Engineering, 2022, 14, 602-612
https://www.scirp.org/journal/eng
ISSN Online: 1947-394X
ISSN Print: 1947-3931

Numerical Simulation of the Thermal Behaviour of a Building with or without Typha Using the Commercial Software Visual TTH

Joseph Sambasene Diatta[1*], Issa Sy[1], Marthe Tatiana Diatta[2], Seydou Ba[2]

[1]Assane Seck University, Ziguinchor, Sénégal
[2]Centre Sectoriel de Formation Professionnelle aux métiers du Bâtiment et des Travaux Publics (CSFP-BTP), Diamniadio, Sénégal
Email: *jsdiatta@univ-zig.sn

How to cite this paper: Diatta, J.S., Sy, I., Diatta, M.T. and Ba, S. (2022) Numerical Simulation of the Thermal Behaviour of a Building with or without Typha Using the Commercial Software Visual TTH. *Engineering*, **14**, 602-612.
https://doi.org/10.4236/eng.2022.1412045

Received: November 5, 2022
Accepted: December 27, 2022
Published: December 30, 2022

Abstract

The use of low thermal conductivity materials plays an important role in the construction of energy-efficient buildings. Indeed, the improvement of the thermal properties of building walls reduces energy consumption. This study aims to determine the thermal and energy balances of a building enveloped with Typha australis on the one hand, and a building without Typha on the other hand (a building constructed with conventional materials) using the commercial software Visual TTH. The results of the heat loss calculations show that the Typha building is 62% more efficient than the conventional building. Also, the studies on air-conditioning needs resulted in energy savings of 1577.136 kWh per year for the Typha building, *i.e.* 1219 kg per year of CO_2 avoided in the air according to the SENELEC emission factor 0.773/MWh in Senegal.

Keywords

Building, Typha, Modelling, Thermal Behaviour, Energy

1. Introduction

With the commissioning of the Manantali and Diama dams, the context of Senegal's river delta is marked by the proliferation of several species including Typha. This proliferation threatens the hydraulic functioning of the delta and the exploitation of its resources (space, water, agriculture, etc.) because it is considered an invasive plant and is very difficult to eliminate [1]. To remedy this problem, numerous studies have been conducted in Mali, Senegal and Mauritania [2]. These studies attempt to valorise Typha by incorporating it into construction.

Bederina *et al.* [3] studied the effect of adding wood chips on the thermal conductivity of sandcrete. The results show that the inclusion of wood chips in sandcrete significantly reduces the density of the material, while the structure remains homogeneous and has a strong wood-matrix bond. In addition, the thermal conductivity is improved.

Diatta *et al.* [4] worked on the determination of the thermal and mechanical properties of Typha australis. Their results showed that the average conductivity of Typha is 0.045 W/m.K and an average density of 69.68 ± 0.014 kg/m^3. Also, Typha alone, *i.e.* without being incorporated into another building material, insulates better. In addition to this advantage, it has no thermal inertia. The work of Abdelhakh *et al.* [5] showed the improvement in energy efficiency of buildings using lightweight concrete based on Typha australis. Their results showed that the incorporation of Typha aggregates in concrete decreases its density and increases its thermal resistance. It is then more advantageous to agglomerate it to use it as thermal insulation panels.

The technologies needed to produce thermal insulation materials from Typha have been developed and validated in Europe with Typha latifolia and Typha angustifolia [6]. The question of the relevance of this construction technique for buildings is topical, as is its complementarity or competition with other techniques for providing comfort inside buildings [7]. Its use as insulation in the building sector, in extreme temperature conditions as in Senegal, has also shown very promising results [8]. Nevertheless, there are few quantitative and qualitative studies to show the energy contribution of this material compared to conventional materials such as concrete, which is widely used in Senegal.

To answer these questions in part, the development of reliable and robust numerical models seems to be a great asset. Indeed, it will be possible to predict the complete thermal behaviour of a building constructed with insulating materials and thus show their added value compared to a building constructed with conventional materials [9] [10]. The main objective of this study is to know the evolution of the thermal behaviour of a building constructed with Typha australis via the commercial software Visual TTH [11]. This numerical model will be validated by the results of the experiment.

