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Research Article

Toward improving thermal behavior of passive solar structures by natural ventilation and extraction – case study –

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ABSTRACT

Improving the energy performance of passive energy buildings is based on reducing their consumption. These reach very high levels in overheating periods because of the mechanical ventilation systems. This work proposes to implement ventilation strategies to reduce the indoor temperature of an academic building considered a passive solar structure and designed to benefit as much as possible from solar radiation. Using TRNSYS software, with its two components, TRNBUILD and TRNFLOW, different likely scenarios were tested and allowed to identify significant results. The mechanical extraction system is a solution if the extraction threshold temperature is 21-19°C to keep the Hall_1 temperature lower. While, to make the temperature of all areas of the building more comfortable, three natural ventilation scenarios were evaluated. Obtained results highlight that natural ventilation scenario (circuit 2) is the optimal scenario which makes the different zones very comfortable and lowers the temperature by an average of 4°C compared to mechanical ventilation. Thanks to the proposed ventilation scenarios, we have shown that we can, thanks to natural ventilation, renew the air inside the different areas of the building and maintain the comfort temperature. Natural ventilation can be an alternative to mechanical ventilation if we consider appropriate scenarios. This will strongly reduce energy consumption.

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INTRODUCTION

Lately, cities are under the threat of global warming and urban heat island [1]. These phenomena of climatic transformation are characterized by an increase in temperature [2]. Among the consequences of global warming is increasing the risk of heatwaves and exceptionally hot days [3]. Among the reasons for the increase in the severity of this phenomenon is the increase in the concentration of

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greenhouse gases. So, reducing greenhouse gas emissions in all possible areas has become a priority. The building tertiary sector is one of the major producers of greenhouse gases and is therefore subject to numerous pressures to reduce its emissions [4]. This decrease can take place in several ways. To preserve the planet's energy resources and fight against climate warming, the European Union is issuing more and more directives and regulations. It also tackles the consumption of energy to cope with its constant increase. By reducing energy consumption, it is possible to reduce CO_2 emissions, the greenhouse gas responsible for a large part of climate warming [5]. The main energy consumers are the industrial sector, transport, and the building sector. One way to reduce greenhouse gas emissions is to increase energy efficiency, that is, to waste less. The reduction in the heating and cooling consumption of the various buildings leads to the reduction of fossil fuel consumption and thus to the reduction of greenhouse gas emissions [6].

In the building sector, the ventilation of office buildings constitutes an important item of energy consumption [7,8]. It also influences the distribution of energy flows and thermal comfort in the building because it helps to maintain acceptable thermal comfort conditions for the occupants, mainly in the hot season, thanks to a supply of fresh air. Through natural or mechanical ventilation, the fresh air directly cools the occupants, by convective exchanges [9], contributes to the cooling of the structures of the envelope [7], and also minimize the energy consumption [10]. Ventilation from the outside can create a thermally comfortable indoor environment with acceptable indoor air quality [11]. Cooling by ventilation can only be effective if it is ensured that the outside air is cooler than the air present in the premises [12]. Ventilation rates result from the simultaneous action of wind, thermal draft, and mechanical ventilation, which generate a pressure distribution in the building and on its envelope [8].

A significant amount of research has shown better thermal comfort and indoor air quality to be part of the advantages of the application of natural ventilation in buildings, studies showed by Mukhtar et al. [13] and Aflaki et al. [14]. Natural ventilation is still an effective method especially when the indoor temperature is close to ambient temperature to reduce energy consumption in buildings [15,16]. Although existing studies support the efficiency of natural ventilation compared with mechanical ventilation e.g. Khanal et al. [17], wrote that Natural ventilation is increasingly being offered as an alternative to mechanical ventilation systems due to its potential benefits in terms of operating cost, energy requirement, and carbon dioxide emissions. Another study in the same direction shows that natural ventilation lowers the consumption of primary energy between 18 and 33% compared to mechanical ventilation while maintaining classroom comfort levels [18]. The same was demonstrated by Cuce et al. [19] in school buildings where single-sided ventilation and cross ventilation can positively affect cooling and improve air quality. To achieve thermal comfort in the building, Oropeza-Perez et al. [20], showed that there is a 90% reduction in hours of the possible use of mechanical ventilation, using passive ventilation, and they concluded that results contribute to an assessment of the economic and environmental benefits of using natural rather than mechanical ventilation on large-scale scenarios located in temperate conditions. A similar finding was presented by Cakyova et al. [21], in the hot Mediterranean and subtropical climates due to the risk of overheating, nighttime ventilation offers new opportunities to explore potential natural ventilation strategies. In the temperate climate, no mechanical cooling is necessary, [22] where the properly designed and controlled natural ventilation presents good functionality in the buildings.

