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Underground Building's Geothermal Potential: an Alternative Passive Sustainable Construction Facing Hot-Arid Climates. Case of historical NLA Hospital in Bitam

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ABSTRACT/RESUME

Abstract: *This research aims to evaluate the energy conservation potential benefit of earth-shelter building. There are as many types of earth building methods as there are variations in soil, climatic, and cultural conditions. As an alternative to energy consumption in upper-ground building, the underground building was and still one of the oldest building morphology models for thermal issue's solution especially in hot and arid regions. This paper aims to assess the thermal environment of an old underground building in "Bitam" a hot-arid region in Algeria. In order to evaluate the thermal environment assessment of underground buildings, In order to extract the thermal potential, an annual measurement campaigns were conducted for both summer and winter seasons using a digital multifunction monitoring instrumentations (LM/FI20, Testo 865, Testo 830-T2) for the quantification of the thermal advantages and extract most of its bioclimate value especially thermal environments. Thereafter, we use testo software tool "IRSoft" for thermal analysis of the existing underground building and the software "DesignBuilder" will be used for different environment simulations (thermal, CFD and daylighting) of an underground building model. The important findings relate to a high thermal potential using beneficial soil temperature and a large amounts of earth isolation that protect the building envelope from insulation. The underground building model proposed using passive techniques face extreme seasonal climate changes and interacts in a systemic way to enhance indoor thermal comfort.*

I. Introduction

This research aims to evaluate the energy conservation potential benefit of earth-shelter building [1]. There are as many types of earth building methods as there are variations in soil, climatic, and cultural conditions [2]. In order to evaluate the thermal environment of underground buildings, an annual on-site measurement campaign is indeed to cover seasonal variations, the qualification of the thermal advantages concerns and extract most of its bioclimatic value [3] [4] [5].

In arid areas, the underground construction is a traditional method of reducing the effect of outdoor air temperature on the indoor ambient temperature [6]. The principle underground construction is based on a high thermal capacity of the soil to cool indoor spaces in summer and warm it in winter. Historically, underground buildings were more common in hot and dry climates, which meant they needed to provide better cooling [7]. In the course of history, underground buildings or protected dwellings of the earth have been built in different parts of the world, including Tunisia, China, Iran, Jordan and Turkey [8].

II. Underground Building Advantages

In general, the underground buildings have their roofs and facades completely covered with earth, most important advantages of this building typology can be summarized as follows:

- Energy saving
- Less responsive to the impact of extreme outside air temperatures
- Protection against strong and dusty winds, hailstones, tornadoes, hurricanes and earthquakes; less fire susceptibility, less maintenance and natural soundproofing
- Offers maximum protection against natural disasters, but also man-made disasters such as explosions, nuclear accidents and burglaries
- The only way to get total privacy [6].

In other side, some parameters might be taken into consideration such as:

- Topography, local climate, vegetation, water table and soil type all play a dynamic role in the design of these original constructions
- It is recommended to plant draining species to limit the risks in case of strong periods of humidity [6].
- Also recommended the search of an adequate ventilation system for heating and cooling [9].

III. Impact of Depth on Temperatures

The energy of solar radiation and other atmospheric agents is continually transferred to the Earth's surface, affecting temperature at near-surface depths [10]. Soil temperature observed at different depths was studied several decades ago. Since then, no new theoretical approach in this field has been found in the literature, but obviously what have evolved with technological advances are measurement systems and data.

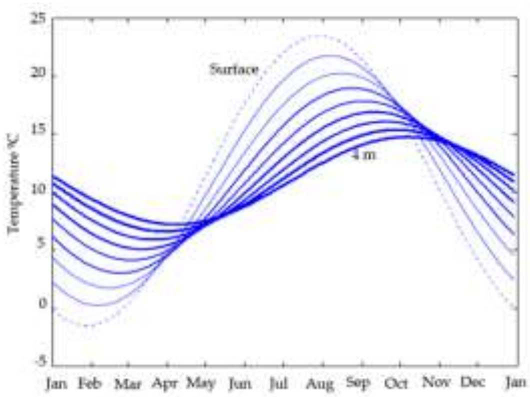

Figure 1. *Typical temperature behavior of the soil close to the surface at different depths*

Underground buildings are often not considered an option to reduce energy requirements. The environment in which an underground building is placed is the basement or the ground. In general due to seasonal changes, the temperature varies in the first 15 meters of sinusoidal depth over time. Even if it's weakened and delayed (relative to the soilless season), the soil temperature stabilizes at about 15 meters average annual depth (fig.1). The curves show the evolution of the temperature from the surface (0 m) to 4 m depth in steps of 0.5 m [11].