2. Materials and Methods

The building is rectangular in shape, 6.07 m in length and 4.94 m in width. It is divided into three separate rooms. The rationale for this design is that new buildings will have to reduce energy consumption by providing optimal thermal performance, thus considerably reducing heat loss [12]. The plan is simple: an office, a corridor and a bathroom. This was modelled using Revit, a building design software with 2D and 3D models [13]. **Figure 1** shows the geometries of the real and model building and the 2D plan.

The external wall is composed from the outside to the inside of a 2 cm thick wooden cladding, a 22 cm thick box filled with Typha and a 1 cm thick plywood

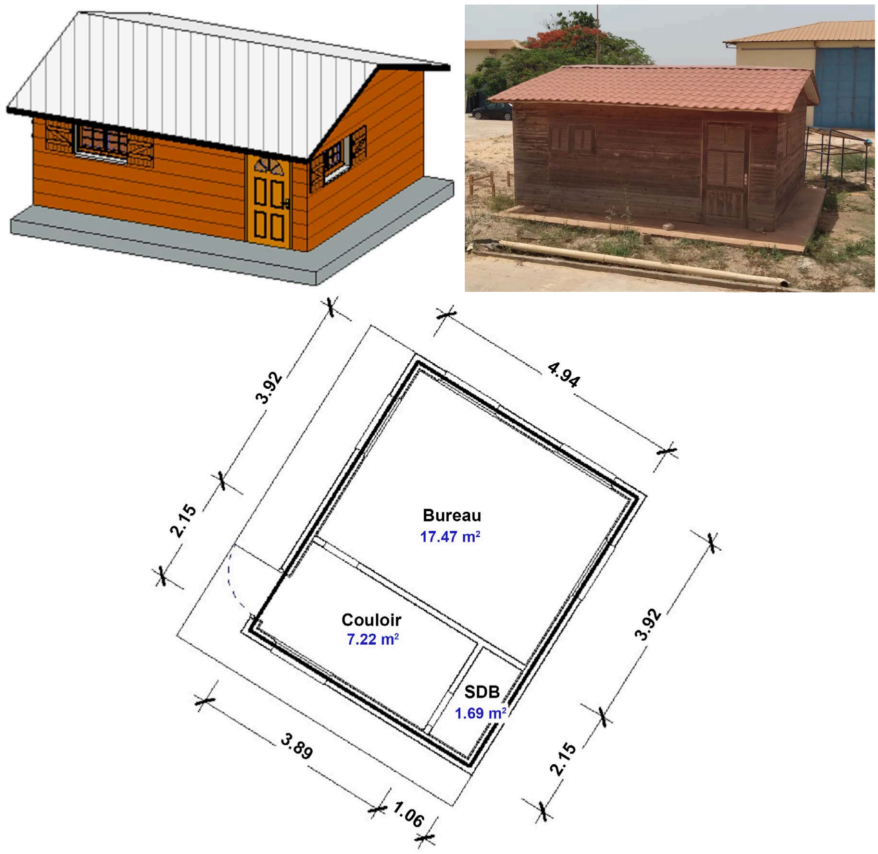

Figure 1. Building models in Revit and the real building.

panel. The floor is made up of a 30 cm thick reinforced concrete slab to prevent settlement. The roof is made of 0.7 mm thick zinc to ensure water tightness control and a 10 cm thick Typha box supported by wooden beams.

Table 1 shows the properties of the building materials.

The Heat Flow Meter (HFM) was used to measure the thermal conductivity (λ) of Typha australis. The sample is prepared and placed between the hot plate and the cold plate. The heat flux created by the temperature difference (ΔT) is measured by a heat flux sensor. The output voltage (V) created between the two flow transducers is proportional to the heat flux (q) in the measurement area and the proportionality constant (N) can be used to convert the voltage signal into heat flux [14]. For a sample 20 cm length, 15 cm width and 5.5 cm thick, the thermal conductivity found is 0.03319 $W \cdot m^{-1} \cdot K^{-1}$ ± 3% with a density of 350 $kg \cdot m^{-3}$.

$$\lambda = N \times V \times \frac{\Delta x}{\Delta T} \quad (1)$$

To gain insight into the thermal behaviour of the building, J-type thermocouples are placed at several locations in the building and the data is recorded with the Agilent 34970A-data-acquisition-data-logger. The thermocouples are placed in pairs on the interior, exterior and mid-height surfaces as shown in Figure 2. This instrument is also capable of measuring voltage, current, frequency, resistance and temperature.

