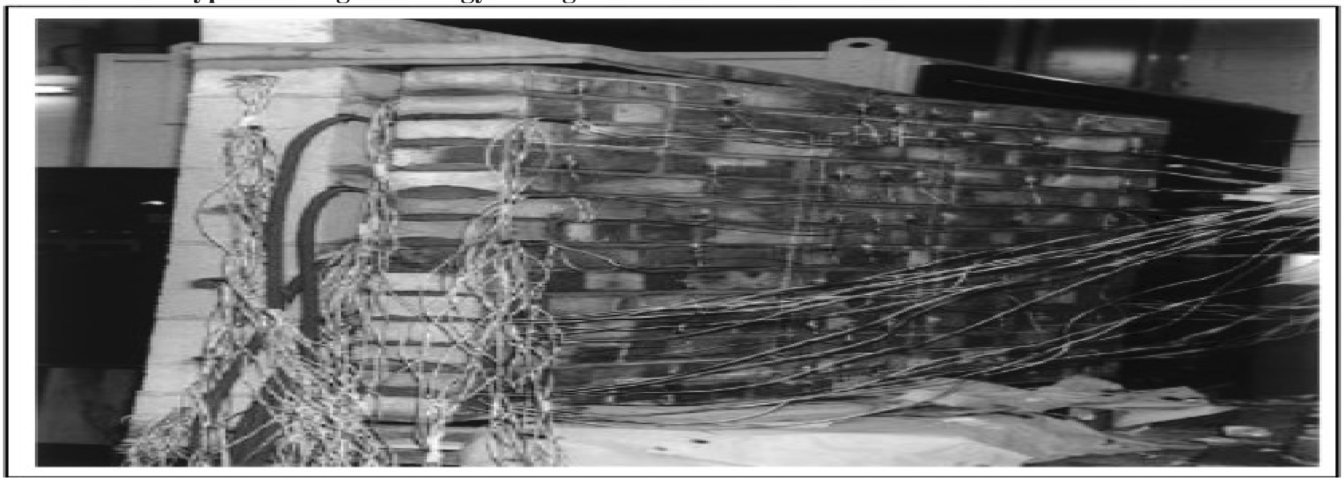


Figure15 Construction of a double wall prototype with variable air gap thickness (Aviram et al. 2001)

buried or semi-buried buildings offer very comfortable indoor environments. Due to the considerable increase in the thermal inertia of the envelope, the daily variation of temperatures disappears; only the annual cycle weighs on the indoor environment (Figure 6). Experimentally investigated examples have shown that an interior temperature can be kept stable around 30°C, while the surface temperature in the exterior walls exceeds 40°C (Zermout 2011). According to the same author, other measurements show that near the surface, the temperature fluctuates daily around the average diurnal temperature, but with depth, the integration period of the average temperature increases and at some depth, the amplitude eventually stabilizes around the annual average of the outdoor temperature.

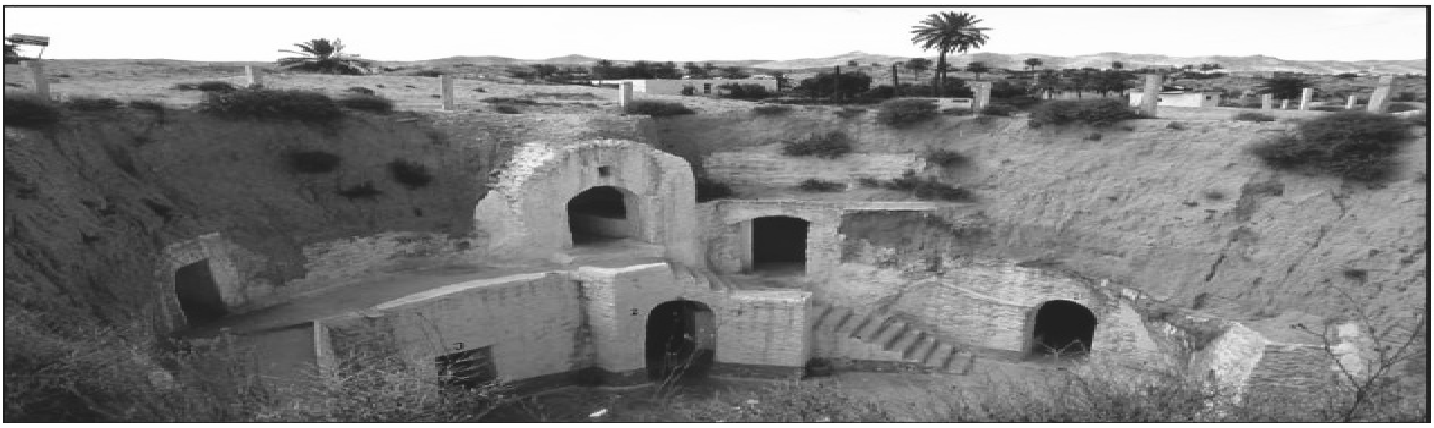


Figure16. An example of troglodytic architecture in "Matmata" in Tunisia, building

Transparent walls A glass window (window, door, veranda...) is typically composed of a transparent part: the glazing, single, double or triple, and an opaque part: the frame: steel, aluminum, wood or PVC, as well as some

accessories. The thermal performance of a glass wall is essentially guaranteed by the quality of its components: glazing, seals, profile, pre-frame... a transparent wall is characterized by the phenomena of transmission and reflection of light.