Recent studies that promote natural ventilation for the cooling of open spaces in the building, also increase the air quality and the well-being of the occupants inside. the studies of the effect of natural ventilation on the level of CO2 and the concentration of viruses circulating inside buildings have been evaluated. Case studies in the north of Spain before and during COVID [23], or A fresh (air) look at ventilation for COVID-19[24], Natural ventilation, and the COVID era in Mediterranean climate [25]. All results show that natural ventilation decreases the risk of indoor spread of infectious diseases, increases the amount of fresh air, and significantly reduces energy consumption in buildings.

On the other hand, other alternative systems are taken into account in ventilation studies, such as air conditioning, mechanical ventilation and free cooling in energetic terms. Zeinelabdein et al. [26], demonstrated that A free cooling system has the potential to meet around 42% of a typical building cooling load and has the ability to save up to 67% of building cooling energy load in summer season compared to conventional air-conditioning systems in hot arid climates.also, Stasi et al. [27], proved that combined use of nocturnal ventilation with mechanical ventilation system reduces the cooling energy demand by 14.4%, while free cooling produces a less effective decrease in electricity consumption of 7.7%. Free cooling and nocturnal ventilation generate more benefits in the middle-season when lower minimum outdoor temperatures occur. Particularly for the case study building, we can save cooling energy by up to 5.6 kWh/m^2 per month in the optimal natural ventilation mode while minimizing the negative health impact of ambient pollution by introducing more fresh air from the cleaner side [28]. Air movement is considered the key requirement in the natural ventilation process. Although the solar chimney (extractor) helps to achieve better thermal environments and displays even better performance by producing relatively high ventilation rates [3], the effectiveness of natural ventilation depends on several factors. Bai et al. [29], studied the driving force of nocturnal ventilation and the pressure difference [30] to provide sufficient airflow for building cooling. A field study was carried by Gupta et al. [31], to evaluate the thermal comfort in a building. It was found that an increase in air velocity up to 0.5 m/s was achieved by Cross Ventilation while a drop of 2.0–2.5°C in the air temperature was found using Night Ventilation. Three natural ventilation scenarios were evaluated by Bay et al. [32], in a historic building and found that the mechanical functioning of the system can be reduced, particularly in spring, when the proposed night ventilation scenario is able to maintain air temperatures and optimal relative humidity levels for occupant comfort and the preservation of such historic buildings.

In overheating periods, natural ventilation can be an alternative to mechanical ventilation if we consider appropriate scenarios. This will strongly reduce energy consumption. The main objective of this research work is to implement ventilation strategies for an academic building considered a passive solar structure and designed to benefit as much as possible from solar radiation, thanks to its design (shape, orientation, glazed surface, insulation, thermal inertia, etc.), and efficient ventilation which allows air intake and humidity to be controlled. A numerical study was performed using the advanced simulation method based on the software TRNSYS with its two modules TRNFLOW and TRNBUILD.

STUDY BUILDING DESCRIPTION AND OVERHEATING PROBLEM

The building subject of this study hosts the Department of Environmental Sciences and Management of the Faculty of Sciences, located at the Arlon Campus Environment of Liège University, founded in 1971 in Arlon, in the province of Luxembourg in Belgium.

It has been extensively used in a research project of the International Energy Agency (IEA) devoted to the study of passive solar-type buildings. The main function of this type of construction is to derive maximum benefit from natural energy resources while limiting losses to the environment.

Building Description

The studied building is a passive solar building, facing south and located on relatively horizontal terrain. Rectangular in shape (30 x 14m), it consists of two floors of 2200 m^3 in total. On the ground floor, there are two auditoriums, between them an entrance hall, and opposite the entrance door, there are sanitary facilities (Figure 1). Upstairs, there are two meeting rooms, five offices, the archives room, a small kitchen, and in the middle, a space with direct gain located on the south façade (Figure 2). Two-thirds of the south façade surface is glazed (135 m^2 of glazing) and has a large opening (the main door of the building), while towards the north the facade is completely closed. Insulation of the walls with a 12 cm thick layer of glass wool and waterproofing on the exterior surfaces provided by slates. A 25 cm thick reinforced concrete slab separates the two levels and reinforces the thermal inertia of the building.