Table 1. Properties of the building materials.

Walls	Compositions	Conductivity λ in W·m⁻¹·K⁻¹	Resistance R in m²·K/W	Density ρ in kg/m³	Deducted surface transmission coefficient Ut in W/(m²·K)
Exterior wall	Wooden cladding	0.23	0.086	650	0.144
	Typha box	0.03319	6.628	360	
	Plywood panel	0.13	0.077	400 to 600	
Roof	zinc	116	6.03448E−06	-	0.317
	Typha box	0.03319	3.012	360	
Slab	Reinforced concrete	1.7	0.176	2400	2.587

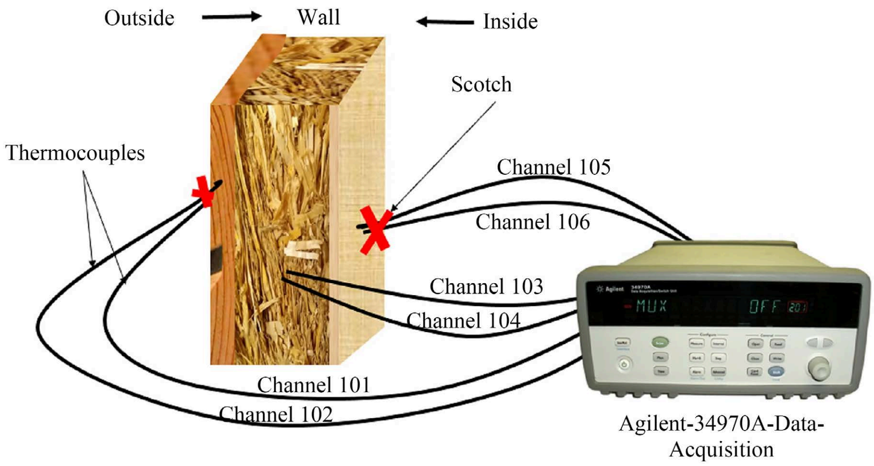

Figure 2. Technique for measuring the temperature through the wall with the Agilent 34970A data acquisition.

The Dynamic Thermal Simulation (DTS) was carried out using the Visual TTH software. This is a software package for calculating thermal and energy balances according to RT 2012 regulations [15]. This software was chosen because it produces complete, accurate and customizable calculation notes and has been evaluated several times by the CSTB (Centre Scientifique et Technique du Bâtiment). Visual TTH is part of a BIM (Building Information Modeling) approach. It allows the calculation of heat losses, air-conditioning loads with the EnergyPlus engine, the Dynamic Thermal Simulation (DTS) with the EnergyPlus engine and the annual energy costs in the framework of the energy supply feasibility study. After modelling the building in Revit, spaces and zones must be defined to export the file as IFC or gbXML in Visual TTH. Table 2 gives the necessary information or input data to be entered into the simulation software. This software is based on building information modelling (BIM).

3. Results and Discussions

To highlight the energetic contribution of Typha in new constructions and the improvement of the thermal comfort of the habitat in a hot climate, different simulation studies have been carried out. A study of the thermal behaviour of

Table 2. Information from the building.

Number of main rooms	3
Type of heating	No
Type of ventilation	Closing the windows
DHW production	No
Air conditioning	No
Occupation of the premises	Do not apply a ratio on occupancy periods
Indoor temperature set point	25˚C
Winter base temperature	16˚C [16]

the building constructed with Typha australis was carried out and allowed the validation of the numerical model since the numerical results were compared with those of the experiment. This validated numerical study will be extrapolated with a second study on a building without Typha (conventional building) with the same dimensions, this time with a cinder block brick wall covered on both sides with a 1.5 cm thick waterproof coating.

3.1. Validation of the Model

The numerical simulation carried out on the building with Typha resulted in **Figure 3**. This graph represents the evolution of the air temperature inside the building (numerical and real) over 24 hours. **Figure 4** shows the difference between the simulated temperatures and the experiment. It can be seen that the numerical and experimental results agree with each other, with a temperature difference of no more than 1˚C.