There are many types of soils. The composition differs in almost all places and under different climates [12]. In the arid areas, there are many floor materials: clay, peat, saturated sand and unsaturated sand. Taking the map of the Algerian arid area, one can roughly divide it in two: in the north, the soil consists mainly of clay or peat and to the south, mainly sandy soils (fig.2).

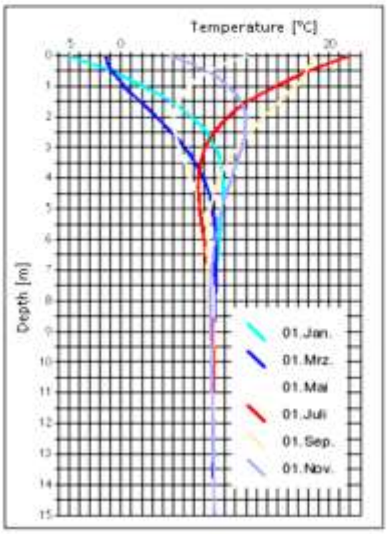

Figure 2. *General profile of underground temperature*

About 20 to 25% of the building's total energy loss comes from its roof, and a green roof can reduce that part of the energy loss in buildings. This technique increases the thermal resistance and reduces the solar gain of the roof. The green roof also absorbs heat during the day and releases it into the house at night [9]. The geometric design shape and cross ventilation have also an impact on energy saving [13] [14].

IV. Underground building case study

The underground building selected for the study has been chosen for historical and environmental values in the Bitam region. The specificities of the Bitam area resumes in the richness landscape. In the same area we can see 3 different landscapes: tellian, oasien and desert (fig.3).

Our earth building case study is a hospital under the moving dunes. The underground hospital of the National Liberation Army (NLA) of Nebka in Bitam region west of Batna, certainly figure among the places of memory that deserve to emerge from

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oblivion (Algérie presse service). An anthropological use provides camouflage and concealment and offers the defensive advantage and the shelter from attack. In a desert environment, you enter the underground building by a small opening just wide enough to let a person, by a staircase cut on the floor overlooking a corridor and rooms in which seats are set in the limestone. The whole is equipped with an ingenious ventilation system.

Figure 3. *Particular desert landscape in the Bitam region*

The figure 4 below summarizes the conditions of the underground building studied.

