Improvement temperatures of a studio apartment through judicious choice of materials and eco building materials under an arid climate - case study Ghardaïa

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Abstract. The aim of this study is to approximate the thermal comfort in the home by the judicious use of building materials and the reinforcement of the envelope by the thermal insulation using eco materials. Our task was to investigate minutely the construction materials that are specific to the site and commercially available on the Algerian market under hot climatic conditions. EnergyPlus software was used for energy simulation with “OpenStudio plugin for SketchUp” as an interface. Results indicate that the most suitable building material in terms of thermal comfort for cold seasons and even hot seasons is brick. The simulation allowed us to discover that insulation of the roof is an advantage not to be neglected, as long as it has a considerable influence on the interior temperatures, and it makes it possible to reduce remarkably the fluctuations of the temperature. Eco-friendly material, both environmentally and energy-efficient, is an inevitable alternative to any construction. Our choice has focused on the air gap, if this could be proved experimentally, will therefore be profitable even economically since the cost of an air gap is virtually zero.

1. Introduction

There is a growing consensus among scientists and the oil industry that we will reach the peak of oil over the next twenty years and that we might have already reached that point. Global demand is skyrocketing, while world production is falling and oil is expected to become increasingly expensive and scarce. The construction industry relies heavily on cheap oil, on the manufacture and transportation of its materials, on machines and tools used in demolition and construction. It uses vast quantities of fossil fuels, accounting for more than half of the total carbon emissions that cause climate change. The built environment is also responsible for large amounts of air, soil and water pollution and millions of tons of landfill waste. It is a situation that must obviously change.

There are plenty of studies that have compared alternative building materials and their effect on the environment. Monteiro and Frei reassessed seven different wall schemes and result reveal that timber wall is most preferable scheme due to less release of CO₂ emission[1]. Bjorn Berge [2] provides technical data to enable design and building professionals to choose the most appropriate materials for a project: those that are least polluting, most energy efficient, and from sustainable sources. For the selection of construction materials and taking into account the thermal aspect, the chemical analysis of...
building materials such as gas concrete, cement, sand, marble, brick, roofing tile, lime and gypsum used in Turkey were carried out to assess the chemical components of these samples [3].

An eco-friendly construction can therefore not only help create a better external environment but also contribute to the construction of a comfortable and healthier indoor environment.

There are many good reasons why we should use environmentally friendly building materials and methods. This can improve the health of our planet and the health of our own lives. It also supports local businesses and helps strengthen the local economy, which in turn helps build our communities in vibrant, prosperous and desirable places to live.

2. Construction materials

What will my house be made of? This is the legitimate question that arises as soon as we decide to build. Each material has its strengths and weaknesses. There is no designated winner. Choosing is therefore not an easy matter, because you have to know the criteria to be considered, and determine which ones are relevant to our case. The thermal behavior of a building at a given moment clearly depends on the construction materials and the climatic conditions of the place where it is located, not to mention the architectural arrangements. The thermal comfort in the different areas of the habitat cannot be achieved without making a preliminary and judicious choice of building materials. Habitat must therefore ensure a direct response to climatic constraints specific to each region.

For heat exchanges between the exterior and interior environments of the habitat, the envelope plays a decisive role thanks to its thermal properties. Depending on the nature of the envelope materials, the heat from the outside can be damped and even delayed before it enters the room.

The present work was developed in the framework of a collective research aimed at defining the criteria of adaptable, accessible and judiciously implemented housing uniting key players in the construction sector. Therefore our study will be carried out on a studio apartment that has been designed in such a way as to be able to respond directly to the specific needs of a person, allowing them to circulate and use all their functions independently. The plan was designed by a member of our team (Figure 1).

The material of the wall plays a major role on the internal thermal comfort and the energy consumption of the habitat at the same time. Indeed, it was found that the density of the non-insulated wall plays an important role in particular for determining the temperature curves. More mass is more important, time to ascent or descent the temperature will be long. Density is not the only factor that influences heat storage capacity. The thermal conductivity and thermal inertia of the material, in turn, constitute significant factors for the choice of these materials [4,5]. Our task is to minutely investigate the construction materials that are specific to the site and the materials commercially available on the Algerian market, it was first necessary to investigate these materials in order to define all thermo
physical properties (thermal conductivity, Density, specific heat ... etc.) and also define the dimensions of the walls and the thicknesses of the different layers.