The results of the building calibration according to the temperature variation are given in **Table 3**. It can be seen that the values of NMBE (Normal Mean Bias Error), CVRMSE (Coefficient Variation of Root Mean squared Error) and the correlation coefficient R^2 following the criteria described by ASHRAE 2002 and 2014, *i.e.* respectively less than 10% and 30% and greater than 0.9 for R^2 [17]. Thus, the different results of the model validation criteria for indoor air temperature, show that the building modelling with Typha meets the different ASHRAE validity criteria well.

3.2. Impact of Typha on Building Performance

An analysis of the weather data shows very high temperatures during the months of July to October. Lower temperatures are noted in January and February [16]. The meteorological data provided by the meteorological station on the site made it possible to compare two days with extreme temperatures. The coldest day was 21st January 2021 and the warmest day was 18th September 2021.

Figure 5 shows the evolution of the temperature inside the buildings (with and without Typha) on the coldest day which corresponds to 21st January 2021. The green curve represents the simulated temperature of the building with Typha

Figure 3. Evolution of the air temperature (numerical and real) inside the building for 24 hours on June 16th, 2021.

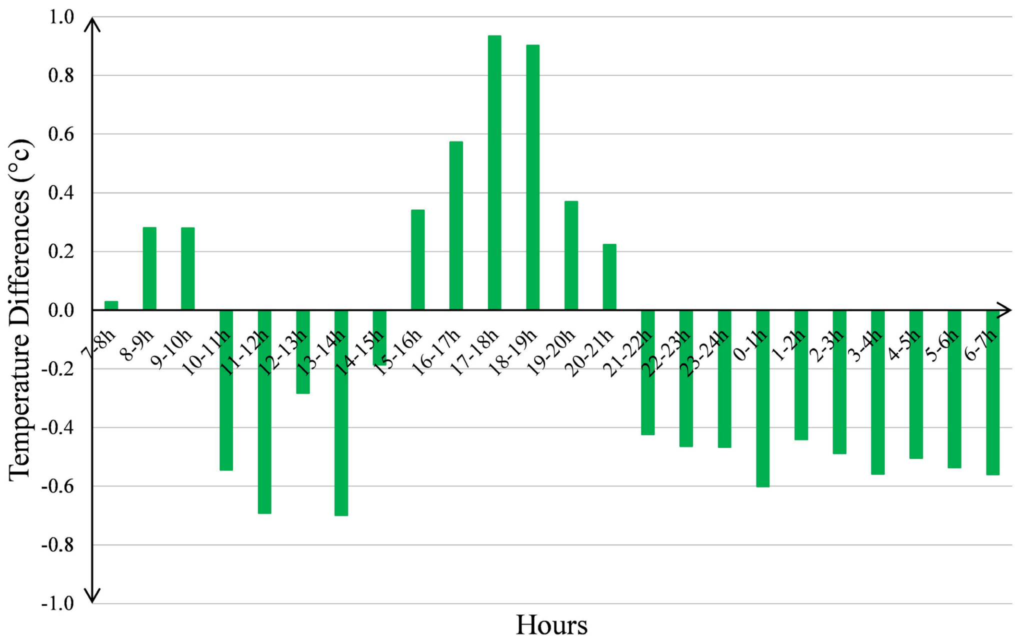

Figure 4. Difference between numerical and actual air temperatures inside the building for 24 hours on June 16th, 2021.

Table 3. Building calibration results according to ASHRAE 2002 and 2014 criteria.