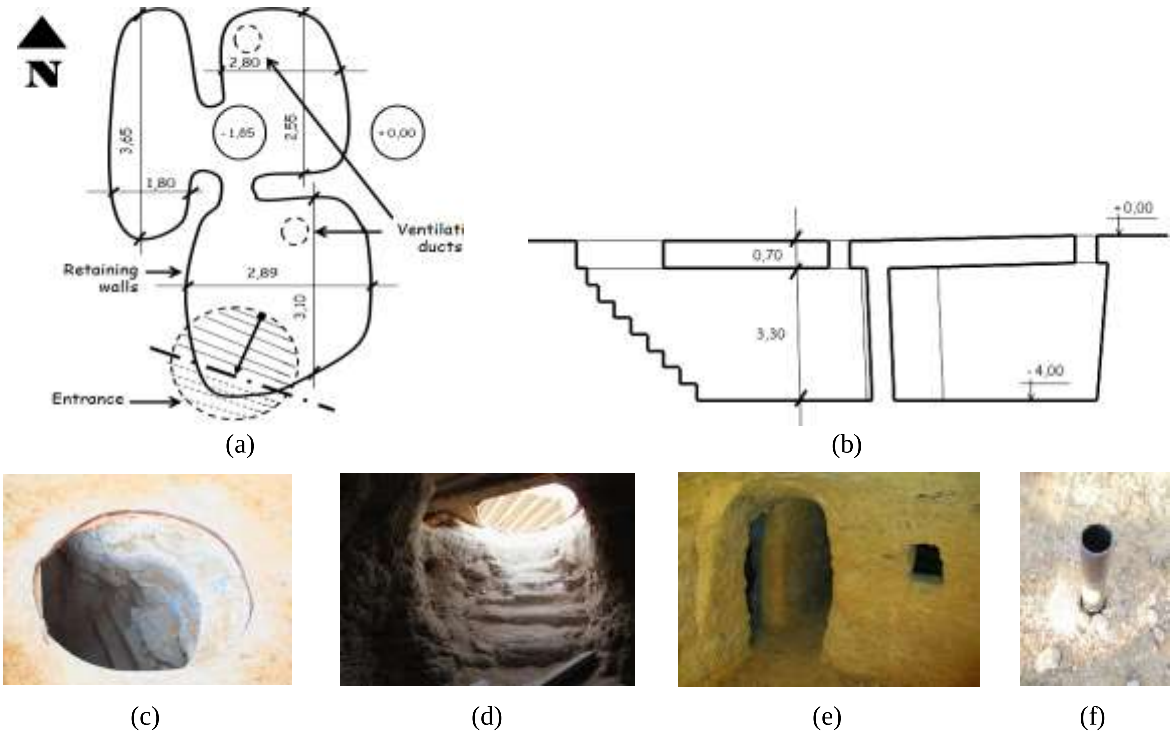


Figure 4. *Underground building conditions: (a) Undergroun building plan, (b) Undergroun building section, (c) Entrance, (d) Staircase, (e) Indoor spaces, (f) Ventilation Ducts.*

V. Monitoring campaigns

V.1. Underground Building Zoning

Three thermal main zones can be defined in terms of topological underground building configuration, an inside part which is the core, the intermediate zone separated the indoor spaces from the upper-ground or the exterior (fig.5). This subdivision has been applied to evaluate the thermal environments conditions in the different zones and between seasons [15].

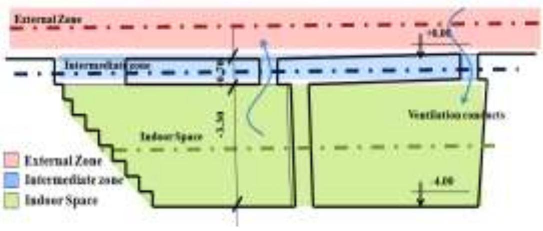


Figure 5. *Section showing the adjacent zones of the underground building studied*

V.2. Measurement Protocol

The monitoring campaigns were under extreme weather conditions, hottest days in July for the summer season and coldest ones in February for the winter season. These two months are supposed to represent the actual extreme weather conditions of the semi-arid region of Bitam, the on-site measurement tasks are:

- Recording the important thermal environment indicators: air temperatures (T) and relative humidity (RH) of the different zones
- Recording period: every two hours from 6:00 am to 0:00 pm under clear sky conditions for summer and winter seasons

V.3. Measurement Instrumentations

The monitoring instrument used to measure air temperature and the relative humidity is an "LM/FI 20" a digital multifunction measurement instrument combined 4 in 1: anemometer, hygrometer, thermometer and light meter. It records values with high accuracy. The second monitoring instrumentation is a testo 865 thermal camera combines all the important features for high quality thermographic measurements: it is accurate, fast and reliable. The testo 865 offers: high quality thermography, very high measuring accuracy of ± 2 ° C, visualize temperature differences from 0.12 °C, Automatic detection of hot and cold spots. The third monitoring instrumentation is a testo 830-T2 - Infrared thermometer with 2-point laser marking (12:1 optics) enables you to carry out efficient, non-contact surface temperature measurements with connectable temperature probe (TC type K).

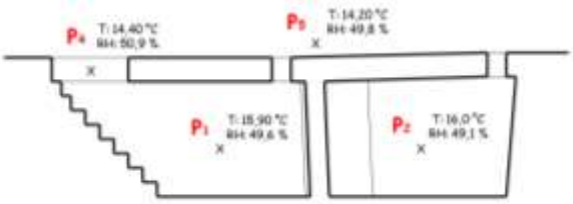
Figure 6. *(Left) Thermal camera (Testo 865), (right) Infrared thermometer (Testo 830-T2)*

VI. Results and discussion

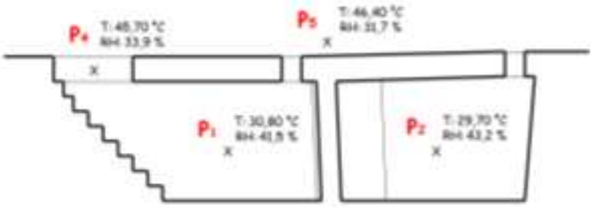
VI.1. Thermal Environment analysis

Building's bioclimate winter objectives are heating the indoor thermal environment and minimize thermal exchanges between interior the exterior zones. The indoor air temperature differs from the outdoor cold air temperature degree, the variation interval between indoor and outdoor air temperature recorded is approximately 2°C.