The following table summarizes the thermal properties, wall thicknesses and envelope characteristics [6].

### Table 1. Materials and composition of walls.

| Materials and composition of walls | L (m) | \( \lambda \) (W m\(^{-1}\) K\(^{-1}\)) | \( \rho \) (kg m\(^{-3}\)) | \( C_p \) (J kg\(^{-1}\) K\(^{-1}\)) |
|-----------------------------------|------|-----------------|------------------|------------------|
| Wall type 1                        |      |                 |                  |                  |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Cinderblock                        | 0.3  | 3.96            | 1300             | 1080             |
| Plaster                           | 0.015| 0.56            | 1400             | 1000             |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Stone                              | 0.4  | 2.3             | 2000             | 1000             |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Plaster                           | 0.01 | 0.56            | 1400             | 1000             |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Stone                              | 0.15 | 2.3             | 2000             | 1000             |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Wall type 2                        |      |                 |                  |                  |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Plaster                           | 0.01 | 0.56            | 1400             | 1000             |
| Wall type 3                        |      |                 |                  |                  |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Plaster                           | 0.01 | 0.56            | 1400             | 1000             |
| Wall type 4                        |      |                 |                  |                  |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |
| Plaster                           | 0.015| 0.56            | 1400             | 1000             |
| Wall type 5                        |      |                 |                  |                  |
| Mortar cement                      | 0.025| 6.14            | 2300             | 875              |
| Ground floor (ground)             |      |                 |                  |                  |
| Mortar cement                      | 0.02 | 1.4             | 1800             | 1000             |
| Ceiling                            |      |                 |                  |                  |
| Mortar cement                      | 0.015| 1.4             | 1800             | 1000             |

2.1. 3D habitat design (Google Sketch Up)

The building can be modeled by Google Sketch Up program, a free drawing software capable of creating three-dimensional models. With the Open Studio plug-in, it is possible to export files created in Google Sketch Up into thermal simulation software. It has numerous advantages, notably in terms of the ease of use of its presentation interface as well as the numerous opportunities offered for the presentation of the model. Its versatility makes it today a tool used by many fields of study; it is possible to modify the display of the different volumes present in the 3D world. Thus, it is possible to decide whether to make opaque or transparent the thermal volumes drawn but also to make opaque, transparent or even invisible elements of the environment imported. All of these options are available in the menu, by checking the various options (Figure 2) [7,9].

Therefore, the first step is to model or import the geometry of the building. It can be achieved in different ways:
- Creating 3D drawing geometry with the Open Studio plug-in in Google Sketch Up (generating a *.osm or *.idf file),
- Importing an *.idf file into the simulation software.
2.2. Simulation with Energy Plus

Our previous studies were always based on the Matlab computation code, this time a new program was chosen for the simulation of our habitat. Simple and interactive, EnergyPlus™ is an open source thermal and energy building simulation program developed by DOE (Department of Energy, USA) that allows building analysis using dynamic simulation, even allowing calculation of the heating and cooling loads required to maintain the thermal control setpoints.

Here is a list of some features of the first version of EnergyPlus. Although this list is not exhaustive, it aims to give an idea of the rigor and the applicability of EnergyPlus to different simulation situations:

- The time step per hour, user-definable for the interaction between thermal zones and the environment.
- Time, input, and output files based on ASCII text, including Hourly or Secondary environmental conditions, as well as standard and user-defined reports.
- Heat balance based on a thermal load solution technique allowing simultaneous calculation of the radiative and convective effects in both the inner and outer surface during each time step.
- Transient heat conduction through building elements such as walls, roofs, floors, etc. Using the conduction transfer functions.
- The combined heat and mass transfer model that explains the adsorption / desorption of moisture either as layer-by-layer integration in the conduction transfer functions.
- Thermal comfort models based on activity, indoor dry temperature, humidity... etc.
- Anisotropic sky model for improving the calculation of diffuse solar energy on inclined surfaces.
- Advanced glazing calculations, including controllable window blinds, electro-chromed glazing, layer-by-layer heat balances that allow correct allocation of solar energy absorbed by windows and a performance library for many types of windows [8].

Further details on each of these features can be found in the different parts of the EnergyPlus documentation library.