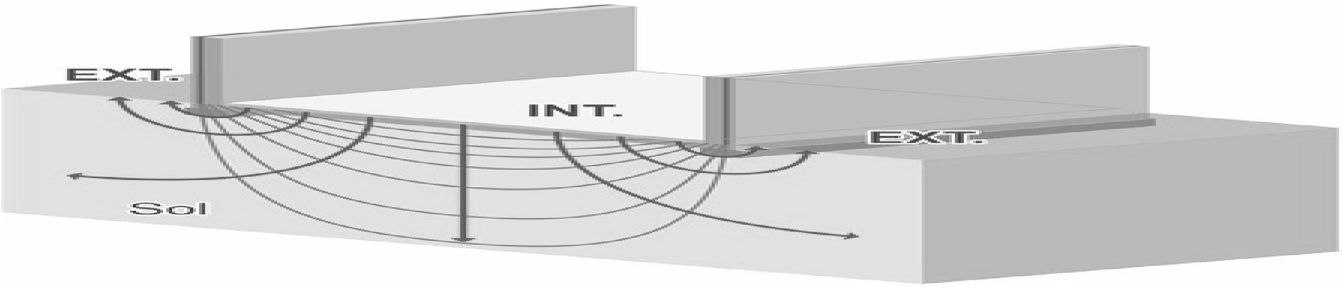


Figure 17: Example of low floor insulation

-Controlling thermal bridges: Thermal bridges are points of concentration of thermal leaks and are the consequence of a discontinuity in the insulation. Thermal bridges have several disadvantages: they cause cold spots that generate condensation and mold, and are factors of overconsumption of heating and air conditioning. To avoid thermal bridges, it is recommended to insulate from the outside.

-Building inertia : The thermal inertia of the building depends mainly on the characteristics of: - Exterior walls; - Interior walls or partitions; - Roof and intermediate floors. A strong inertia of the walls makes it possible to attenuate the fluctuations of temperature and heat flow, and to maintain a comfortable interior temperature by smoothing the variations of diurnal and nocturnal external temperature. The most inert materials, which lend themselves well to heat storage, are dense materials such as concrete, stone and solid bricks. A large surface area for interior double walls, partitions and floors is very beneficial in terms of inertia.

-Daylighting: In order to optimize the energy consumption of the building's lighting, while preserving the visual comfort of the users, a study of the optimization of the natural lighting and the daylight factor (FLJ) would be very judicious. It would allow to identify the critical areas and to optimize the size of the openings

- Energy Budget Optimization: In order to justify and prioritize energy efficiency actions, a pre-study estimating the cost-effectiveness of proposed energy efficiency actions is recommended. This includes the following: - The extra cost of implementing the requirements of the thermal regulation; - The extra cost of installing more energy efficient equipment compared to conventional solutions; - The payback time of these actions by integrating the extra cost of operating the energy equipment to assess the economic profitability. the law 47-09. **2.3) Focus on** **Although the issue of energy efficiency in existing buildings is very important given the size of the stock in Morocco, the proposed thermal regulation covers, initially, only new buildings. The treatment of the segment of existing buildings can be treated through energy audits and the implementation of energy efficiency measures that result.**

2.4) Thermal simulations and analysis The **objective of these simulations is to establish the optimal technical options to significantly improve the thermal performance of the target buildings compared to the current situation, considered as a reference. For this purpose, a series of thermal simulations were carried out on reference buildings using the TRNSYS software.Choice of reference buildingsSeven reference buildings were chosen in consultation with the ministries in charge of the sectors concerned, to be the subject of thermal simulations:**

Parametric energy analysis: The parametric energy analysis consists in modifying the parameters of the reference building envelope one by one and simulating the impact of each modification on the annual heating and cooling needs of the building under standard conditions of use and in different climatic zones. The simulated parameters are :

❯ wall insulation (3 or 4 insulation thickness variants);
❯ roof insulation (3 or 4 insulation thickness variants);
❯ window insulation (3 or 4 window variants);
❯ solar protection of glazing (3 or 4 variants of glazing Solar Factor "FS") ;
❯ solar protection of windows (3 or 4 variations of awnings and 3 or 4 variations of side overhangs)
❯ building orientation (2 different orientations).
❯ 5 to 10 most characteristic combinations of previous parameters. Thus, for each simulated parameter, the new thermal requirements are evaluated and compared to the requirements of the reference situation.

