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Modeling and Simulation of the Thermal Behavior of Nubian Vault Walls

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Abstract: In this study, we simulated the thermal behavior of the mud-brick walls of a Nubian vault. We used EnergyPlus software for the simulation. The results obtained showed that the indoor temperature varies from 25.5 ℃ to 26.5 ℃ for the period of January 2018 . It varies from 33.2 ℃ to 33.6 ℃ with an average value of 33.1 ℃ for the month of April 2018. For the period of July 2018, it varies from 30.3 ℃ to 32.2 ℃ with an average value of 31.2 ℃.. Relative humidity for the period of July ranged from 62.3% to 73.5%, with an average value of 67.9%. The simulation enabled us to compare simulated and measured temperature and humidity values. We found that the level of thermal comfort in the Nubian vault is acceptable in both cool and hot periods. In view of these results, we can say that the Nubian vault is an architecture suited to our climate. The technical concept of the Nubian vault is adapted to the climatic conditions and traditional know-how of the Sahel. We also found that the use of raw earth, a locally available material, and the Nubian vault architectural process, contribute to thermal comfort and a reappropriation of local and adapted know-how.

Key words: Thermal simulation, architectural technique, temperature, walls, thermal comfort.

1. Introduction

The building and construction sector alone accounts for 40% of total energy consumption and around 35% of greenhouse gas emissions [1]. The building sector must implement new technical and architectural solutions to meet society's expectations in terms of energy saving and climate protection. Against this backdrop, the EnergyPlus dynamic thermal simulation tool aims to provide players with a design aid adapted to these new demands [2]. Modeling consists in applying a certain number of simplifying hypotheses to a real problem, so as to be able to translate this problem mathematically. Dynamic thermal simulation aims to precisely define the thermal behavior of a building as a function of its location in its environment, its geometric characteristics, the composition of its envelope, and the local climate. Thermal modeling of housing is now our days a common practice, with a range of tools of varying complexity [3].

In particular, modeling enables comfort levels to be assessed, and energy requirements for heating and cooling to be determined for each zone [4].

First, we present the software used for the simulation, EnergyPlus. Next, we present and analyze the results of the simulation of indoor temperature changes as a function of time.

For existing buildings, simulation results are compared with measured temperatures over a given period to validate the model.

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2. Materials and Methods

The building's dimensions and geometric shapes were modeled using OpenStudio and google SketchUp, which enable 3D modeling. This concerns the walls, roof and openings. The building plan is shown in Fig. 1.

The monozone model considers the building as a whole as an enclosure with perfectly uniform internal characteristics. Fig. 2 shows the geometry of the building studied.

The thermal zoning adopted is probably the most important modeling assumption, as it can impose strong constraints on the applicability of the model.

A thermal zone corresponds to a space (air mass) considered to have a homogeneous temperature. There are several zoning approaches, each with its own advantages and limitations.

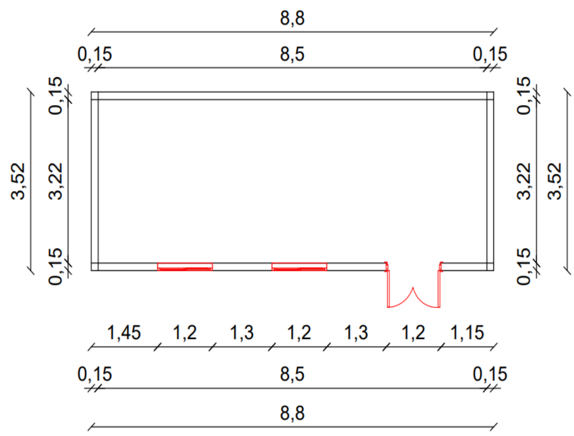

Fig. 1 Building level plan.