2.3. Auxiliary Programs

a. IDF-Editor (*.idf file editor)

For users who want a simple way to select files and run EnergyPlus, EP-Launch provides this and more. In addition, EP-Launch can help open a text editor for input and output files, open a spreadsheet for post-processor results files, a web browser for the table's results file, and start a viewer for the selected drawing file.

Figure 2. Opaque plan of the studio apartment.
b. **Elements (creating weather files)**

Is a free, open-source software tool, platform for creating and editing custom weather files for energy modeling construction. It can generate several types of files (bin, fmt, epw ... etc). The epw extension is used by EnergyPlus.

c. **Essential data for the simulation**

All data required for the simulation must be predefined in EP-Launch's * .idf file editor. We must begin by introducing the building materials specific to our habitat while defining their thermo physical properties, their thicknesses, and even their nature of roughness. Subsequently, the types of constructions (different layers of walls, floors, ceilings and even types of glazing and insulating layers) must be defined. Since our study is simple, based solely on solar contributions, additional data concerning any form of internal gain has been omitted (presence of persons, electrical equipment...etc.). The weather file (*.epw) includes not only the values of solar radiation, ambient temperature, wind speed and direction, but also particular information to the Ghardaïa site such as the latitude, longitude and altitude of the place. An old TMY2(type file used by the TRNSYS software) file for the Ghardaïa site that was used by a previous study was converted for simulation. The average monthly soil temperatures were generated from the RetScreen software.[7].

The output variables for an execution are selected by choosing the output object: Variable Dictionary. This object displays the output variables available on the eplusout.rdd (regular variables) and eplusout.mdd files. Note that IDF-Editor can interpret both sets of files and help us get output variables in our input files. First, we have to run the input file first. In our case, we are particularly interested in the interior temperatures of the studio.

3. **Simulation results**

The complex internal geometry of our studio apartment (many separations), and being beginners in the use of this software (lack of time) were major constraints that forced us to consider (for a start) the studio as a single thermal zone. This will not in any case be an obstacle in our next studies to take into account these separations, so we will be faced with simulating several thermal zones, which will give a better credibility to our work.

The choice of the simulation days was meticulous, a plot of ambient temperatures throughout the year 2013 (Figure 3) allowed us to choose two different periods, this two periods being the hottest and the coldest throughout the year. Note that these temperatures were extracted from the weather files collected from the weather station of our research unit (Figure 4) [8].

![Figure 3. Ambient temperature of 2013.](image1)

![Figure 4. Radiometric station of the research unit of Ghardaïa.](image2)
The plots in Figure 5 represent the studio temperatures for two different periods, (a) being the coldest period of the year and (b) the warmest period. Our reasoning on the classification of building materials will be based on two simple ideas, for the winter period, the temperatures of each material must be ranked in descending order during the day during during the night, this amounts to that our goal will be to have always the highest temperature. On the other hand, for the summer period, the temperatures of each material must be classified in ascending order during the day and during the night, with the aim of having the lowest temperature this time. Making the difference between day and night refers to the behavior of materials that have better behavior during the day but their behavior is reversed during the night, as is the case with a layer of 15 cm stone.

Therefore, we will define five categories: Very good, good, medium, weak and very weak, each material will be classified to one of these categories according to its behavior. Then we will attribute to each class a number of points: from 5 for the Very good to 1 for the weakest. The sum of the points of each material will allow us to classify them from the best to the worst. The following table is a summary of our study.

| Material  | Cold period Day | Night | Hot period Day | Night |
|-----------|-----------------|-------|----------------|-------|
| Cinderblock | good            | medium | medium         | medium |
| Stone 40 cm | weak            | very weak | very good      | very weak |
| Stone 15 cm | very good      | weak         | very weak      | very good |
| Brick 30 cm | very weak      | good       | good           | weak |
| Brick 20 cm | medium         | very good | weak           | good |

This table leads us finally to classify these materials as follows:

The Brick 20 cm: 14 points, the cinderblock and the stone of 15 cm: 13 points, the Brick of 30 cm: 11 points and finally the stone of 40 cm: 08 points.

The 20 cm brick is therefore the most suitable and suitable construction material for our study, with the lowest temperatures during the summer period and the highest during the winter. Which brings us closer to the required thermal comfort.