The figure 7 shows the comparison of thermal environments in different seasons, Results show a broad variation in the thermal environment between indoor and outdoor zones, and between seasons.



(a)



(b)

Figure 7. *Air temperature/relative humidity seasonal collected data: (a) during winter season, (b) during summer season*

In all cases, underground building acts as a temperature regulator, reduce heat in summer and warm up air temperature in winter (fig.7). In summer season, air temperatures decrease from the upper floor to the underground zone depending on:

- Case 1: Intermediate zone thickness
- Case 2: Indoor space geometric caracteristics
- Case 3: Depth of the indoor spaces
- Case 4: Natural ventilation system
- Case 5: The underground building roof conditions

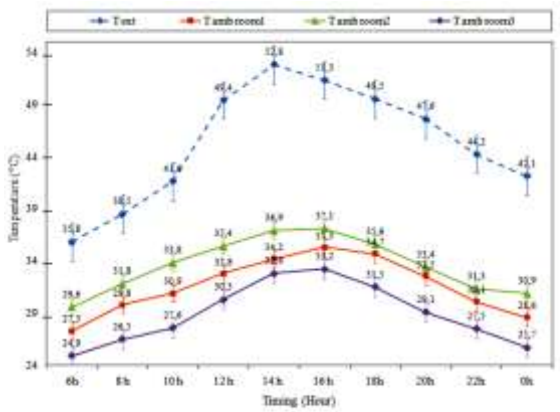


Figure 8. *Air temperature variations between indoor spaces and outdoor during summer season*

The thermal conditions vary between the indoor spaces and the exterior, the difference in air temperatures degree is around 13°C. This air temperature variation is due to the total sun protection of the ground soil (fig.8). The opening ratio is very low with no openings except the ventilation ducts; this low opening/closed ratio has a negative impact on the RH rate (fig.9).

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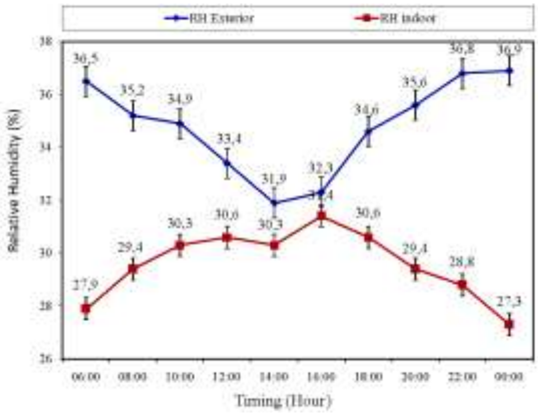


Figure 9. *Relative humidity variations between the indoor spaces and the exterior - summer season*

VI.2. Surface temperature analysis

The summer on-site measurement using the infrared thermometer to measure the different indoor surface temperatures: walls, ground, and under the ceiling. The measurement was carried out at 2 pm the maximal temperature of the day.

According to data results, the thermal difference between the indoor surfaces presented small intervals with an external surface temperature of 48 °C. We can conclude that the underground building is a solar protector and can minimize heat transfer. The figure 10 shows the different surface temperature variations between walls, under ceilings and soil.

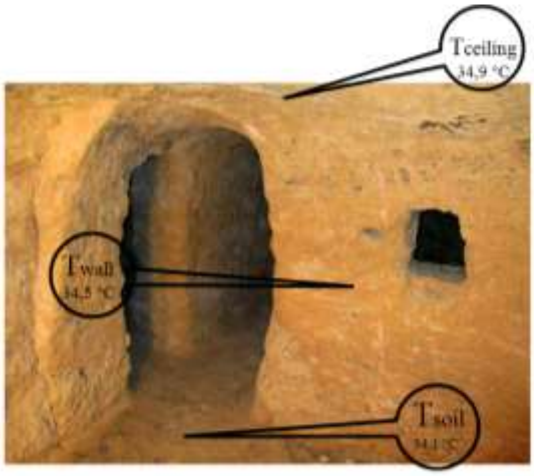


Figure 10. *Surface temperature variations: walls/ceiling/soil*

The different surface temperatures between the indoor surfaces of soil, walls and ceiling presented small intervals with a surface temperature of 34 °C. We can conclude that the underground building is a solar protector and can minimize heat transfer. The highest exterior surface temperature registered is of 56,9 °C reached at around 2:00 pm, on a summer sunny day (fig.11).