The "passive solar" characteristic is achieved by the presence of a:

- Direct gain area made up of double glazing, directly connected with the central part of the building (Figure 3).
- Indirect gain zone which includes double glazing, a mass wall in the side parts, and between these two elements a buffer space (Figure 4).

To reduce night-time losses through the glazing and the risk of overheating in sunny periods, blackout shutters are placed on the outside of the glazing.

Independently of the different passive solar systems, the building is equipped with an auxiliary heating system, centralized powered by a gas boiler, and two mechanical ventilation systems ensuring the renewal of the air in the auditoriums, offices, and meeting rooms.

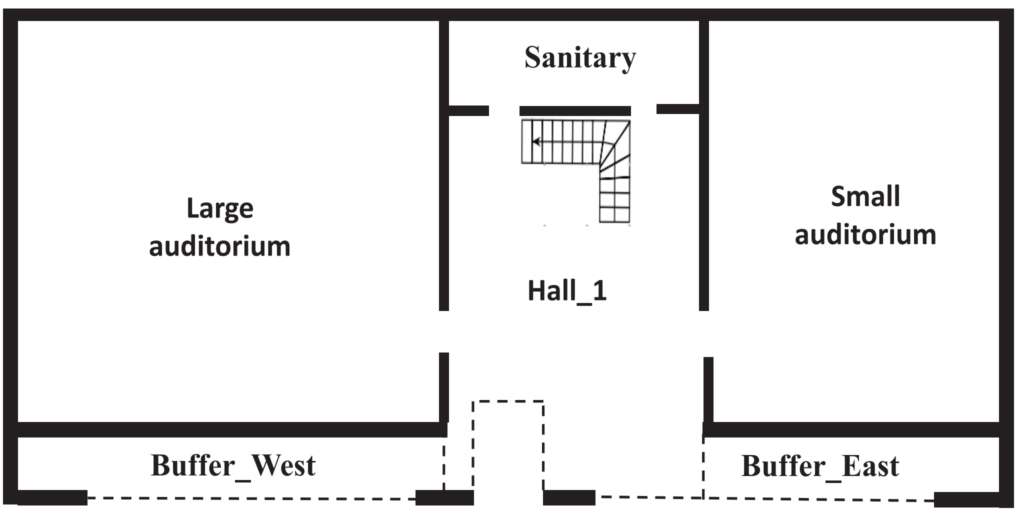

Figure 1. Ground floor plan of the academic building.

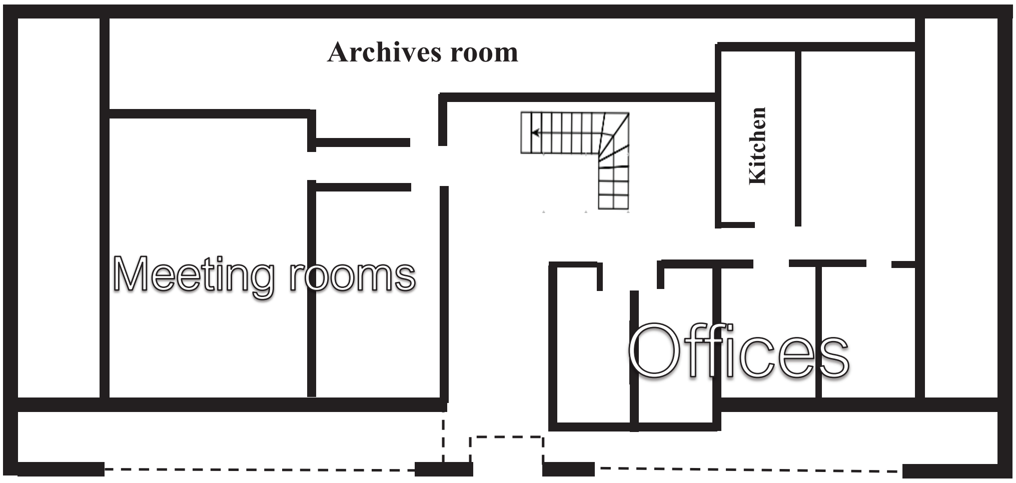

Figure 2. Floor plan of the academic building.