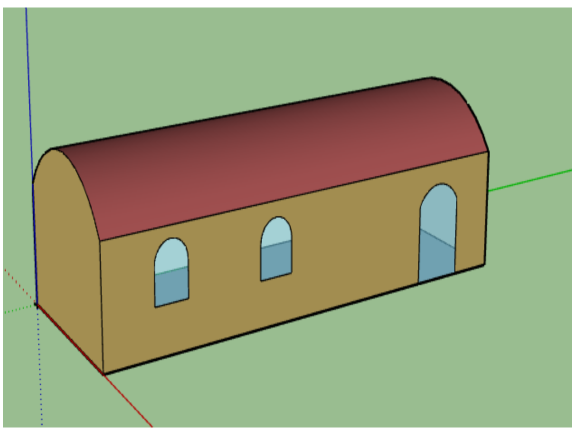

Fig. 2 Building geometry in sketchup.

The monozone model is the simplest, since it treats the building as a single zone with a uniform temperature [5].

It is the fastest in terms of calculation time, but does not take into account temperature heterogeneity between building zones. For example, no distinction is made in terms of temperature between rooms to the north and those to the south.

The multi-zone model consists in dividing the building into several zones (not necessarily one zone per room), ensuring that rooms belonging to the same zone have similar behaviors. The division can be made according to the orientation of the rooms, the different internal loads linked to different uses. This model remains interesting in terms of calculation time, but it has limitations when it comes to handling large volumes and characterizing the local effects of heating, cooling or pollutant sources. Fig. 3 shows the flowchart of the EnergyPlus software [6].

The core of the building model is based on two former executed works file (DOE) monolithic simulation programs: basic local alignment search tool (BLAST) and DOE-2, and the FORTRAN 90 programming language.

It does not have its own graphical interface, but several are available on the market, and an "OpenStudio" plug-in has recently been developed to use the google SketchUp 3D modeler for input data and simulation results processing.

The model considered is the monozone model in our case, as our building contains only one compartment.

3. Results

The various correlation coefficient values obtained range from 0.71 to 0.95, so the simulation results are acceptable, as the coefficients should be between 0.5 and 1 [6]. The simulation concerned indoor temperature and relative humidity. Figs. 4 and 5 were obtained.

Fig. 4 compares model predictions with measurements of average indoor air temperatures. It can be seen that measured and simulated values behave similarly.

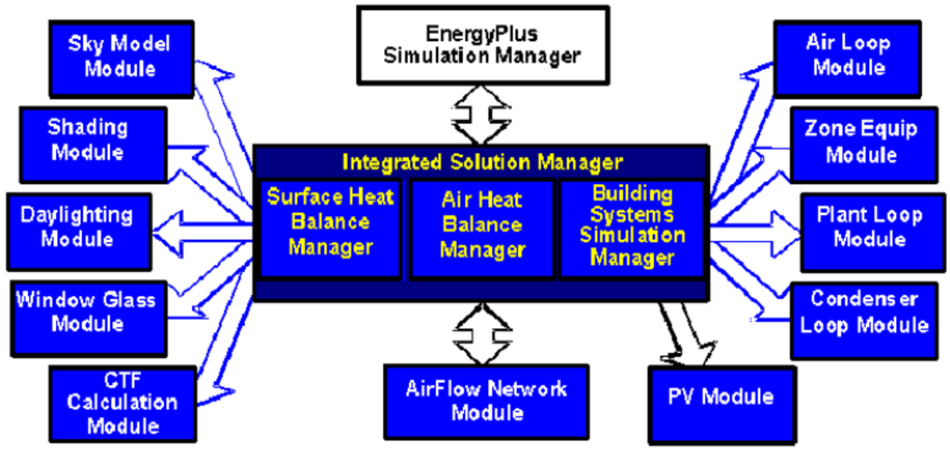

Fig. 3 EnergyPlus chart [6].