4. Improvement of the envelope by eco-materials

The bioclimatic design is based on well-defined criteria, such as design, orientation, compactness...etc. However, thermal insulation remains the most important criterion on the energy efficiency of a home;
the latter contributes remarkably to saving cooling or heating energy, and thus leads to a reduction in the consumption bill. It contributes indirectly to reducing the rate of polluting gases that promote global warming (environmental protection), and is responsible for creating a healthy and comfortable environment for the occupants of the habitat.

During cold periods (typically from mid-October to late April in cold winter climates), the temperature inside the building envelope is generally higher than that of the outside. As a result, heat is lost through the envelope and, unless this heat is replaced, the interior of the building cools down by adapting to the outside temperature. The reverse applies to hot climates (or during hot periods) with excessive heat entering the building through its envelope. Therefore, it is logical to restrict the flow of heat in any building whatever the climate - and this is where the thermal insulation intervenes. Heat losses from exterior walls and roofs account for more than 70% of total heat losses in existing buildings. Therefore, improving thermal insulation is the most efficient way to save energy. At the same time, this will help to improve thermal comfort and prevent structural damage.

A work complementary to the choice of building materials was carried out, but this time the aim is to find the most appropriate insulation material and this obviously by choosing among the eco-materials available on the Algerian market. These eco-materials have become, in time, the inevitable solution for any construction, considering their energy efficiency, their advantages in terms of comfort and health and even their lightness.

Table 2 shows the thermo physical properties of some eco-materials available on the market. These eco-materials were introduced on the IDF file of the construction by a thickness of 5 cm between two walls of brick (construction material selected by the previous study).

| Material    | λ (W m⁻¹ K⁻¹) | ρ (kg m⁻³) | C_p (J kg⁻¹ K⁻¹) |
|-------------|---------------|-----------|------------------|
| Adobe       | 0.65          | 1600      | 1008             |
| Polystyrene | 0.036         | 34        | 1450             |
| Cork        | 0.038         | 130       | 1670             |
| Glass wool  | 0.044         | 100       | 1030             |
| Air gap     | 0.024         | 1         | 1024             |

It should be noted that we started our study by insulation of the roof (the main source of losses) with a 5 cm layer of polystyrene, these polystyrene plates have been marketed in the Algerian market in recent years. The aim is to reduce the losses caused by the roof and to see the effect of its insulation in spite of the walls of the envelope. The next step was to simulate insulated walls for each type of eco-material.

Figure 6 indicate the temperature variations in the studio area over five days, for a cold period and a warm period of the year. Roof insulation has proved to be very attractive in terms of avoiding temperature fluctuations, especially for the hot season, with a remarkable difference, a temperature stability also significant for the cold period.
Concerning eco-materials, the choice seems a bit difficult if one has to take into account the two seasons, cold and hot, as long as the choice for the cold season is clear: the air gap remains the most convincing, but for the warm season, our choice is on the adobe. However, noting that the difference in temperature during the hot season between the air space and the adobe is minimal, our choice is much more lean towards the air space, and this for both cases (hot periods and periods cold).

5. Conclusion
The choice of material to build a building has always been a question of relevance to architects and builders, as long as the choice is based on several criteria: cost, aesthetics, durability, and availability, thermal and sound performance ... etc. All these parameters must be taken into account while respecting the climatic stresses of the construction site (type of climate).

Our task therefore was to take stock of this issue in the framework of our research project whose goal is to minimize the energy needs of a structure built in a Saharan climate by integrating adapted architectural concepts. Choosing the most suitable material for the site of Ghardaïa and for a construction in the form of a studio is above all to take into consideration the materials available on the market. The selection is then based on thermal and energy criteria.

However, the material itself is in no way sufficient to meet our concerns, isolation by an appropriate eco-material is a privilege as to our construction for our study, and which must in turn be available. The EnergyPlus software simulation resulted in the following results:

- The most suitable building material in terms of thermal comfort for cold seasons and even hot seasons is brick.
- The simulation allowed us to discover that insulation of the roof is an advantage not to be neglected, as long as it has a considerable influence on the interior temperatures, and it makes it possible to reduce remarkably the fluctuations of the temperature.
- Eco-friendly material, both environmentally and energy-efficient, is an inevitable alternative to any construction. Our choice has focused on the air gap, if this could be proved experimentally, will therefore be profitable even economically since the cost of an air gap is virtually zero.
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