STUDY OF THE THERMAL BEHAVIOUR OF AN EXPERIMENTAL BUILDING AT THE NATIONAL RESEARCH CENTRE FOR DEVELOPMENT IN CHAD

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4 Abstract

5 This experimental study of thermal behaviour is being carried out as part of the search for solutions to exploit local building materials. It focuses on an experimental analysis of a 24 m² office-type cell built in N'Diamena. 6 7 Measurements of the temperature and humidity of the indoor and outdoor air and of the walls of the envelope 8 were taken using hygrothermal sensors of the SHT75 and SHT35 types. Temporal variations in temperature were 9 determined on the internal and external faces of the walls, as well as in the walls making up the envelope of this cell. The results obtained were used to analyse and understand the operation of the experimental cell envelope 10 11 and its thermal behaviour. The thermal input through the roof is greater, as the temperature at sheet level reaches 12 56.80°C at the same time as the outside temperature reaches 41.70°C. An overheating effect occurs in the attic 13 ceiling. This analysis showed that the experimental cell did not meet the required thermal comfort conditions of 14 a maximum temperature of 29°C according to the literature. These results have made it possible to understand 15 and analyse the thermal behaviour of the cell.

16 Key words: Thermal behaviour, local materials, thermal comfort and insulation in warm climates

17 1. Introduction

18 This work, carried out as part of the CABET (Construction Alternative Basse Energie au Tchad) research and 19 development project, relates to the effort to master building thermal engineering with a view to energy efficiency

- and to making the most of local building materials in the construction sector, which is a worldwide concern. This
- concern has led to the adoption of thermal and energy regulations (ISO-13790, 2008) and (ASHRAE, 2002). To
- this end, an experimental cell builted and instrumented with thermo-hygrometric sensors in order to quantify the
- overall indoor environment and in particular the thermal ambience, which is characterised by two physical quantities: the temperature and relative humidity of the air and the walls making up its envelope. However, the
- 25 so-called contemporary detached houses built in Chad, particularly in the city of N'Djamena, do not meet the 26 requirements of comfort in general and thermal comfort in particular. This is due to the fact that a number of 27 criteria are not taken into account from the outset of the design phase, such as architectural construction, thermal
- insulation of the external envelope of houses, thermal inertia and, above all, ignorance of the thermo-physical
- 29 properties of building materials.
- Analysis of the thermal behaviour of a building in real climatic conditions gives an idea of the real situation of
 the interior environment and hence of 'thermal comfort', taking into account the physical and thermal
 characteristics of the materials making up its envelope and their arrangements (BATAN, 2011).
- The parameters often measured are the temperature and relative humidity in the different thermal zones defined inside the building. These two parameters are very important criteria in defining and determining the thermal comfort conditions for occupants (ASHRAE, 2002) and (ISO 7730, 1994). A number of numerical and experimental research studies have focused on thermal behaviour in buildings (Derradji, et al., 2011), (Chelghoum, 2011) and (BATAN, 2011). Some have studied the influence of geometric parameters, others the influence of thermo-physical parameters, as well as the nature of materials (Fati, 2021) and climatological parameters (Oudrane, Aour, Zeghmati, Chesneau, & Hmouda, 2018) on the thermal behaviour of buildings.
- 40 The aim of this study is to analyse the thermal behaviour of the experimental cell under real climatic conditions.
- The analysis of the thermal behaviour of the cell involved an in situ study and a campaign of in-depth measurements of the cell.

43 2. Materials and methods

2.1. Thermo-physical properties of materials

The various values of the thermo-physical properties of the materials used in the construction of the
experimental cell are given in Table 1. These materials include : cement-stabilised mud bricks (CSB), aluminium
sheet, plywood, mortar plaster, tiles and glass.

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Table 1: Thermo-physical properties of materials

Materials	Thermal Conductivity (Wm ⁻¹ K ⁻¹)	Density (kg,m ⁻³)	Heat Capacity (J,kg ⁻¹ ,K ⁻¹)
CSB	0.586	1487	1115
Aluminium sheet	160	2800	880
Plywood	0.14	600	2720
Mortar plaster	1.15	1800 - 2100	880
Tiles	1.15	1800	700
Glass	1.2	2530	720

50 2.2. CABET experimental cell

The CABET (Construction Alternation Basse Energie au Tchad) experimental cell that is the subject of this study has a living area of approximately 24 m² and is therefore similar to a conventional office or single room commonly found in Chad (Figure 1). It was built using the materials listed in Table 1 on the CNRD site, more specifically in the town of N'Djamena. The town of N'Djamena is part of the BSh climatic zone, known as the dry, hot steppe climate according to the Köppen climate classification. This climatic zone is characterised by a hot, dry summer.



