International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

September 2024	Issue 60	Volume 16	Number 3	Pages 102-112

EFFECT OF A BEE-INSPIRED ADAPTIVE ENVELOPE ON EXISTING ADMINISTRATIVE BUILDING IN A SEMI-ARID CLIMATE

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Abstract- In Algeria, building is the most energy-consuming sector, particularly during the summer. The half of energy consumption is related to air conditioning; therefore, this study aims to evaluate the indoor thermal environment in an existing administrative building in Batna City (semi-arid climate). For this purpose, two methods are used: first, in-situ investigation was carried out during the hottest day of the summer on July 25th, 2022 that showed internal overheating. On the other hand, energy simulation was performed after the application of a thermal rehabilitation by using a bee-inspired adaptive envelope that was integrated on the south and north facades to promote cross-ventilation and improve summer cooling. On the south facade, we placed a complex envelope composed of two layers that are separated by an air cavity with a downdraft evaporative cooling system to refresh the air before entering the building. Furthermore, opening and closing of the external cells are guaranteed by applying an intelligent material (shape memory alloy, or SMA) as a sensor and actuator that autonomously adapts to the external stimuli while reducing operating and maintenance costs. The obtained results show an improvement in the internal thermal environment and reduced internal overheating with a drop in temperature reaching a maximum value of 7.59 °C. These results promote energy efficiency and reduce the impact of the building on the environment.

Keywords: Adaptive Envelope, Bee, Shape Memory Alloy, Cross-Ventilation, Administrative Building, Semi-Arid Climate.

1. INTRODUCTION

Building is probably the challenge of the next decades, so we should build according to the climate and move towards energy transition with more energy efficiency and renewable energy by ensuring eco-construction in Algeria [1]. Hence, the current issue is to protect and enhance people's comfort and reduce energy consumption as well, particularly concerning heating and air-conditioning [2].

However, Batna municipal buildings of municipal heritage are distinguished by their high energy consumption, this was translated by a bill which increased from 1,400,000 DA in 2014 [3] to 5,140,000 DA in 2022, with an increasing amount of expenditure reaching 467 500 DA/year. This will negatively influence the municipal budget as stated by the Batna municipality's finance department. Because these buildings are highly glazed and their design was only based on the facade' aesthetics, ignoring their ability to adapt to the local climate and internal heat gain causing an increase in the inner temperatures which negatively affects both internal thermal comfort and well-being. To deal with this situation, air-conditioning systems are applied to their facades to improve the internal thermal environment and the workers' thermal sensation. However, this increases energy consumption and negatively affects the aesthetic aspect and the architectural reading of the building.

In this regard, this study focuses on biomimetic architecture as an approach that can inspire climate-adapted architectural solutions for hot environment [4]. In order to reduce energy consumption of cooling, improve working conditions, promote sustainability and protecting the environment. To this end, it is necessary to create nature-inspired breathing envelopes and incorporate advanced technology to promote natural ventilation and indoor air quality in these public buildings, especially since the COVID-19 pandemic, thus improving energy efficiency.

2. MATERIALS AND METHODS

The current study aims to evaluate the indoor thermal environment in an administrative building recognized as a municipal building part of the municipal heritage of Batna during a hot period. The study design is divided in two phases, as shown in Figure 1:

- The first part used a post-occupancy evaluation approach that includes an objective investigation using in-situ experiments in the case study characterized by the collection and analysis of quantitative data obtained from

Registered: 231203 Article Info: 1836 Accepted: 240828
Reserved: 240424 Available: 240930

08 a.m.to 04p.m. during the hottest day on July 25th, 2022.

• The second part is devoted to the presentation of the thermal rehabilitation strategy proposed for this building via modeling and numerical simulation procedures. First, the followed process of generating nature inspired adaptive envelope (using Top/Down technique) is presented, then the followed path to develop 3D modeling of this parametric design using the Rhinoceros/Grasshopper software. Finally, energy simulation using the Ladybug and Honeybee plugins to evaluate its performance.