Validation criteria	*Results*
NMBE (%)	0.542
CVRMSE (%)	2.599
R^2	0.932

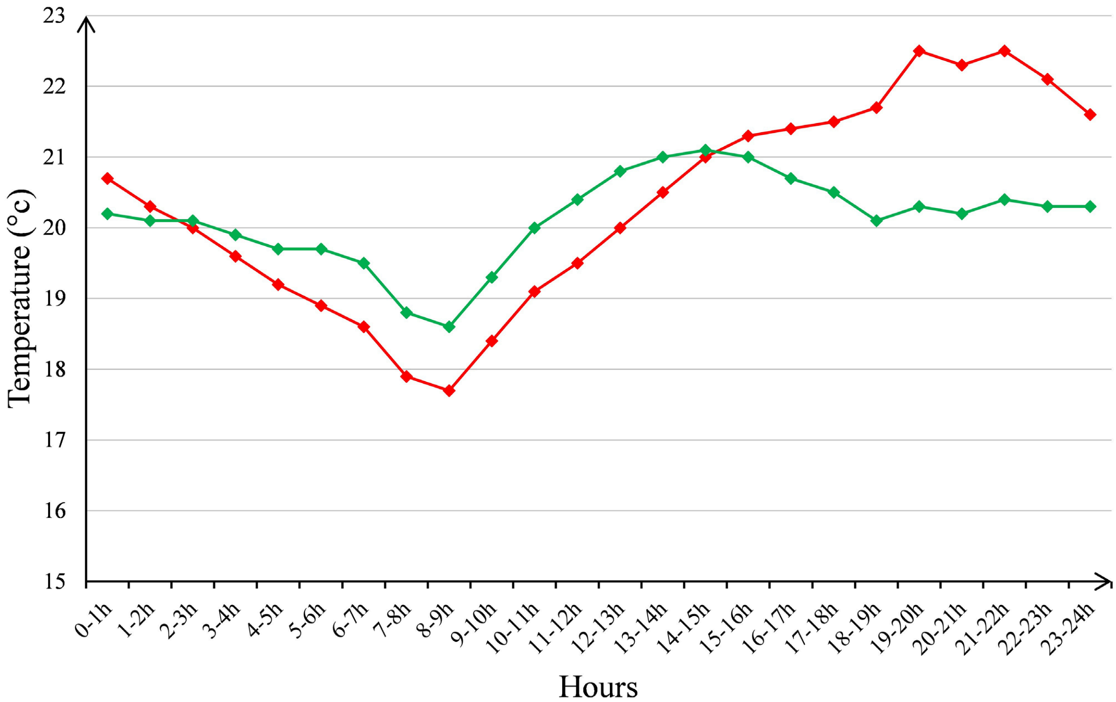

Figure 5. Comparison of simulated indoor air temperatures in the office of both buildings on the coldest day: January 21st.

and the red curve represents the simulated temperature of the building with a cinder block. The results show that the temperature of the cinder block building (conventional building) is lower from 2 am to 3 pm. At this time of the day, the temperatures outside are low. The cinder block building keeps these temperatures low while the Typha building allows less flow to keep the temperature higher. This situation does not change until around 4 pm as confirmed in **Figure 6** where a temperature rise is observed. This change continues until 1 am because the cinder block building contains constituents such as cement which can retain heat accumulated during the day and release it at night.

Figure 7 shows the evolution of the temperature inside the buildings (with and without Typha) on the hottest day, which happens to be 18th September 2021. On this date, the temperature of the cinder block building evolves rapidly to high values at 12 pm. It reaches its maximum of 37˚C at 7 pm while the temperature inside the Typha building evolves in such a way as to keep its variation within the comfort zone of temperatures. This temperature difference is more visible in the evening as shown in **Figure 8**. This is due to the constituents of the cinder block, particularly the cement, which can store heat during the day and release it at night. The release of heat continues throughout the night. This is the reason why we always see high temperatures inside the building at night. Chemically, cement is composed of 80% limestone and 20% clay and its manufacturing process goes through several stages, including a stage where it is heated to 1450˚C and cooled sharply to give clinker [18]. This explains its ability to retain heat and redistribute it at night.