Figure 3. Central zone with direct gain.

Figure 4. Buffer space with indirect gain.

OVERHEATING PROBLEM

This assessment reveals quite a few problems relating to the excessively large glazed surface on the southern facade, the poorly sealed outer casing, poor mechanical ventilation, etc. The fact that the academic building is not functioning optimally, produces an overheating problem, especially during the summer months.

To fight against overheating in the administrative building, a heat extractor has been installed (Figure 5). This system placed in a chimney of the building consists of a central fan and two side shutters. The principle of this device is to

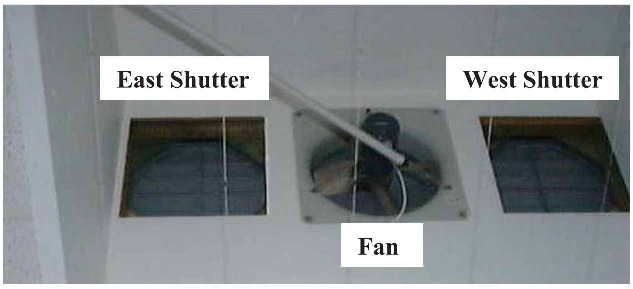

Figure 5. Heat extractor system.

extract the hot air from the hall naturally by the two roller shutters or forced by the fan.

Ventilation and extraction systems operate as follows:

- Ventilation system operates at low speed during building occupancy periods, from Monday to Friday. Outside of these periods, i.e. from 6 p.m. to 8 a.m., the fan starts up if the temperature inside (in the offices) exceeds 21°C and the difference between it and that of the outside is greater than or equal to 4°C.
  The ventilation system stops in two ways: either the temperature in the offices drops below 20°C or the outside temperature is no longer sufficient for it to lower the temperature in the offices.
- Extractor system: the side shutters of the extractor open if the temperature in the hall exceeds 25°C. However, if the hall temperature exceeds 27°C, the fan is activated and the shutters close to prevent the intake of outside air (by short circuits).

The technical characteristics of the fan are presented in Tables 1 and 2. Given Table 1, the power consumption is quite reasonable and the noise nuisance does not influence the occupants of the offices.

The building is equipped with a “solar” cabinet collecting free energy through six photovoltaic panels attached to the balcony above the main door of the building on the south façade. The extractor is powered by batteries that store the energy coming from photovoltaic panels.

MECHANICAL AND NATURAL VENTILATION POSSIBILITIES

Mechanical Ventilation System

The academic building is equipped with a mechanical ventilation (Figure 6) system which includes three distinct elements:

- A first system responsible for renewing the air in the auditoriums and the upstairs offices (supply + extraction);
- A second whose function is similar but for the upstairs meeting rooms (supply + extraction);
- The last system which works continuously during the day, in the toilets (extraction only).

New air taken from outside the north side of the building, enters through the intake grille and passes through a filter, then it goes through heating exchangers (HE), then through a humidifier (H) and arrives in the supply duct to be distributed in the spaces ventilated by this unit; through the exhaust fan, the air is evacuated from the rooms to the outside.

Overheating problems in the upstairs offices led to the placement of an additional ventilation circuit in these rooms, connected in parallel to the auditorium circuit. The ventilation circuit in the building has then two dampers (valve A, valve B), which direct the blown air, either

Table 1. Technical characteristics of the extractor fan (Mfg.: S.A.Codumé; Type: VWL450)

Speed (tr/min)	Amperage		Power (W)	Noise Db (A) at 7m	Weight (Kg)
	Amp.	Amp. Max			
915	0.55	0.7	114	44	12.3

Table 2. Pressure and flow rate characteristics of the extractor fan

Pressure (Pa)	0	10	20	30
Flow rate (m^3/h)	3800	3550	3250	2800

When the sun reaches its maximum, a single solar cell can thus provide a direct voltage of around 0.5 V and a direct current of 30 mA per cm^2 of area, i.e. a power of 150 W/m^2.

$$P = 0.5 \times 0.03 = 0.015\ W/cm^2 = 150\ W/m^2 \quad (1)$$

This power will be sufficient to operate the extractor fan. However, when the batteries in the solar cabinet are discharged, the extractor is then directly connected to the network, allowing continuous operation.