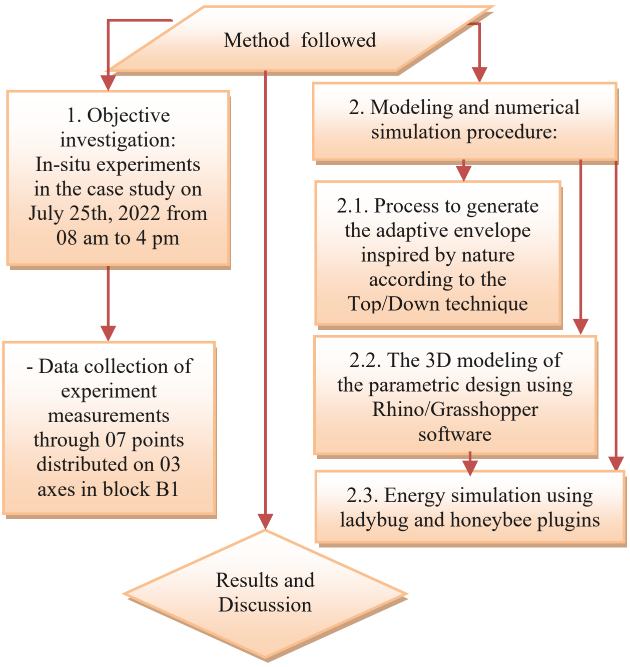


Figure 1. Summary of the method followed

2.1. In-Situ Experiments in the Case Study

2.1.1. Situation and Climatic Context

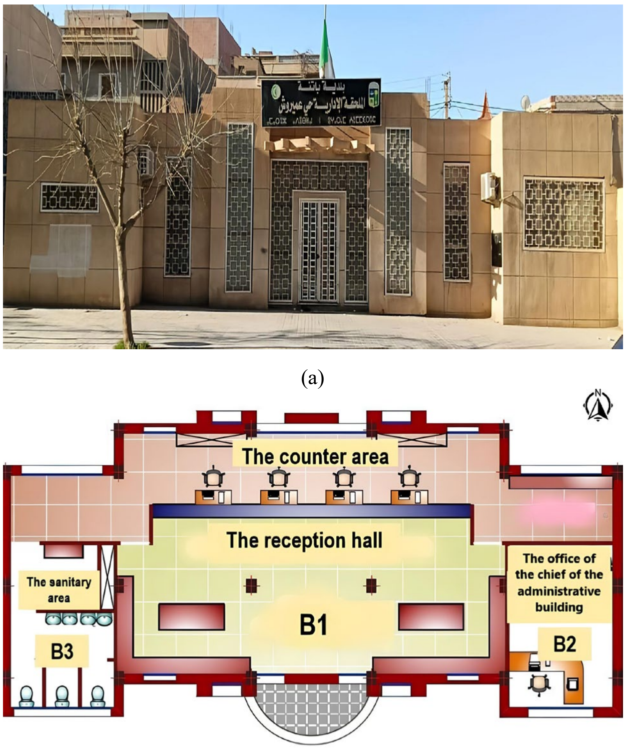
The city of Batna (Chief town of Wilaya) is located in the North-East of Algeria, at 35° 33′ north, 6° 10′ East. It is characterized by a semi-arid climate (zone C) apparent by long, extremely hot, very dry summers and very cold winters [2]. Table 1 shows the climate data of Batna City presented by the Ladybug plugin using weather files downloaded from the website EPW Map.

Table 1. Climatic data details of Banta city (Ladybug plugin)

Parameter designation	Minimum	Maximum
Average monthly temperature	5.6 °C in January	26.28 °C in July
Average monthly relative humidity	37.58% in June	75.35% in January
Average monthly direct radiation	173.30 kWh/m^2 in February	335.94 kWh/m^2 in July
Average monthly wind speed	2.04 m/s in January	4.61 m/s in March

2.1.2. Description of Building Case Study

The chosen case study is an administrative building oriented to the South, situated in an urban area named Amirouche (Figure 2a), and it is one of the most common types of administrative buildings found in Batna. This building is composed of three juxtaposed blocks (Figure 2b), the central block (B1) which represents the reception hall and the counter area with two lateral blocks, one is reserved for the office of the chief of the building (B2) and the other for the sanitary area (B3) (Table 2). It operates 5 days a week from 08 a.m. to 04 p.m. The period from 12 p.m. to 01 p.m. is reserved for the lunch break therefore the building will be empty and closed (Table 3).



(a)

(b)

Figure 2. a) Administrative building, b) Plan of the administrative building

Table 2. Description of the case study

	Descriptions		U-Value in W m^{-2} K^{-1}
Area of block B1	93.38 m²	Total area = 152.28 m²	/
Area of block B2	29.45 m²		
Area of block B3	29.45 m²		
External wall	Thickness = 0.34 m	(0.02 m plaster) + (0.1 m hollow brick) + (0.05 m air gap) + (0.15 m hollow brick) + (0.02 cement)	0.95
	Paint color: Beige		
Internal wall	Thickness = 0.14 m	(0.02 m plaster) + (0.1 m hollow brick) + (0.02 m plaster)	3.10
	Paint color	A base with a height of 1.20 m is colored in grey paint and the rest of the wall is in white paint	
Floor	Only the ground floor		5.63
Color and type of floor	Made of 40×40 cm brown floor tile		

covering			
Roof	slab with hollow body roof	thickness = 0.16+0.04 m	4.13
Windows	Simple glazing		5.68
HVAC	No heating, No ventilation, No air conditioning, because it was turned off during the investigation (01 unit in the reception hall, 02 units in the counter area and 01 unit in B2)		
Artificial lighting	Panel ceiling lights 60×60 (20 units in B1 and 03 units in B2) and waterproof lamp (03 units in B3)		
Equipment	04 computers, 04 printers, 04 small display panels and a large display screen are located in B1		

Table 3. Occupancy and Schedules

Days Schedules	5 days per week (from Sunday to Thursday)
Operating hours	The first tranche is from 08 a.m. to 12 p.m., and the second tranche: is from 01 p.m. to 04 p.m.
Lunch break	From 12 p.m. to 01 p.m.
Occupants	Surroundings 150-200 citizens/day + 06 person's personnel of administrative building Sex: male and female Clothing: Lightweight with bright colors Position: citizens in the reception Hall, personnel in the counter area and in B2

This building is located in a residential area with 48 984 inhabitants according to the population census of 2022. Consequently, a fairly high level of public frequentation permits the citizens to obtain their needed papers in addition, the presence of a large glazed surface with a higher percentage of non-openable windows (Table 4), and the absence of access to natural ventilation, especially in block "B1" (Figure 3). This led to the excessive use of air-conditioning throughout the exploitation of the building. As a result, there was a very pronounced electricity consumption in the summer.