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Figure 1: CABET experimental cell, seen from the north and west

Representing a full-size building but of small dimensions, it consists of vertical opaque walls, two single-glazedwindows, a glazed door and a roof incorporating a ceiling.

61 2.3. Description of the cell's instrumentation

62 Temperature and relative humidity measurements at various points in the cell carried out using SENSIRON

63 SHT75 and SHT35 type thermo-hygrometers (Figure 2). In all, nineteen sensors installed and connected to two
 64 acquisition and recording units (SHT DaqBox) through the envelope and inside the cell. These sensors are
 65 regularly calibrated to check the results of each sensor and detect any anomalies in the measurements.



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Figure 2: Position of the various sensors in the CABET experimental cell

A DAVIS Vintage Pro 2 mimi wireless weather station is installed near the cell on a wall approximately 5 metres
 above the ground. This weather station is used to acquire and record the various parameters of the site's climatic

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conditions, namely: air temperature, relative air humidity, atmospheric pressure, wind speed and direction, as
 well as direct horizontal solar radiation and precipitation.



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Figure 3: Weather station (a) and its acquisition and recording console (b)

74 **3.** Results and discussion

75 This study analyses the results of the thermo-hygrometric measurements carried out during the most 76 unfavourable period of the summer, i.e. the month of April, on the thermal behaviour of the CABET 77 experimental cell. These results relate to the days of 09 and 10 April 2022.

78 In order to carry out this study of thermal behaviour, we chose the results of the measurements when the cell was 79 in free evolution, i.e. there were no occupants (no activities), and the door and windows remained closed all the 80 time during the measurement periods. There were also no other internal heat inputs. The results of the 81 measurements are as follows:

82 **3.1.** Evolution of ambient temperatures (outside and inside)

83 In order to take account of the vertical difference in temperatures in the cell, sensors were installed vertically at three positions. Figure 4 shows the changes in outdoor and indoor air temperatures at the different sensor 84 85 positions. These temperatures move in the same direction. Despite the high thermal inertia of the vertical walls, 86 the measurements show a temperature damping of around 8°C. The average air temperature inside the cell is 87 between 34°C and 41°C most of the time, which does not meet the requirements for thermal comfort during the 88 summer in a hot climate (ANSI/ASHRAE-55-2017, 2020) and (NF EN ISO 7730, 2006) with a maximum 89 temperature of 29°C (IFDD, 2015). This can be explained by the lack of thermal insulation of the walls and 90 especially the roof.





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Figure 4: External and internal temperature trends

3.2. Evolution of the temperatures of the internal surfaces of the walls and ceiling

The variation in the temperatures of the internal surfaces of the walls and ceiling is shown in Figure 5. It can be seen that the temperatures of the internal surfaces of the walls and ceiling show asymmetries of variation with them, known as radiant temperatures. These asymmetries in radiant temperatures can be a source of thermal discomfort in the cell (ANSI/ASHRAE-55-2017, 2020). It should be noted that the temperature of the inside face of the ceiling has a higher thermal amplitude, with a maximum of 45.59°C, than the temperature of the outside air, with a maximum of 42.6°C. This can be explained by the fact that the attic of the ceiling acts like a thermal oven due to the lack of thermal insulation in the roof.



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Figure 5: Temperature trends for the internal surfaces of the walls and ceiling

Two sensors were installed on the inside of the east wall to check the thermal homogeneity of the surface. The results of the measurements showed that there is a difference in temperature, with a maximum difference of 2.7°C (Figure 6). This result shows that the internal surface of the east wall of the cell is not isothermal. The same would be true for the other wall surfaces.





3.3. Temperature trends on the external surfaces of the walls



112 differently according to the path of the sun. The figure shows that the temperature of the external face of the east

113 wall reaches its maximum value before those of the south and west external faces respectively.





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Figure 7: Temperature trends on the external faces of the east, west and south walls

3.4. Temperature trends through the vertical walls

In addition to the sensors installed on the inside faces of the vertical walls (walls), sensors are installed on the outside faces and in the walls to a depth of about 2/3 of the wall thickness. In this section, we analyse the temperature distribution across the cell walls. Figure 8, Figure 9 and Figure 10 show that the temperatures of the internal faces, the walls and the external faces have similar variations and move in the same direction. The temperatures of the external faces reach maxima of 44.06°C, 45.15°C and 43.25°C, while those of the internal faces reach 40.05°C, 42°C and 40.17°C respectively for the South, East and West walls.

We have observed temperature damping between the external and internal faces of the walls. These are approximately 4°C, 3.16°C and 3.08°C with phase shifts of 3h15, 5h and 1h15 respectively for the South, East and West walls.