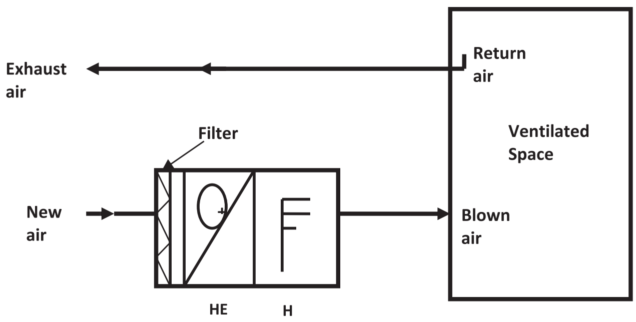

Figure 6. Air treatment station.

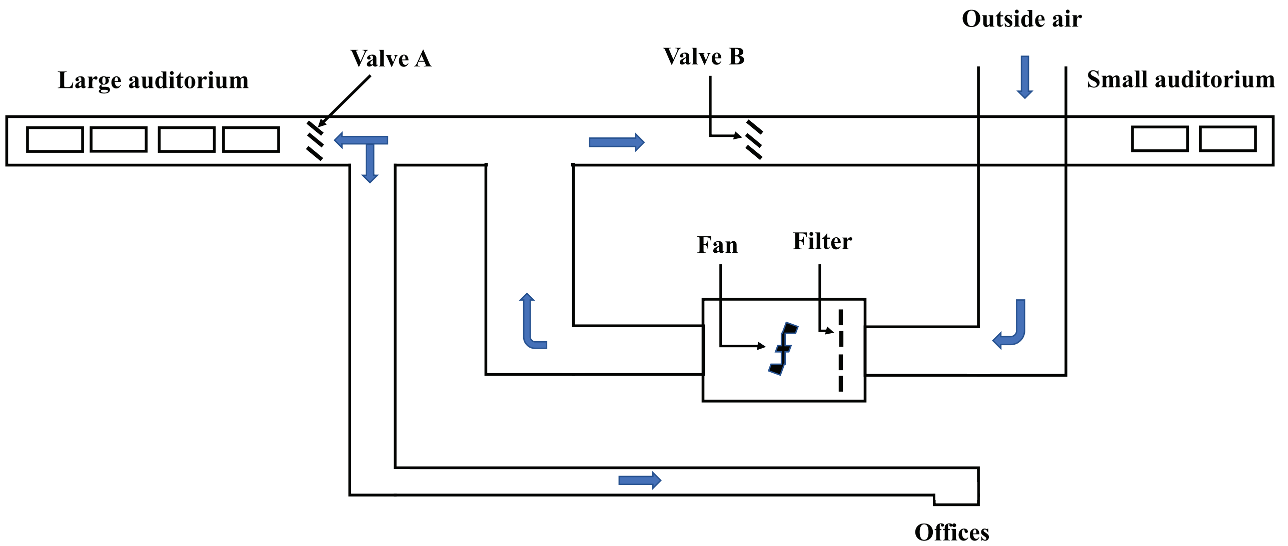

Figure 7. Diagram illustrating the direction of outdoor air conditioning in the building.

towards the offices and the auditorium (s) or towards the offices only as shown in Figure 7.

Natural Ventilation

The academic building has different openings that allow ventilation of areas without energy consumption. There is an emergency door on the west facade of the building (1.01 m x 2.10 m) allowing a possible rapid evacuation of the large auditorium. Another emergency door (1.01m x 2.10m) connects the small auditorium to the east facade of the building, and finally the main building door (2.43m x 2.10m) to the south facade.

To exhaust air, there are openings, two exterior shutters of the extractor (by thermal draft) at the highest point of the building (detailed in the extractor section), and office windows.

So, thanks to the pressure differences that exist between the facades of the building and thanks to the difference in density of the air according to its temperature, the air moves from one place to another, crossing the opening of the staircase that connects the ground floor with the first floor.

DYNAMIC THERMAL SIMULATION

TRNSYS software was used to analyze the thermal behavior of the building through the commissioning of ventilation and exhaust systems on the one hand and the implementation of a natural ventilation strategy on the other hand. TRNSYS is well known by the design offices as a global leader in the field of dynamic thermal simulation and air flows in buildings. It is an energy simulation software suitable for systems that evolve with time; it is dedicated to calculating the thermal performance of single or multi areas buildings and their equipment, as well as thermal systems in general [33].