Table 4. Facades' details

Blocks	South facade			North facade		
	percentage of plein	percentage of Opening window	percentage of non-opening window	percentage of plein	percentage of Opening window	percentage of non-opening window
B1	50.28%	8.19%	41.53%	52.46%	0.70%	46.84%
B2	70.67%	7.33%	22%	70.67%	7.33%	22%
B3	91.89%	2.70%	5.41%	70.67%	7.33%	22%

(a)

(b)

(c)

Figure 3. a) Windows in counter area, b) Windows in reception hall, c) Maximum opening of window

2.1.3. Data Collection of Experiment Measurements

The experimental measurements in the current study were recorded during 05 successive days between July 24th and 28th, 2022 (the hottest season) from different measurement points that are distributed in blocks B1, B2 and B3 in the building from 08 a.m. to 04 p.m. Physical parameters of thermal comfort in this article were taken from the reception hall and the counter area forming Block B1 because it represents the busiest space during July 25th, 2022 considered the hottest day of this period, it was characterized by an open sky with an average daily temperature of 29.21 °C and relative humidity of 30.34%. Data collection is done in 07 carefully selected measurement points that are distributed horizontally on the 03 axes.

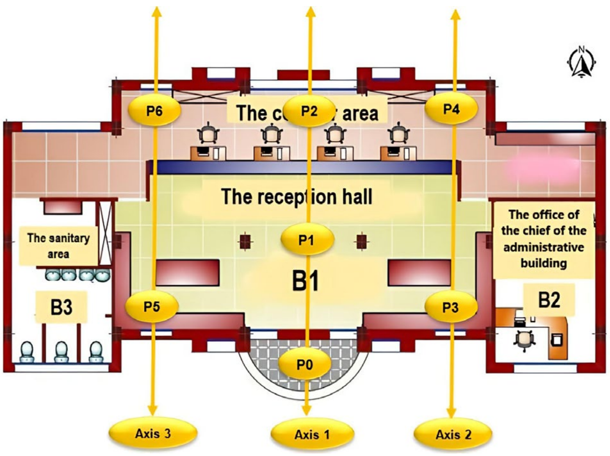


Figure 4. Position of measurement points

The first axe passes in through the middle of the block B1 and the other two axes are positioned on either side of the central axis as demonstrated in Figure 4. These measurements are taken at a height of 1.1 meters according to ASHRAE-55-2010 using the measuring instruments as illustrated in Figure 5 and their function and location as shown in Table 5.

(a) (b) (c)

Figure 5. Measuring instruments used

Table 5. Measuring instrument's function and position

N	Tool designation	Function (Measurement)	Position
(a)	Anemometer LT Lutron LM-8000	-Outdoor air temperature (°C) -Outdoor relative humidity (%) -Wind speed (m/s)	Esplanade: P0(outside)
(b)	Pistol Bosch: Thermo-hygrometer	-Indoor air temperature (°C) -Indoor relative humidity (%)	Reception hall: P3, P5 Counter area P2, P4, P6
(c)	Indoor station delta OHM	-Indoor air temperature (°C) -Indoor relative humidity (%) -Air velocity (m/s)	Reception hall: P1

2.2. Modeling and Numerical Simulation Procedure

To maintain the required temperature for indoor thermal comfort and to ensure energy efficiency, we proposed to carry out a thermal rehabilitation of this building by creating an adaptive envelope inspired by the nature that is considered as solutions database, because living organisms have solved similar problems over 3.8 billion years. This process is carried out using a direct approach following the Top/Down technique based on the search for biological analogies to discover technical solutions to architectural problems.

Indeed, the survival mechanism observed in the world of bees is defined by different adaptation systems: physiological, morphological, and behavioral once, offering great examples for mimicry to contribute to the optimization of the thermal performance of buildings, by reducing the energy required for cooling and improving natural ventilation [5]. In this regard, we tried to transform this biological fortune into functional architectural technical solutions.

2.2.1. Process to Generate a Bee-Inspired Adaptive Envelope

Our adaptive envelope will be generated as a complex device and its process will be developed in the following steps:

2.2.1.1. Inspiration from Physiological Adaptation

This phase is devoted to imitating the respiratory system of bees, in particular, the functioning mechanism of the stigmas "spiracles" which are 10 pairs orifices found on the skin of bees (3 pairs on the thorax and 7 pairs on the abdomen). They are characterized by a symmetrical distribution serving to control the gas exchange patterns allowing the entry of O_2, the exit of CO_2 and limiting the loss of water [6], [7]. In bees, the air is inhaled via the abdominal spiracles (inlet) and exhaled via the thoracic spiracles (outlet) in a unidirectional airflow[8]. The abdominal spiracles are open during the inhalation allowing air to enter and the thoracic spiracles are open during exhalation permitting air to exit creating airflow in an opening/closing mechanism (Figure 6).

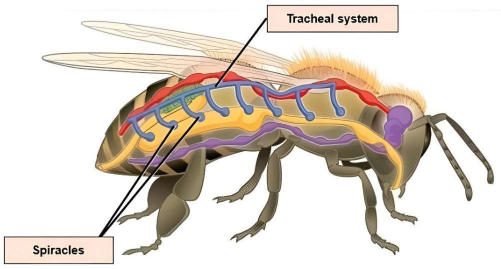


Figure 6. Bee spiracles

2.2.1.2. Inspiration from Morphological Adaptation

After determining the source of inspiration, we found a geometric shape for the spiracles; we kept the same context of bees' world. The hexagonal design of hives (nests) that are made of natural wax minimizes the amount of construction materials while maximizing the storage capacity per unit, in contrast to the other geometric shapes that leave unused space between cells and thus a waste of building materials (Figure 7) [9].