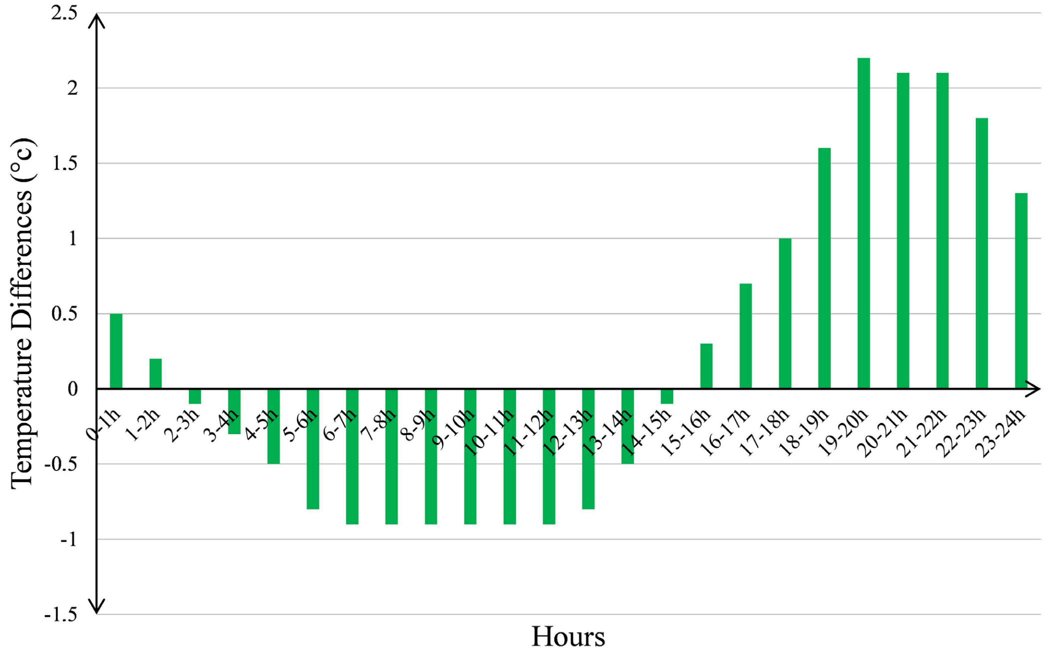

Figure 6. Simulated indoor air temperature differences in the office of both buildings on the coldest day: January 21st.

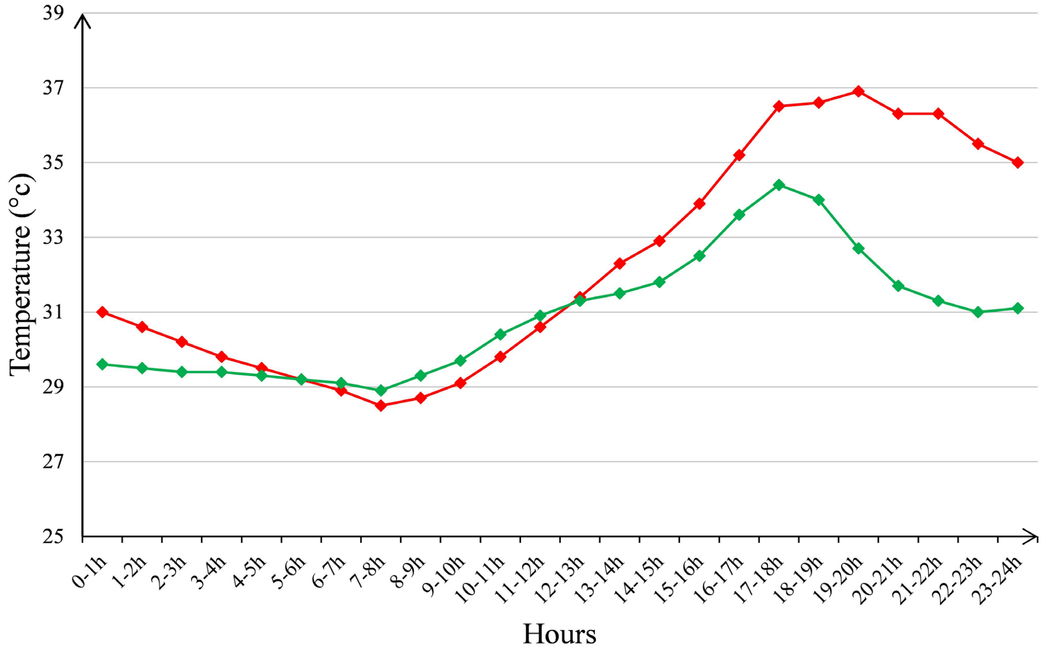

Figure 7. Comparison of simulated indoor air temperatures in the office of both buildings on the hottest day: September 18th.