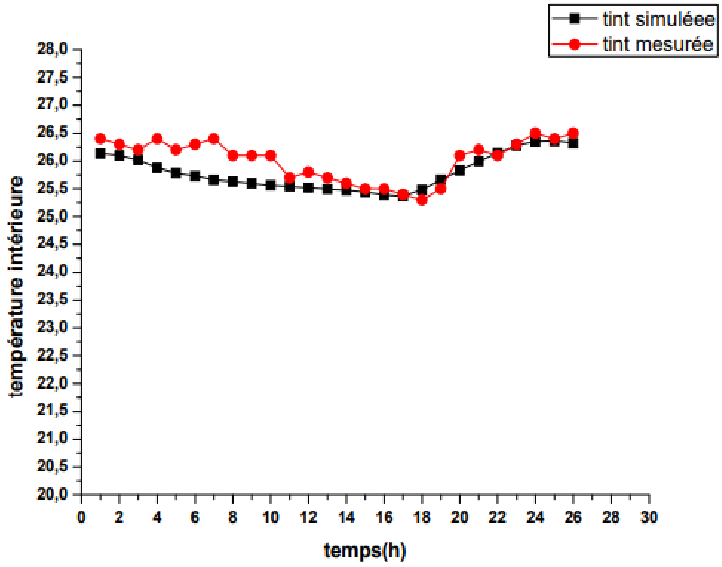

Fig. 4 Indoor and simulated temperature on January 14, 2018.

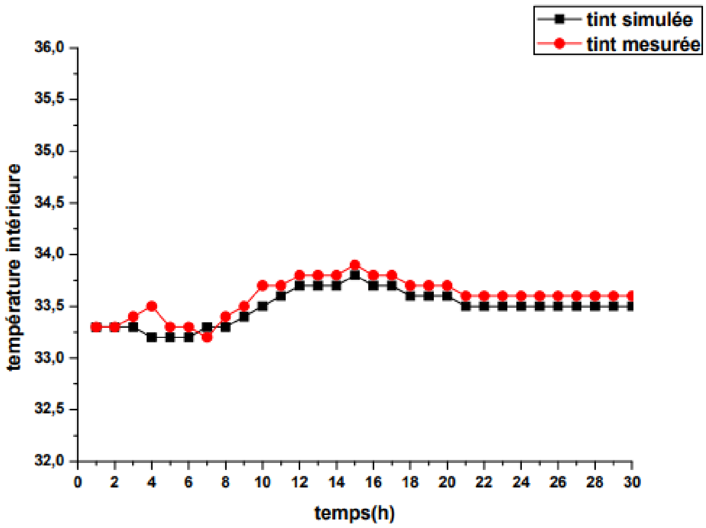

Fig. 5 Simulated and measured indoor temperature on April 7, 2018.

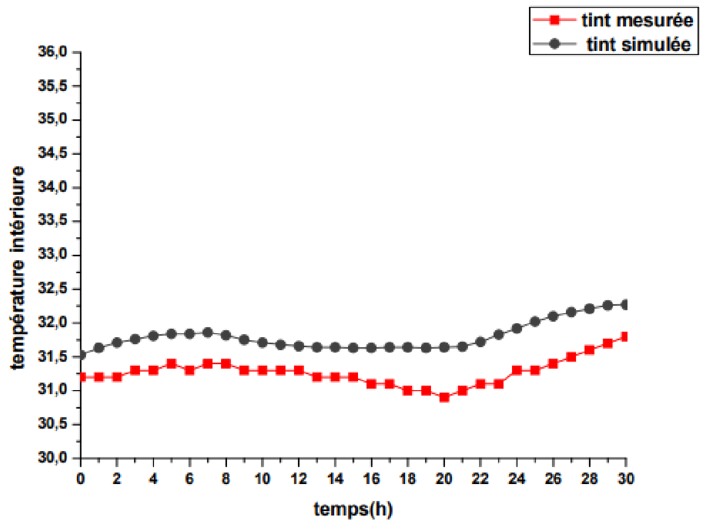

Fig. 6 Internal temperature measured and simulated on July 18, 2018.