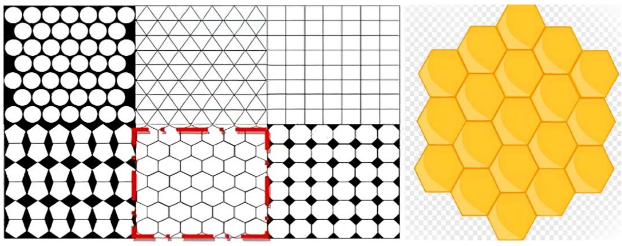


Figure 7. Hexagonal shape of beehives compared to other forms [9]

This step is devoted to giving more details to our envelope. This is done through return to vernacular Auresian architecture (the Chaoui house) notably that of the Oued Abdi valley (wilaya of Batna), defined by variety of building methods and employed environmentally friendly materials [10]. We focused our inspiration in the apertures characterized by specificities that were essentially linked to the microclimate of each Dechra. These apertures are placed at the top of the walls and serve much more for ventilation than for lighting and opening to the outside [11]. In this context, the apertures in the divided hexagonal form emit a splitting of the sun's rays with the maintenance of a significant and refined rate of luminosity, as well as good ventilation (Figure 8) [12].

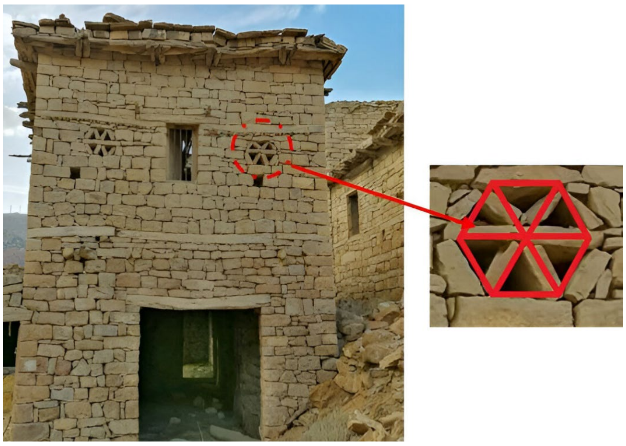


Figure 8. Habitat apertures of the vernacular Auresian architecture of the Oued Abdi valley

2.2.1.3. Inspiration from Behavioral Adaptation

Bees show excellent thermoregulation strategies for their hives, especially the central brood zone, which must be maintained at an optimal average temperature of 35°C, while outside temperatures vary from 3,7°C to 30,7°C [13]. Consequently, they serve to create a ventilation mechanism to evacuate the hot and stale air outside the hive to be exchanged with fresh air from outside to avoid overheating, control humidity, ensure better air quality and reduce CO_2 concentration [14]. This is manifested in the following two strategies:

- The first strategy is the heat shield, which involves positioning the bees as a thermal screen to capture heat to protect their brood from excess heat and then flying to a cooler area of the hive to dissipate the heat absorbed or stored in their ventral side of the body (Figure 9) [15].

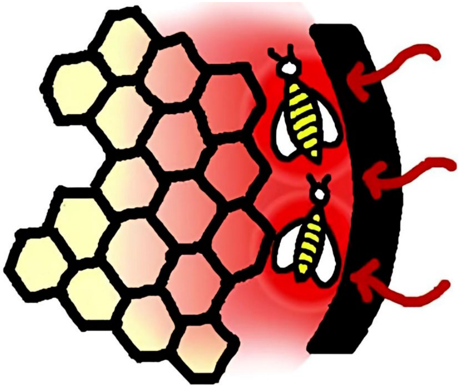


Figure 9. The heat shield strategy [15]

- The second strategy is evaporative cooling which was in response to a need for additional water to cool the hives and reduce the internal temperature of the brood nest and the nutrition of immature bees. Some worker bees spit out the water they have been carrying or just collected to spray it into the hive while they vent from above causing water evaporation and actively creating cool and moist air that circulates through the hive ensuring its cooling. Since bees instinctively recognize that fresh air is falling, they typically vomit water from the top under the hive cover (Figure 10) [9], [14], [15]. Lessons can be learned from bees' survival model, specifically, their capacity to ensure internal thermal regulation, where each individual can respond to external and internal stimuli with an appropriate response in their immediate neighborhood, via a technique known as decentralized control. These methods can be used in the field of construction to create environmentally friendly and sustainable buildings [9].