In addition, the results recorded on the losses have made it possible to conduct a dimensioning of the air conditioning to evaluate the energy efficiency of the two buildings. This study allows forecasting air conditioning costs, a deterrent for customers. After sizing, the total heat balances (Btu/h) of the two buildings were evaluated at 15499.8 Btu/h for the conventional building and 7308.3

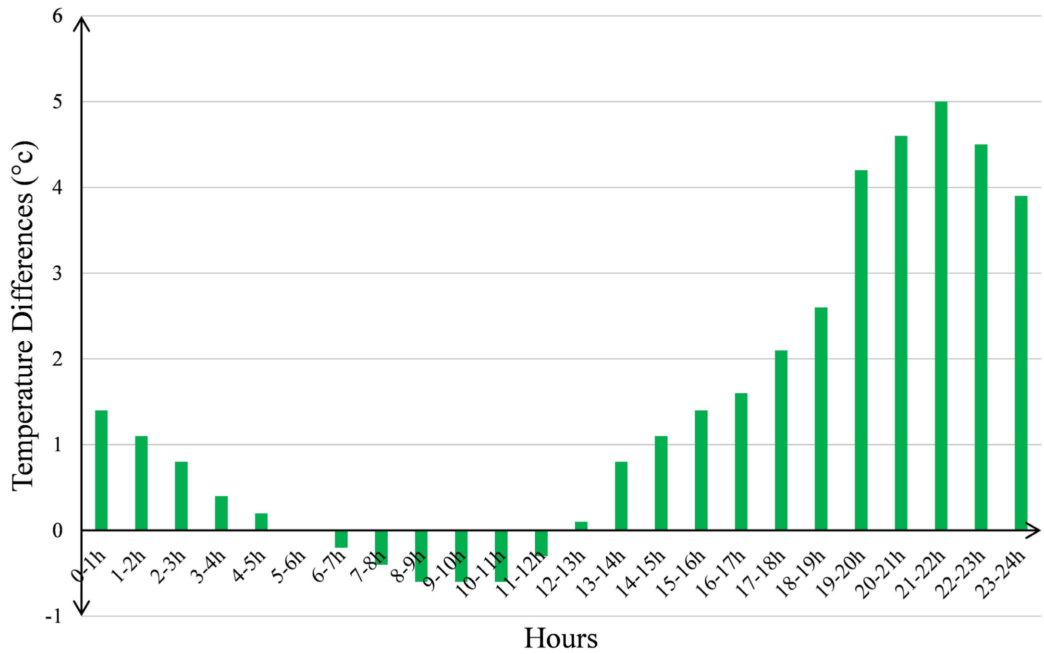

Figure 8. Simulated indoor air temperature differences in the offices of both buildings on the hottest day: September 18th.

Btu/h for the Typha building respectively. Taking into account the results and in order not to undersize (insufficient power) our air conditioning, two LG Split systems of 9000 Btu/h were chosen for the classical building and only one LG Split system of 9000 Btu/h for the Typha building.

The energy consumed in (kWh)/day for the conventional building and the Typha building is 14.331 (kWh)/day and 7.162 (kWh)/day respectively. Taking into account the price of electricity according to prepaid meters in Senegal, the consumption costs amount to 802 F CFA/day for the Typha building and 1605 F CFA/day for the conventional building. This corresponds to an annual expenditure of 176,470 CFA francs per year and 353,109 CFA francs per year respectively. The annual savings are 1577.136 kWh per year or 176,639 CFA francs per year. The difference in terms of savings should be even greater when the buildings studied are larger, as it should be remembered that this study was carried out in a small area. According to the SENELEC report on environmental protection, the equivalent in CO_2 avoided kg per year according to the SENELEC emission factor 0.773/MWh is 1219 kg per year.

4. Conclusions

In this study, the thermal and energy balances of a building with Typha on the one hand and without Typha, on the other hand, were calculated. It was found that the building with Typha is more efficient (62% more efficient) in providing indoor thermal comfort.

In addition, the air-conditioning study avoided 1219 kg per year of CO_2 in the air according to the SENELEC emission factor of 0.773/MWh.

The current study is a basic model for understanding the impact of using Typha australis in new construction. Therefore, understanding its weakness to use it intelligently and get the best possible performance should be seen as a stepping stone for further research. However, with the increasing capacity of computer resources, it would be interesting to simulate the airflow, lighting and acoustic behaviour of a building constructed with Typha.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Triplet, P., Ndour, S., Gueye, F.K. and Harouna, M. (2020) Rapport Technique Interne. 44.

[2] Terrier, G. and Vrielynck, P. (2016) Caractérisation de la combustion de charbon de typha dans un foyer amélioré mauritanien. 75.