TRNSYS is a component-based program, and the simulation studio allows for the connection of all the components of the simulation together to create a model. As can be seen from Figure 8 the main component of the TRNSYS file constructed for this purpose is "Type 56a" element which includes all the building data. This component models the thermal behaviour of a building having thermal multizone. It was defined in the TRNBUILD program which includes the walls, air change rate, and number of occupants.... For this element to give consistent results, it must be provided with a series of inputs such as the temperature and the relative humidity outside. The inputs come from the "Type15-6" element which allows to search an external database for climate data from the countries of the five continents of the world. "Type 65" (Result data) allows printing results. "Type 2b" differential temperature controller, which controls the temperature in the Hall, and operates the heat extractor if the temperature exceeds the imposed thresholds. "Equa" (Equation editor) was used to insert an equation to calculate the volume of extracted air depending on the temperature in the Hall. This program is composed of:

- TRNBUILD, the interface for editing the building structure. It encodes the surfaces of the walls, their orientations, their glazed surfaces, their constitution, solar protection, heating regulation modes, cooling regulation, internal gains specific to each zone, ventilation, and infiltration (this list is far from exhaustive but includes the most common parameters).
- TRNFLOW, allows simulating a natural and mechanical ventilation circuit. The only difference between TRNFLOW and TRNBUILD regarding ventilation is that in TRNBUILD it is necessary to impose the airflow rates between the different places, while in TRNFLOW

the rates are calculated automatically as a function of temperature and pressure differences.

Four classes of nodes are used in TRNFLOW to define the air circulation network: constant pressure nodes, thermal zones, auxiliary nodes, and external nodes. Each node has a reference altitude, for example for an exterior node the reference level is the ground, while for an interior node its reference level is the floor of the room. Node pressures are defined as the pressure differences between the pressure in the node and the ambient atmospheric pressure at the building reference level. This means that for example, a constant pressure node with 0 Pa has no additional pressure compared to the ambient pressure.

The wind pressure [Pa] on a facade is defined as the difference between the effective local pressure and the calm wind pressure on the same building altitude. It can be calculated according to the equation [34,35]:

$$\Delta P = \frac{\rho\, C_p\, v_0^2}{2} \tag{2}$$

Where ρ is air density [kg/m³], v_0 is local wind velocity at a specified reference height [m/s], and C_p is wind pressure coefficient. Wind speed evaluation and the wind pressure coefficients data used were taken from the Air Infiltration and Ventilation Centre (AIVC) [34,36]. In our case, the facades of the building have been divided into 7, and for each facade, 4 wind directions have been chosen (0°, 90°, 180°, 270°) with a C_p value defined in a given table (see Table 3).

To calculate the velocity at the external nodes, the same reference wind velocity v_0 at the building reference altitude h_0 is used. Usually, the location and altitude of the weather station do not correspond to the location and altitude of the building reference. It is assumed that the wind velocity at height h_0 of the weather station is equal to the wind velocity at height h_0 at the building location [34].