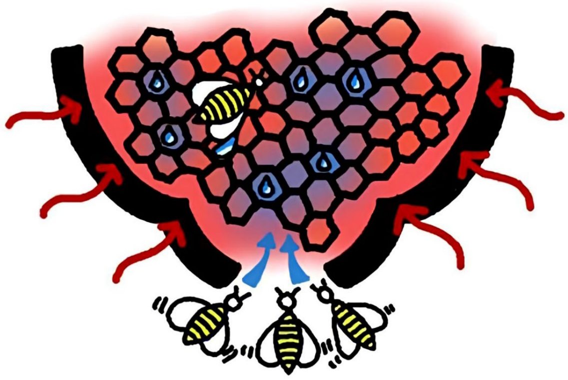


Figure 10. Evaporative cooling strategy [15]

2.2.1.4. Functioning Mechanism (Intelligent Material)

To create a dynamic design in the form of an adaptive envelope, there is a growing interest in adopting advanced technology. This is manifested through the use of intelligent materials as autonomous sensors/actuators integrated into the building envelope, and characterized by their change in shape when they are affected by a stimulus such as a temperature to ensure envelope deformation. These materials can replace costly fixed hard components found in mechanical systems that use mechanical actuators that need upkeep and energy to function automatically [16]. In this regard, we used a thermo-sensitive intelligent material with shape change according to intrinsic properties that are called Shape Memory Alloy (SMA) in the "Nitinol" type composed of nickel-titanium (NiTi) in the form of restressed wires. They allow an autarkic and adaptive reaction to external stimuli such as air temperature or solar radiation, causing a modification of the wire lengths. This phenomenon does not require any computing device, but it is due to its elasticity that can perform millions of cycles without the need for activation by electric power or other energy sources [17]. This material is used in the field of architecture for the creation a flexible and efficient envelope at a low cost [18].

2.2.2. 3D Modeling of Parametric Design

It was suggested to design an adaptive envelope consisting of 14 outer hexagonal cells placed on the south facade and 5 cells on the north facade of block B1 along with 4 cells on the south facade and 1 cell on the north facade of blocks B2 and B3. Each unit occupies an area of 1.50 m² and each cell consists of six film panels in a hexagonal frame attached by elastic cords. Six tubular elements allow the panel to rotate. Each opposing panel is connected by an SMA wire which functions as an independent sensor/actuator inspired by the Airflow (er) model generated by LIFT Architects in 2007 [19].

The integrated Rhinoceros/Grasshopper program was selected as parametric modeling software for this envelope (Figure 11), due to its inherent interface which allows parameterized manipulation of geometry and they provide a level of flexibility that is not achievable by traditional 3D tools [20]. For this purpose, our idea is developed as a complex system whose air passes through the following spaces:

- The Cells Applied to The South Facade (Layer 01): They are inspired by the operating system of the bees' abdominal spiracles (opening/closing), the hexagonal geometric shape of the bees' hives and the apertures of vernacular Auresian architecture (Chaoui house) of Oued Abdi valley. They are consisted of triangular films activated by SMA wires as autonomous sensors/actuators allowing the opening/closing of this external layer by entering the air inside (Air inlet).

When these cells subjected to direct solar radiation, the wires reach a higher temperature than the ambient temperature [21] with an activation temperature of 35-40 °C. This causes the wires contract and return to their original shape (austenitic phase) [22] causing the opening of the cells provoking air to enter. However, when the temperature drops below 20 °C [21], the wires of SMA actuators expand (martensitic phase) [19] and gently return the hexagonal cells to their closed position through their rigidity without using electrical energy.

- The Intermediate Space: is designed in the form of an air cavity of 1.00 m in width for block B1 and 0.60 m wide for blocks B2 and B3. This connecting buffer zone is inspired by two sources: one being the heat shield system generated by the bees to prevent heat transmission to the interior to protect the brood, and the other being the system of water spraying by the bees to ensure thermoregulation of the brood nest. This space is used to provide thermal insulation on its outer side, which is used to cool the air before its entrance to the inner space [23].

This is assumed via a downdraft cooling system by spraying water droplets from its upper part, the lower part of which is equipped with a water collection and recovery tank subject to a closed circuit driven by an acceleration pump [24]. As a result, the dry air that enters is humidified and cooled when it reaches the indoor space [25].

- The Inner Aperture (Layer 02): is situated on the interior wall, having the same form as the south cells but with half of their area (½Sc). They are equipped with filters to prevent airborne particles and other airborne contaminants from entering the room [26]. This difference in cross-sectional area between the openings of the outer and inner layer causes an increase in air velocity through the Venturi effect and Bernoulli's principle (by increasing the inlet/outlet ratio) [27].
- The Interior Space: in which the various administrative activities take place. The air is drawn into the building due to pressure differences between indoors and outdoors, in which air moves from high pressure spaces to low-pressure spaces, such as in the process of inhalation and exhaling in most living organisms [4].
- The Cells Applied to The North Facade: were inspired in the same way as the south façade. They are opened automatically when the interior space is heated above the comfort temperature threshold (26 °C) to evacuate the warm stale air from the inside to the outside (Air-outlet) by providing cross ventilation. However, once the interior space cools beyond its lower temperature threshold (15 °C), the components are closed to maintain the appropriate and optimum temperature [19].

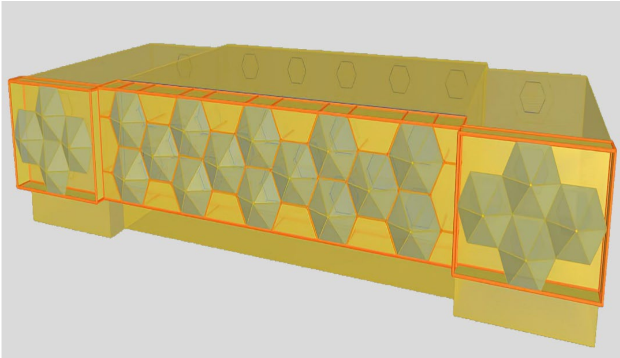


Figure 11. Bee-inspired adaptive envelope

2.2.3. Energy Simulation

The energy simulation was carried out using the Ladybug and Honeybee plugins with the integrated software Energy Plus following the recommendations for indoor thermal comfort presented by APRUE, where the indoor air temperature in summer must be between [24-27 °C] in addition to the application of cross-ventilation at 11 a.m. when the interior temperature exceeded the neutral temperature of 26 °C. The purpose of this simulation was to understand the interactions and geometric configurations of this envelope concerning solar radiation/outdoor air temperature and evaluate its performance and efficiency (Figure 12).