For combinations, the code for example (462,451,930) is interpreted as follows:

Table 3. Example of an energy code					
Wall	Roofing	Floor	TGBV	U Window	FS
4	6	2	45	1,9	30

insulation 6 cm insulation 4 cm insulation % W/m2.K

λ=0.04 W/m2.k λ=0.04 W/m2.k

Parametric analysis of additional costs: This analysis consists of determining for each simulated parameter the additional investment costs related to the implementation of each option. It also allows us to determine the reduction (or even the increase) in the costs of heating and cooling installations (due to the variation in installed capacity) by taking into account the variation in maintenance costs. The additional investment costs were determined by the architect on the basis of the prices of insulation materials currently available in Morocco (wall insulation, double glazing windows, etc.).

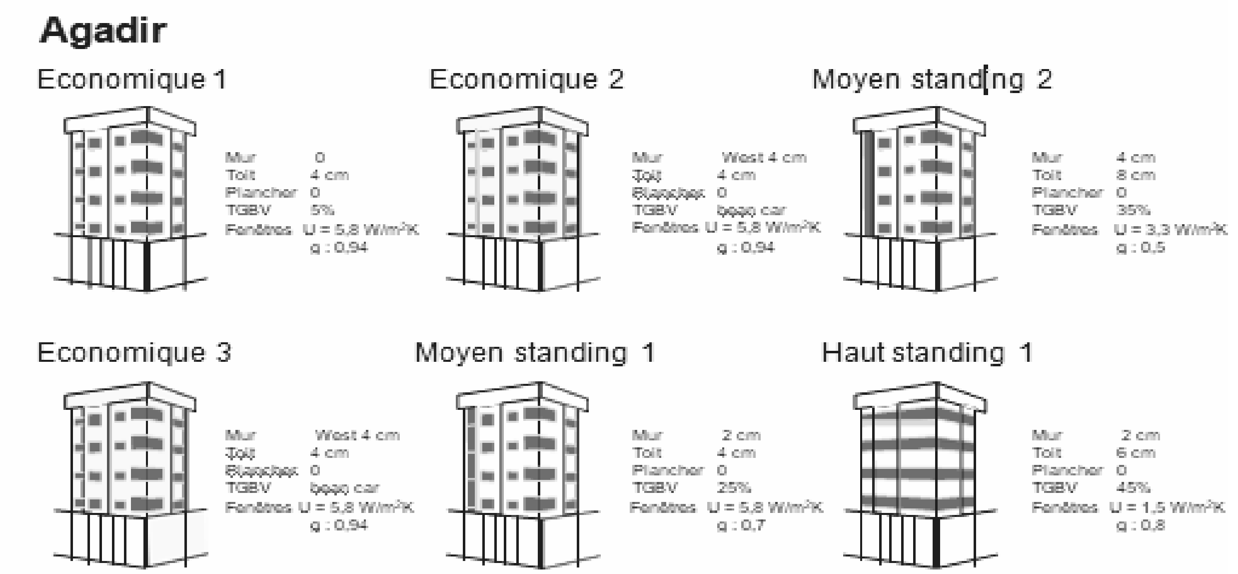


Fig18. Definition of minimum technical specifications for the thermal performance of buildings

Taking into account the additional investment costs on the one hand and the thermal simulations on the other hand, an iterative process allowed to set reasonable levels of envelope performance requirements to be considered as regulatory levels. These levels were defined based on energy saving options that represent a good technical and economic compromise. The RTCM sets performance criteria for the building envelope components, the levels of which will reduce heating and cooling requirements, the energy consumption related to these items, and the electrical power required for building operation. For non-air-conditioned buildings, they will reduce periods of thermal discomfort. The minimum technical specifications for thermal performance can be expressed, for each climatic zone and each type of building, in two ways. These two approaches offer the professionals involved in the design of the building envelope components a great deal of flexibility in the application of the MTR.

The specifications are expressed in terms of minimum requirements for specific annual heating and cooling needs, in relation to reference indoor temperatures (20°C for heating and 26°C for cooling). However, the verification of these specifications requires the use of a simulation tool. A simplified simulation software will be developed and made available to users free of charge. However, the use of heavy software such as TRNSYS or VisualDO3 as well as practical software such as HAP and CODYBA remains valid for large projects justifying the use of this kind of software (in particular in case of HVAC systems dimensioning).

Simplified approach called prescriptive: The thermal characteristics of the walls of the building envelope correspond to the heat transfer coefficients (U) of the roofs, exterior walls, floors on piles and windows as well as the equivalent solar factor (FS*) of the windows and the thermal resistance (R) of the floors on solid ground: The TGBV of the heated and/or cooled spaces of a building is defined by the ratio between the total area of their bay windows and the total gross area of all their exterior walls:

$$TGBV = \frac{\sum \text{surfaces des baies vitrées des murs extérieurs des espaces chauffés et/ou refroidis}}{\sum \text{urfaces brutes des murs extérieurs des espaces chauffés et/ou refroidis}}$$