[3] Bederina, M., Marmoret, L., Mezreb, K., Khenfer, M.M., Bali, A. and Quéneudec, M. (2007) Effect of the Addition of Wood Shavings on Thermal Conductivity of Sand Concretes Experimental Study and Modelling. *Construction and Building Materials*, **21**, 662-668. https://doi.org/10.1016/j.conbuildmat.2005.12.008

[4] Diatta, M.T., Gaye, S., Thiam, A. and Azilinon, D. (2018) Détermination des propriétés thermo-physique et mécanique du typha australis. 6.

[5] Abdelhakh, A.O., Saleh, A.M., Soultan, M., Sow, D., Menguy, G. and Gaye, S. (2016) Improving Energy Efficiency of Buildings by Using a Light Concrete Based on *Typha australis*. 2016 3*rd International Conference on Renewable Energies for Developing Countries* (*REDEC*), Zouk Mosbeh, 13-15 July 2016, 1-5. https://doi.org/10.1109/REDEC.2016.7577512

[6] De Jong, M., Van Hal, O., Pijlman, J., van Eekeren, N. and Junginger, M. (2021) Paludiculture as Paludifuture on Dutch Peatlands: An Environmental and Economic Analysis of Typha Cultivation and Insulation Production. *Science of the Total Environment*, **792**, Article ID: 148161. https://doi.org/10.1016/j.scitotenv.2021.148161

[7] Bozsaky, D. (2019) Nature-Based Thermal Insulation Materials from Renewable Resources—A State-of-the-Art Review. *Slovak Journal of Civil Engineering*, **27**, 52-59. https://doi.org/10.2478/sjce-2019-0008

[8] Joffroy, T., Misse, A., Celaire, R. and Rakotomalala, L. (2017) Architecture bioclimatique et efficacité énergétique des bâtiments au Sénégal. 91.

[9] Benzaama, M.H., Rajaoarisoa, L.H., Ajib, B. and Lecoeuche, S. (2020) A Data-Driven Methodology to Predict Thermal Behavior of Residential Buildings Using Piecewise Linear Models. *Journal of Building Engineering*, **32**, Article ID: 101523. https://doi.org/10.1016/j.jobe.2020.101523

[10] Foucquier, A., Robert, S., Suard, F., Stéphan, L. and Jay, A. (2013) State of the Art in Building Modelling and Energy Performances Prediction: A Review. *Renewable and Sustainable Energy Reviews*, **23**, 272-288. https://doi.org/10.1016/j.rser.2013.03.004

[11] Visual TTH : Logiciel Visual TTH pour les calculs thermiques, énergétiques et règlementaires. https://www.fisa.fr/produit/1

[12] Kisilewicz, T. (2019) On the Role of External Walls in the Reduction of Energy De-

mand and the Mitigation of Human Thermal Discomfort. *Sustainability*, **11**, 1061. https://doi.org/10.3390/su11041061

[13] Logiciel Revit|Obtenir les tarifs et acheter la version officielle de Revit 2022|Autodesk. https://www.autodesk.fr/products/revit/overview

[14] Lawanwadeekul, S., Otsuru, T., Tomiku, R. and Nishiguchi, H. (2020) Thermal-Acoustic Clay Brick Production with Added Charcoal for Use in Thailand. *Construction and Building Materials*, **255**, Article ID: 119376. https://doi.org/10.1016/j.conbuildmat.2020.119376

[15] D'Agostino, D. (2015) Assessment of the Progress towards the Establishment of Definitions of Nearly Zero Energy Buildings (nZEBs) in European Member States. *Journal of Building Engineering*, **1**, 20-32. https://doi.org/10.1016/j.jobe.2015.01.002

[16] Météo et climat: Diamniadio (Sénégal)—Quand partir à Diamniadio? Le Planificateur de Voyages. https://planificateur.a-contresens.net/afrique/senegal/dakar/diamniadio/2595640.html

[17] Haberl, J.S., Culp, C. and Claridge, D.E. (2005) Ashrae's Guideline 14-2002 for Measurement of Energy and Demand Savings: How to Determine What Was Really Saved by the Retrofit. 14.

[18] Pandey, P.R. and Banskota, N. (1970) Process of Cement Production in Nepal. *Bulletin of the Department of Geology*, **11**, 71-78. https://doi.org/10.3126/bdg.v11i0.1545