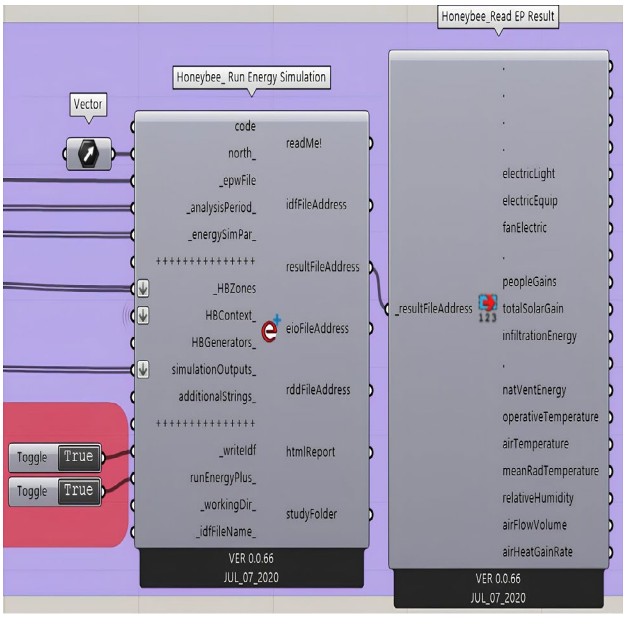


Figure 12. Run energy simulation (Honeybee plugin)

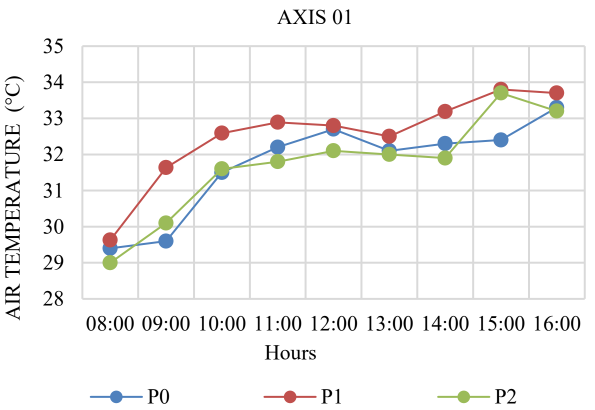
3. RESULTS AND DISCUSSION

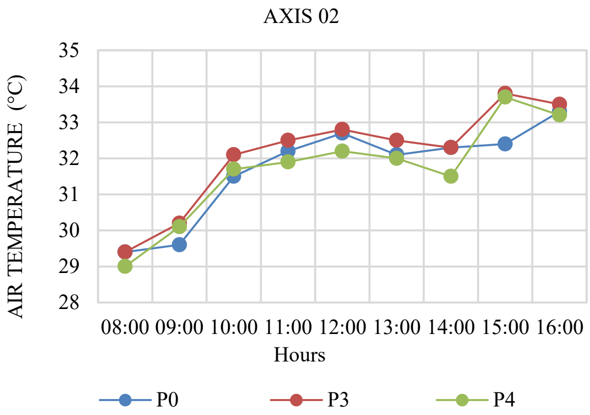
3.1. In-Situ Experiments Evaluation Results

The results of the in-situ experiments during this day show that the air temperature profiles through the 3 axes present values outside the comfort range determined as (24.11 °C - 28.11 °C). These profiles are manifested by a progressive increase in temperature values since the beginning of the measurement (Figure 13). It was noted that the graphs representing the points P1, P3 and P5 located in the reception hall, indicate higher values, defined by a peak reaching 33.80 °C in P1 and P3, and 33.90 °C in P5 at 03p.m. The point P1 represents maximum values compared to the other points, characterized by an amplitude of 4.17 °C. On the other hand, the minimum values are recorded in the counter area with values reaching 29 °C recorded in P2 and P4, and 28.90 °C in P6 at 08 a.m. It is important to mention that a drop in temperature was noted when the building was out of service for the lunch break between 12 p.m. and 01 p.m.

Reading the graphs representing the relative humidity values through the 03 axes (Figure 14), the axis 01 represents very low relative humidity values compared to the other curves, when the P1 curve shows minimum values oscillating between 20.40% and 31.30% with an amplitude of 10.90%. In addition, the curves representing points P3 and P5 show minimum values which are outside the comfort zone that was determined between [35% - 65%], except for those recorded at 11a.m.and reached the values of 40% and 39% in P3 and P5 respectively. While the curves representing the points P2, P4 and P6 maintain the same path with almost similar values, the maximum value that reached 37% is recorded in P2 and 38% in P4 and P6 at 11 a.m.

The results of measurements carried out during this day showed that the values obtained for air temperature and relative humidity are outside the comfort zone and have an inverse correlation between these two parameters, so temperature increases are accompanied by drops in internal relative humidity [28] causing internal overheating that makes the space uncomfortable, thus influencing the users feeling in terms of well-being and thermal comfort.