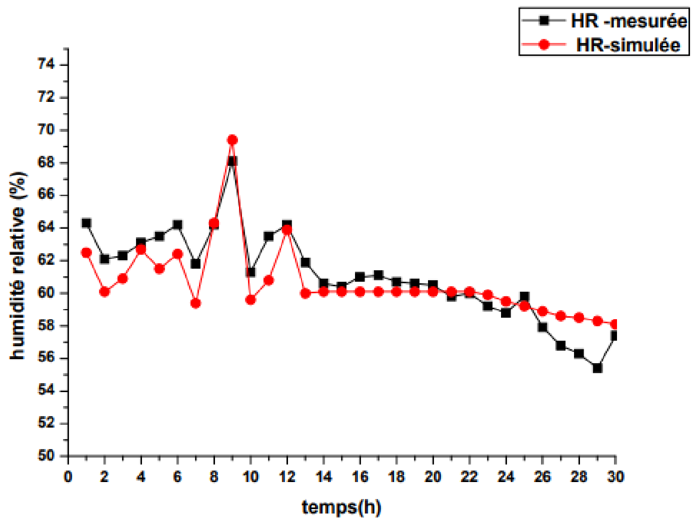

Fig. 7 Measured and simulated relative humidity on July 18, 2018.

The indoor temperature varies from 25.5 ℃ to 26.5 ℃ for the period of January 2018. We note a maximum deviation tending towards 1 ℃. This can be explained by overheating during the day and cooling at night. The correlation coefficient between measured and experimental indoor temperatures is 0.79. The work of Berghout [7] reveals interior surface temperatures of hemp concrete walls that range from 21.6 ℃ to 24.5 ℃ compared to compressed earth brick and cement block walls, whose interior temperatures are between 21 ℃ and 27 ℃ and 19 ℃ and 29 ℃, respectively. Fig. 5 shows the evolution of the measured and simulated indoor temperature for the period of April 2018.

Temperatures ranged from 33.2 ℃ to 33.6 ℃, with an average value of 33.1 ℃. The correlation coefficient between measured and simulated indoor temperatures is 0.95.

Fig. 6 shows the evolution of the measured and simulated indoor temperature for the period of July 2018. Temperatures ranged from 30.3 ℃ to 32.2 ℃, with an average value of 31.2 ℃. On this day, the sky was clear of clouds.

In the study “Impact of Insulation and Wall Thickness in Compressed Earth Buildings in Hot and

Dry Tropical Regions", Neya et al. [8] obtained outdoor temperatures ranging from 23 °C to 43 °C and indoor temperatures ranging from 27 °C to 41 °C for the reference case.

Fig. 7 shows the evolution of relative humidity obtained by experiment and that simulated. Relative humidity ranged from 62.3% to 73.5%, with an average value of 67.9%. The correlation coefficient between relative and simulated humidity values is 0.71.

Earth, a building material that has been used for thousands of years, is still used in Burkina Faso, particularly for rural housing. It is perfectly possible to build with unstabilized earth [7, 9]. Experimental results obtained by Shaik and Talanki Puttaranga Setty [10] reveal an increase in thermal conductivity of 14.7% and specific heat of 9.15% with an increase in the relative humidity of the ambient air in the hygroscopic range.

4. Conclusion

Simulation is a major challenge for the construction and adaptation of buildings to meet the challenges of energy and climate change. Notwithstanding the shortcomings associated with their use by building professionals, simulation software can be used to assess the energy and thermal performance of buildings. These shortcomings may be linked to limitations on input data, assumptions made on the basis of the zoning model, or air transfers between zones and the outside, or between the zones themselves.

However, it should be noted that experimental measurement is used to validate models and simulations and to discover new, unknown phenomena or for validation purposes, whereas simulation is used to understand the interactions of known system components and system behavior. Simulation enabled us to obtain theoretical temperature and humidity values and compare them with experimental values. The study revealed that the indoor temperature ranged from 33.2 °C to 33.6 °C, with an average value of 33.1 °C for the month of April 2018, and 25.5 °C to 26.5 °C for the period of January 2018. For the period of July 2018, the indoor temperature ranged from 30.3 °C to 32.2 °C, with an average value of 31.2 °C. Relative humidity ranges from 62.3% to 73.5%, with an average value of 67.9%.

The results obtained are valid, as the correlation coefficients obtained are between 0.5 and 1. With regard to the results, we note that the level of thermal comfort obtained is acceptable in Nubian vault housing. Comfort is also acceptable in hot weather, despite low temperatures. This level of comfort can be improved by passive air-conditioning or wall insulation. This work shows the relevance of using Adobe and the Nubian vault model in housing. This study will be extended to the thermal behavior of walls, taking into account thermal bridges and heat sources.

Acknowledgement

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