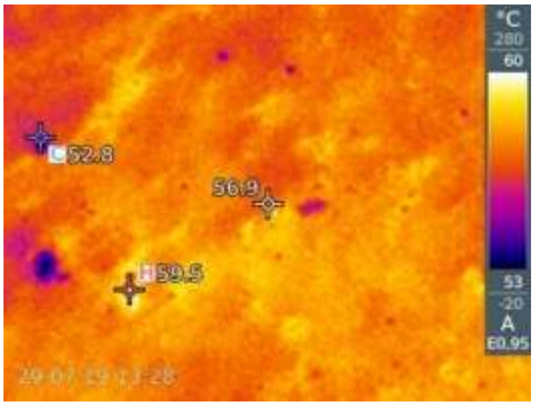


Figure 11. *Surface temperature variations: walls/ceiling/soil*

The figure 12 below shows a series of thermographs illustrating the thermodynamic processes of the different internal and external surfaces. The surrounding indoor surfaces demonstrate high thermal environment protections and a less heat transfer from the outside overheating.

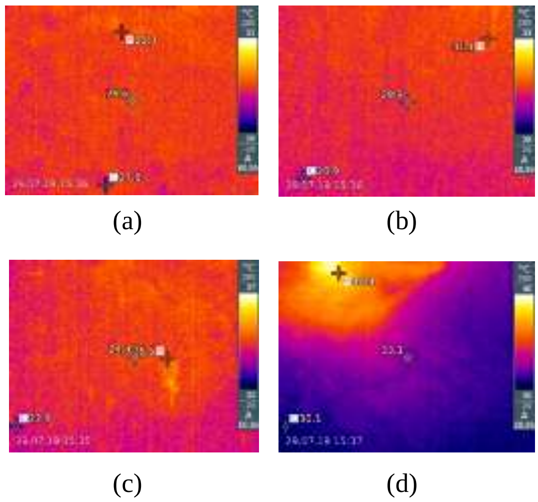
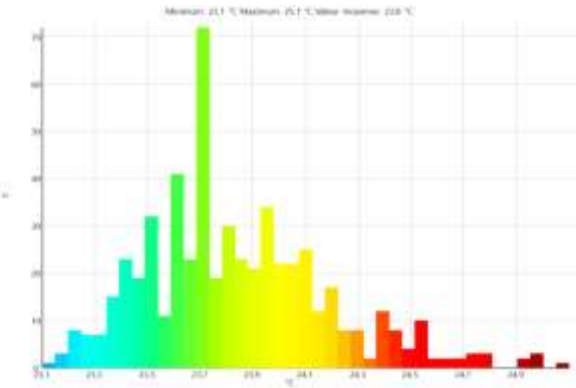


Figure 12. *Thermographs of the different underground building's indoor surfaces: (a) North wall, (b) East wall, (c) Soil, (d) Ceiling*

The data shown in the figure 12 shows very close surface temperature values, except the ceiling side near the ventilation conducts. The thermodynamic variation demonstrates that indoor surfaces are highly protected from the high solar insulation of the arid area; the thermal variation difference is approximately of 30 °C between a 59 °C on the outside ground surface and of 28 °C in the indoor surfaces.