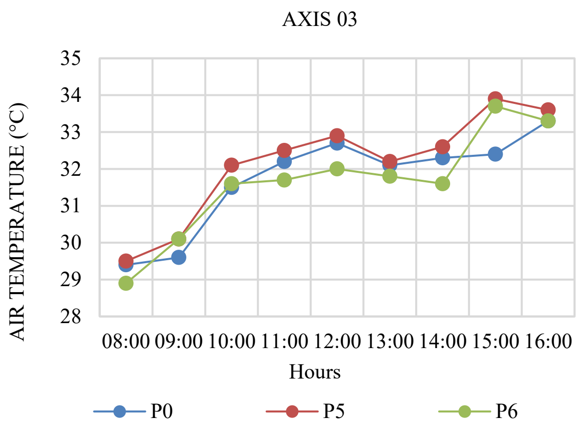
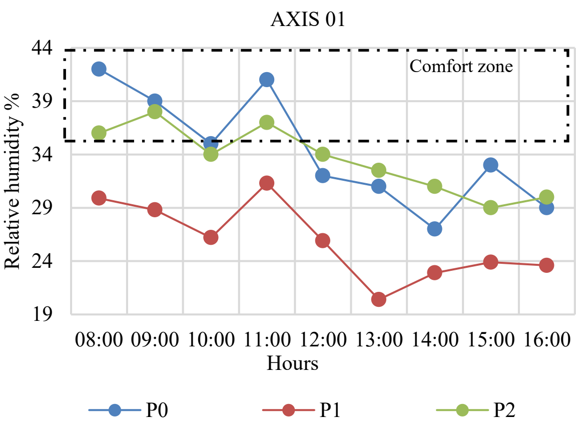
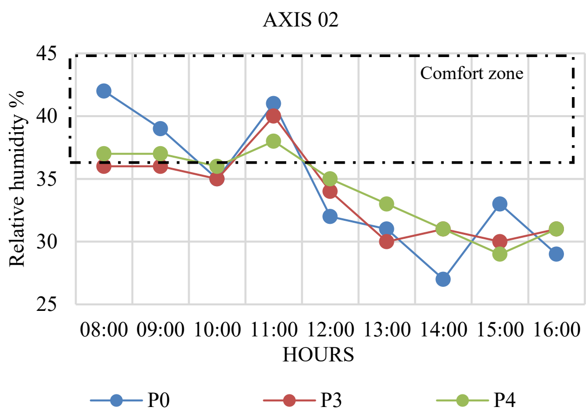


Figure 13. Results of measured air temperature





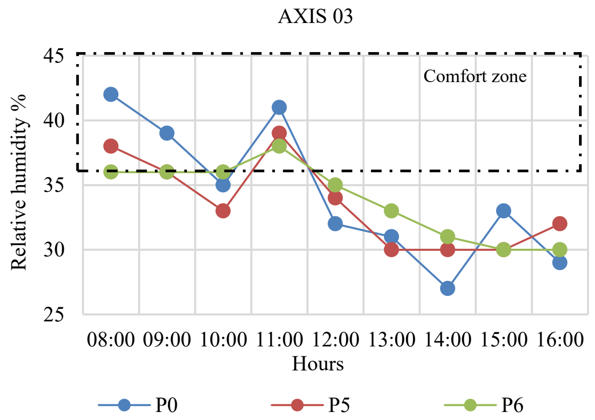


Figure 14. Results of measured relative humidity

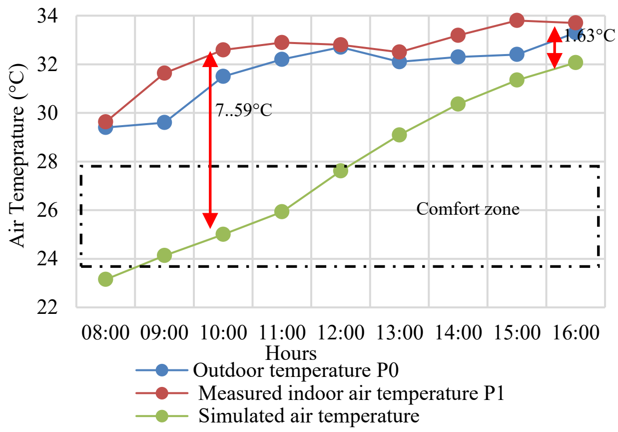
This is due to several factors such as the type and very high ratio of exterior glazed surfaces which affect the incident solar radiation [29], the inertia of the building, the internal heat supply due to the use of artificial lighting and internal electrical appliances and another very important cause is the absence of access to ventilation due mainly to the impossibility of opening the windows of the south and north facades, which coincides with high public attendance. To face these problems, natural ventilation is recommended as a cooling resource to create a healthy natural environment that can achieve acceptable levels of thermal comfort [4], [30].

3.2. Energy Simulation Evaluation Results

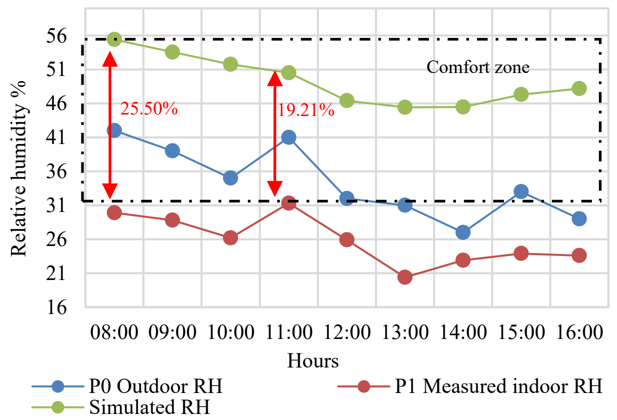
After analysis of in-situ investigation results, it was revealed that the point P1 presents critical values that are outside the comfort range. Therefore, a comparison was made between the values recorded in points P0 (outdoor measurement) and P1 and those obtained by the energy simulation, with the aim of evaluating the reliability of the applied envelope. In this regard, Figure 15a presents the three graphs indicating the variations in air temperature during this day.