Figure 8: Temperature trends through the south wall



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Figure 10: Temperature trends through the west wall

132 3.5. Temperature trends through the roof

133 In order to study heat transfer through the roof, three hygro-thermal sensors were installed on the inside of the ceiling, in the roof space and on the inside of the metal sheet. Figure 11 shows the temperature trend across the 134 135 roof of the cell. At sheet metal level, the temperature measurement carried out gave a maximum of 56.80°C on 136 10 April 2022 at 11:45 a.m. and a maximum temperature of 45.59°C on the inside of the ceiling. This gives a 137 difference of around 11.21°C. On the same day, the outside temperature reached a maximum of 41.70°C. This increase in temperature at roof level is due to the accumulation of heat in the roof space. The attic therefore acts 138 139 as a thermal oven, which shows that the thermal gains through the roof are greater than those through the walls. 140 We can therefore see that solar loads are much greater at roof level than for the cell envelope as a whole.

141 The work carried out by Derradji et al. has shown that good thermal insulation can reduce the heat flow towards 142 the interior of the home (Derradji, et al., 2011). The lack of thermal insulation leads to very significant 143 overheating in the cell.





A large vertical difference (stratification) in air temperature between the floor and the ceiling can cause thermal
 discomfort in a building (NF EN ISO 7730, 2006) and (ANSI/ASHRAE-55-2017, 2020).

Figure 12 shows the vertical profile of the maximum temperature for the three thermo-hygrometric sensors placed vertically and from the ceiling. The vertical temperature difference obtained is approximately 6.14°C for a measurement interval of 1.5 m between the low sensor and the ceiling. This temperature gradient of 6.14°C is very significant because of the solar gain absorbed by the roof, the heat exchange gain and the thermal accumulation effect (overheating) in the attic. The ANSI/ASHRAE 55 standard gives maximum values of 3°C and 4°C for seated and standing persons respectively (ANSI/ASHRAE-55-2017, 2020). Given the significant vertical temperature difference, the experimental cell does not meet thermal comfort conditions.





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Figure 12: Vertical profile of stratified temperature as a function of height

158 Figure 13 shows the evolution of indoor air temperatures as a function of time for vertically positioned sensors.

159 The temperatures measured by the three sensors placed vertically vary between 35.35°C at night and 40.75°C during the day. Even the temperatures measured at night are higher than those required by Givoni's bioclimatic

161 diagram adapted to climates (IFDD, 2015).





Figure 13: Evolution of the vertical difference in indoor air temperatures

3.7. Change in relative humidity

Figure 14 shows the change in relative humidity inside and outside the cell. The relative humidity outside the cell generally varies between 52% at night and 10% during the day. On the other hand, the relative humidity inside the cell varies less during the day (16.46%) than at night (21.85%). What's more, this relative humidity evolves in the same way in the three measurement sensor locations in the cell. These low values of relative humidity inside the cell can be explained by the fact that the cell is in free evolution. This implies a lack of aeration due to the absence of ventilation or air infiltration into the cell.



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Figure 14: Change in relative humidity

173 Conclusion

174 The aim of this work was to analyse the thermal behaviour of the CABET experimental cell under climatic 175 conditions. The experimental results presented have made it possible to analyse and understand the operation of 176 the envelope of the experimental cell and its thermal behaviour. The results show that the temperatures measured 177 are similar. The thermal input through the roof is greater, as the temperature at sheet level reaches 56.80°C at the 178 same time as the outside temperature reaches a maximum of 41.70°C. On the one hand, an overheating effect is 179 taking place in the ceiling space. On the other hand, this analysis showed that the experimental cell does not 180 meet the thermal comfort conditions required by Givoni's bioclimatic diagram (IFDD, 2015) and the 181 ANSI/ASHRAE (ANSI/ASHRAE-55-2017, 2020) and ISO 7730 (NF EN ISO 7730, 2006) standards on the 182 vertical temperature difference and radiant temperature asymmetry of its envelope.

- 183 Bioclimatic design and the use of passive techniques are solutions to be explored, especially for a country like
- 184 Chad. A look at vernacular construction, which used unchanging techniques closely linked to the climate, has
- highlighted the inconsistency in the construction of so-called contemporary housing. The result is a habitat that is
- 186 poorly adapted to its climatic context. This is particularly true in regions with hot, dry climates, offering great
- 187 potential for bioclimatic design and sustainable construction, particularly in terms of energy efficiency. The
- solution lies in understanding the thermal behaviour of the building envelope, and even in the use of appropriate
- 189 passive cooling solutions.190

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