(a)



(b)

Figure 13. *Thermal camera thermographic analysis using IRSoft software: (a) Temperature variations of the external roof surface, (b) Temperature variations of the indoor soil surface*

The graphs in the figure 13 show a large variation between external and indoor ait temperatures. The underground building also regulates the relative humidity rate. Recorded during the measurement campaign, the highest percentage of relative humidity is relatively constant during the winter period; it helps to enhance the thermal environment during summer season. We deduce that underground building indoor conditions inter-correlate and depend on the morphological indicators according to:

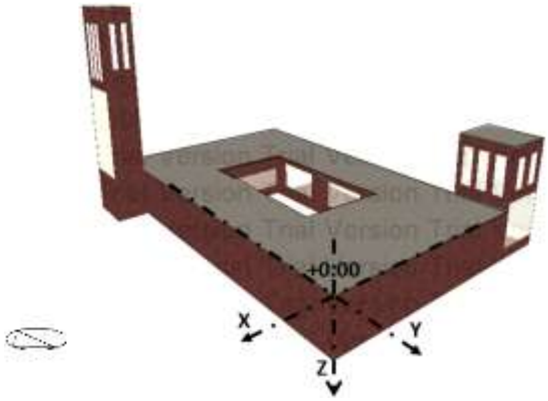
$$\Delta\ (T, RH, V) = \sum(R, D, H) \quad \textbf{(1)}$$

T: Ambient temperature
RH: Relative humidity
V: Natural ventilation
R_{Thick} : Soil thickness
$D_{Soil\ depth}$: depth
H_C : indoor space ceiling height

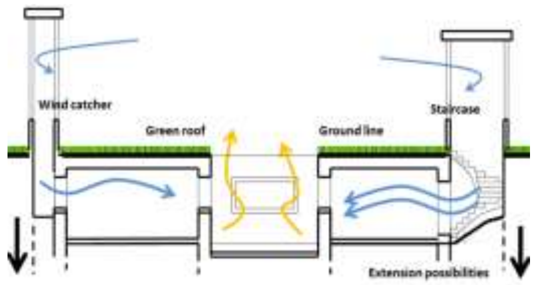
VII. Modelisation and simulation tests

VII.1. Underground Building Model

According to our case study climate conditions, the section below presents the underground building model (fig.14). This model aims to offer an adequate indoor space comfort for users using many thermal and passive ventilation techniques, such as: central courtyard, wind catcher tower, green roof… etc.



(a)



(b)

Figure 14. *Underground building model for simulation tests: (a) 3D view, (b) Section*

The underground building simulation tests using an effective simulation tool "*DesignBuilder 6.1.3.008*" trial version. This software use "*Energyplus*" in thermal computations and "*Radiance"* for daylight simulation. The model will be simulated in a passive way where all active systems are deactivated.

VII.2. Thermal simulation results analysis

Due to the use of passive thermal strategies, the thermal simulation shows a decreasing of the indoor air temperature, such as: courtyard, a wind catcher with geothermal underground building potential. The indoor air temperatures (AT) have been decreased from an outside AT of 56 °C to 34 °C during a hot summer day.

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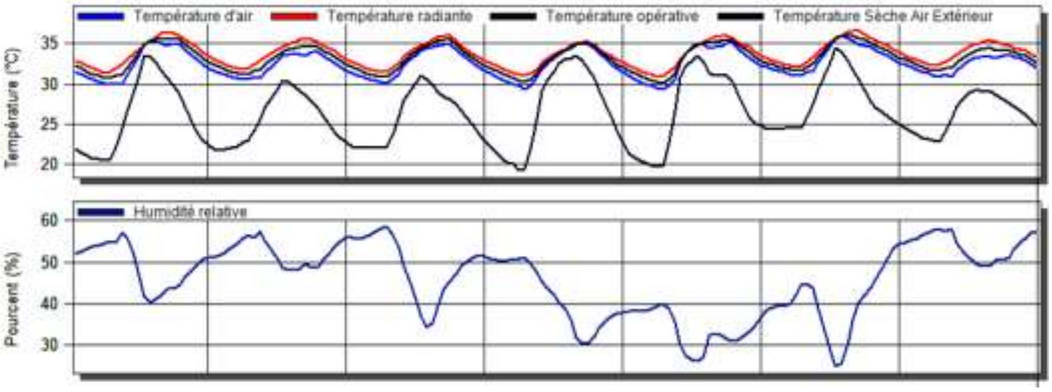

Figure 15. *Thermal simulation tests result during summer season*

In the case of the relative humidity, the simulation results show an important decrease of 20%, the RH rate is at the accept values around 50 % as the maximum (fig.15).

VII.3. CFD Simulation Results Analysis

In order to cooling indoor spaces, a cross ventilation is generated by a passive way between courtyard and wind tower. The CFD simulation tests show an increase of wind speed of 0.3 m/s (fig.16).