It is shown that the curve representing the experimental values follows the same pattern as that of the exterior but with higher values ranging from 29.63 °C to 33.80 °C. However, these two curves are located outside of the comfort zone. This is due to internal heat gain caused by the absence of access to ventilation causing internal overheating throughout the measurement. Whereas the curve showing the simulated air temperature after the application of the adaptive envelope presents a spectacular decrease in temperature values characterized by suitable values oscillating between 23.15 °C and 27.61 °C that are located in comfort range from 08 a.m. to 12 p.m. and at the same time they are much lower than those taken during in-situ experiment manifested by a maximum deviation reaching a maximum value of 7.59 °C at 10 a.m. and a minimum deviation of 1.63 °C at 04 p.m.

Regarding the relative humidity values during the same day illustrated by Figure 15b, it was found that the curve representing the values of the measurements of the real case follows the same pattern as that of the exterior, but with lower values oscillating between 20.40% and a maximum of 31, 30% that are outside the comfort range.



(a)



(b)

Figure 15. a) Results of variation of air temperature, b) Results of variation of relative humidity

However, the graph representing the results of the energy simulation is superior to those of the exterior and the experiment, where the values are within the comfort range during the entire period from 08 a.m. to 04 p.m. This curve is characterized by a minimum value of 45.43% at 1 p.m. and a maximum value of 55.40% at 08 a.m. The minimum difference was recorded between the real values of the in-situ investigation and those of the simulation reaching a value of 19.21% at 11 a.m., and other maximum reached a value of 25.50% at 08 a.m.

This can be explained by the fact that the relative humidity values increase accordingly to the temperature decrease [28] due to dropping water that absorbs heat from the incoming air flow and reduces the air temperature which lower energy consumption better than mechanical cooling systems. This corresponds to the idea of Jomehzadeh, et al. (2017) [31] who reported that increasing air humidity improves the thermal comfort of occupants in dry climates where a breathable wall works by an inside-outside pressure gradient that allows air to slowly migrate through the walls from the highest ambient pressure to the lowest ambient pressure. This allows gradually exchanges of energy and excess water [4].

4. CONCLUSION

The present paper explored the evaluation of the thermal behavior of an administrative building located in the city of Batna, characterized by a semi-arid climate on the day of July 25th, 2022, at 08 a.m.to 4 p.m. time slot. This period is marked by high public use and a large glazed surface area with no access to natural ventilation. This study is carried out using two main methods:

- The first method is an in-situ investigation based on taking measurements of inner air temperature and relative humidity at various points distributed around block B1, which represents the most frequented area. The main results are summarized as follows:

- An increase in indoor air temperature which becomes outside of the comfort zone when the building is in operation.

- As a result, inner overheating makes the space uncomfortable, which has a negative impact on the conduct of administrative activity and causes over use of mechanical air-conditioning leading to very high electricity consumption.

- The second method is devoted to assessing the thermal rehabilitation provided by an adaptive thermos sensitive envelope inspired by the various survival systems found in the world of bees. This system is developed using the Top /Down technique, characterized by the integration of SMA shape memory alloy (NiTi) counting as autonomous sensors/actuators responsible for opening and closing. It is applied to the North and South facades. The latter is designed in the form of two layers separated by an air cavity featuring a downdraft water droplet spraying system to cool the air before it enters the building.

This proposed adaptive envelope was modeled using Rhinoceros /Grasshopper algorithmic software and then subjected to an energy simulation using Ladybug and Honeybee plugins with their integrated software, in particular Energy Plus. The results obtained after integration of the system show:

- A significant improvement in thermal comfort conditions, identified by a spectacular reduction in indoor air temperatures compared to those measured values that belongs to the comfort range during the time slot from 08 a.m. to 12 p.m. During the entire occupancy period, the relative humidity values are within the comfort range.

- Consequently, an improvement of the inner thermal environment by expelling excess heat to the outside through the renewal of the air by cross-ventilation provides a productive working environment and leads to minimizing the use of mechanical cooling means, therefore a reduction in energy consumption and minimize the ecological footprint of the building on the environment.

NOMENCLATURES

1. Acronyms

SMA	Shape memory alloys
DA	Algerian Dinars
DA/year	Algerian dinar per year
COVID-19	Coronavirus disease 2019
3D	Three dimensional
EPW	Energy Plus Weather File
B1, B2, B3	Block 1, block 2 and block 3
P0 -P6	Measuring points
O_2	Oxygen
CO_2	Carbon dioxide
NiTi	Nitinol
½ Sc	Half of the surface of the southern cells
APRUE	The National Agency for the Promotion and Rationalization of Energy Use
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers

2. Symbols / Parameters

°C: Degree Celsius
a.m.: Ante Meridiem or Before Noon
p.m.: Post Meridiem or Afternoon
%: Percentage
KWh/m²: Kilowatt hour per square meter
m/s: Meter per second
m: Meter

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