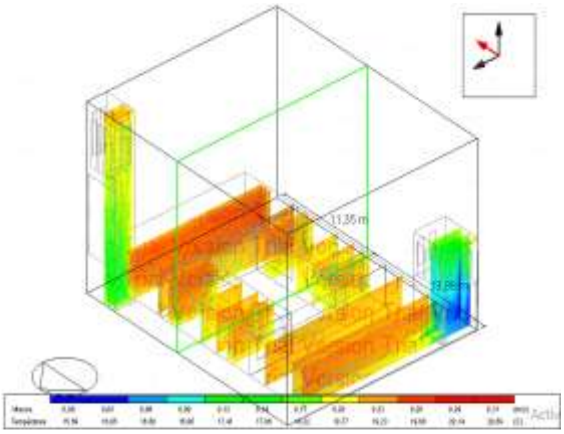

Figure 16. *CFD simulation tests results*

VII.4. Daylight simulation results analysis

The introduction of courtyard in upper-building has many bioclimatic advantages. It has been proved in the previous researches that courtyard has an impact on the luminous environment of its adjacent spaces [16]. The use of the courtyard in the underground building allows an enormous penetration of natural light, especially in the spaces nearby courtyard opening. In the adjacent spaces of the courtyard, the illuminance levels recorded are around 1398 Lux, while FLJ values are around 13.95 (fig.17).

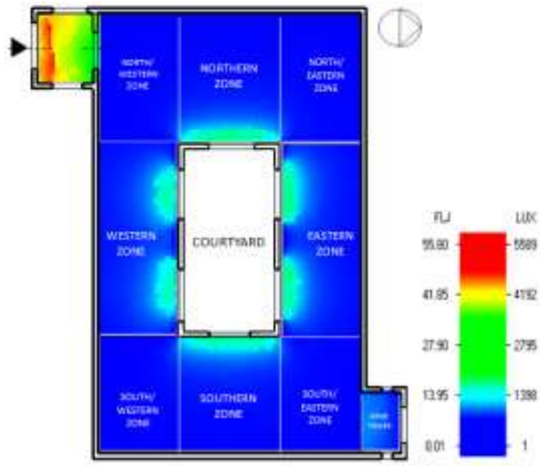

Figure 17. *FLJ and Illuminance levels variations on a work plan.*

VIII. Conclusion

In summer and winter seasons, temperature degree varied differently around the underground building zones. The most relevant result shows that the underground building is a bioclimate solution in hot and arid region; the earth benefit represents a perfect isolation from the entire hostile desert climate conditions especially for the thermal environment. This type of building is a passive strategy of a high thermal potential in hot and arid area, which can offer an adequate thermal control for the indoor spaces and save energy.

The first quality of an underground building, the most important, possibly, is the energy saving it allows. Protected by a thick layer of earth, the building is always at the regular temperature. The result is a building in which the temperature never drops very low in winter, and never rises very high in summer. Furthermore, we suggest the introversion of the building by the introduction of the central courtyard for ventilation issues which allows a natural ventilation, daylighting and solar benefices indeed for the indoor spaces. Greening the roof can also improve the thermal environment in those types of buildings.

The experimentation of a real case study, many thermal issues has been solved by using traditional passive systems. The present research has allowed us the development of an underground building model for hostile climate condition. The simulation tests show that the introduction of passive techniques that enhance thermal environment by increasing natural ventilation and daylighting the indoor spaces of the underground building.

In addition to its seasonal high potential, the underground building allows the integration of passive techniques strategies. All the bioclimatic parameters and geometric indices interact in a systemic combination to increase inside/outside exchange and enhance thermal, hygrothermal and luminous environments.

Depending on function, two possibilities of designing an underground building: whether horizontally plan where the heat exchanges of the interior spaces of the buildings is effected through the roof (ground surface) for specific buildings such as barracks or military hospitals, or vertically by introducing intermediate spaces (courtyard, staircase, wind tower... etc.) between the external surface and the indoor spaces to improve the indoor thermal conditions and preserve the land.

For future research, the model of the underground building tested offers unfinished depth extension possibilities; a new concept of “underground building towers” can be investigated. The test objectives will also be based on energy saving and user comfort. This model can be experimented as an alternative for future construction typology in hot arid regions.

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