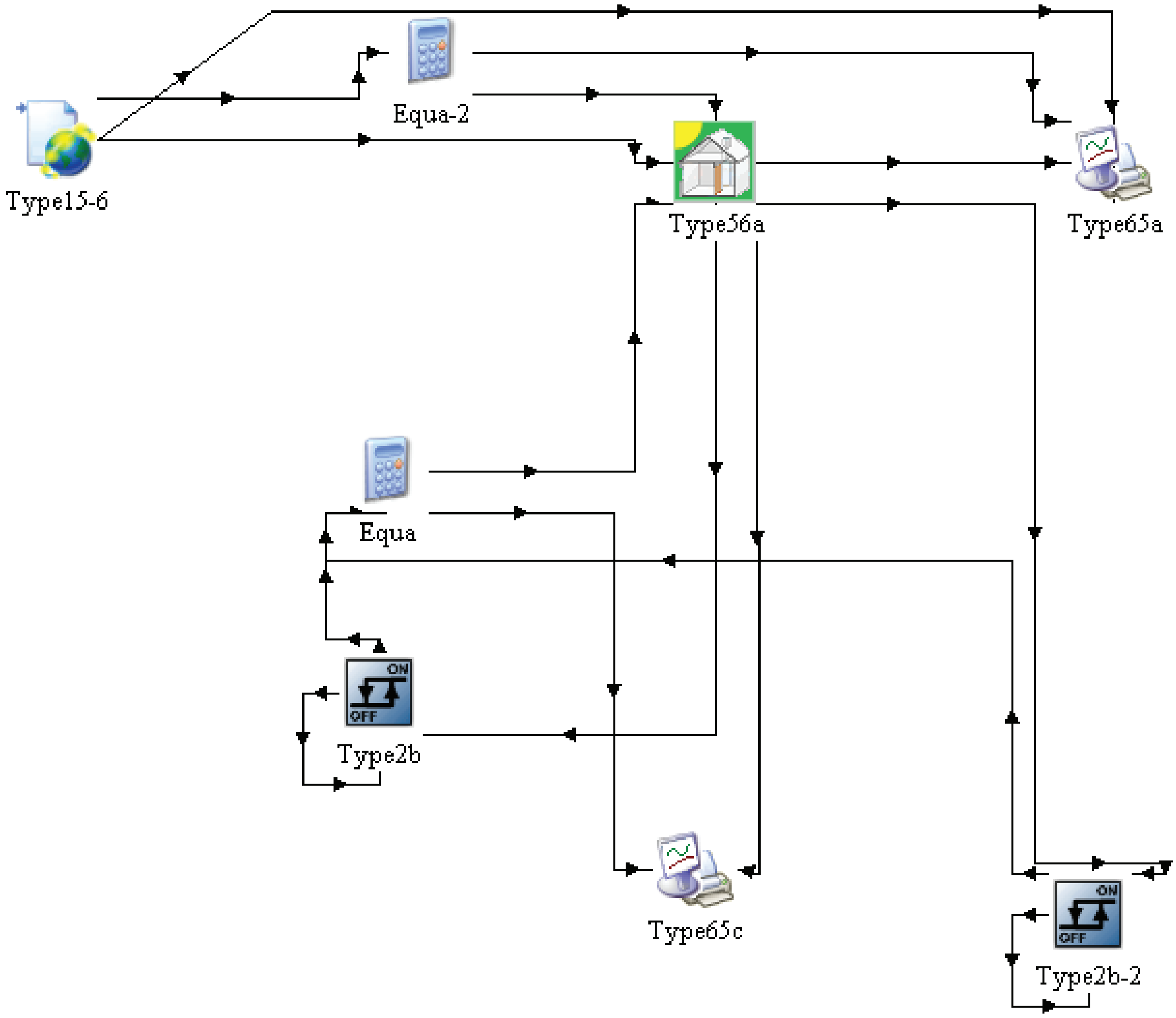

Figure 8. Schema of the TRNSYS system model.

Table 3. C_p values for each building façade

Wind direction angle	Wind pressure cofficients C_p			
External nodes	**0°**	**90°**	**180°**	**270°**
South	-0.5	-0.35	-0.26	-0.35
East	-0.6	0.4	-0.6	-0.3
West	-0.6	-0.3	-0.6	0.5
North_Roof	-0.45	-0.55	-0.6	-0.55
West_Roof	-0.45	-0.55	-0.6	-0.55
North	0.25	-0.35	-0.5	-0.35
East_Roof	-0.45	-0.55	-0.6	-0.55

RESULTS AND DISCUSSIONS

In this section, we first study the reduction in the nocturnal mechanical ventilation threshold. Then we carry out a series of modifications concerning the airflows injected into the different zones of the building according to the operating mode of the two valves A and B. Then, we will implement natural and mechanical ventilation strategies to reduce the indoor temperature of the academic building and make it thermally comfortable. Using the TRNSYS program, with its two components, TRNBUILD and TRNFLOW, different possible scenarios were tested.

The monitoring of the outdoor Arlon city temperature and the indoor temperature of the offices led to establishing the curve in Figure 9. The warmest week of the year was July 19-26 (4777-4945 hrs). The numerical study that follows will concern this week.

Preliminary Test - Effect of Mechanical Cooling on Offices Temperature

To highlight the response of the thermal simulation software, we performed a preliminary test by studying, at first, the effect of mechanical night cooling on the temperature of the offices of the building during the hottest period (19 to 26 July). The simulation results presented in Figure

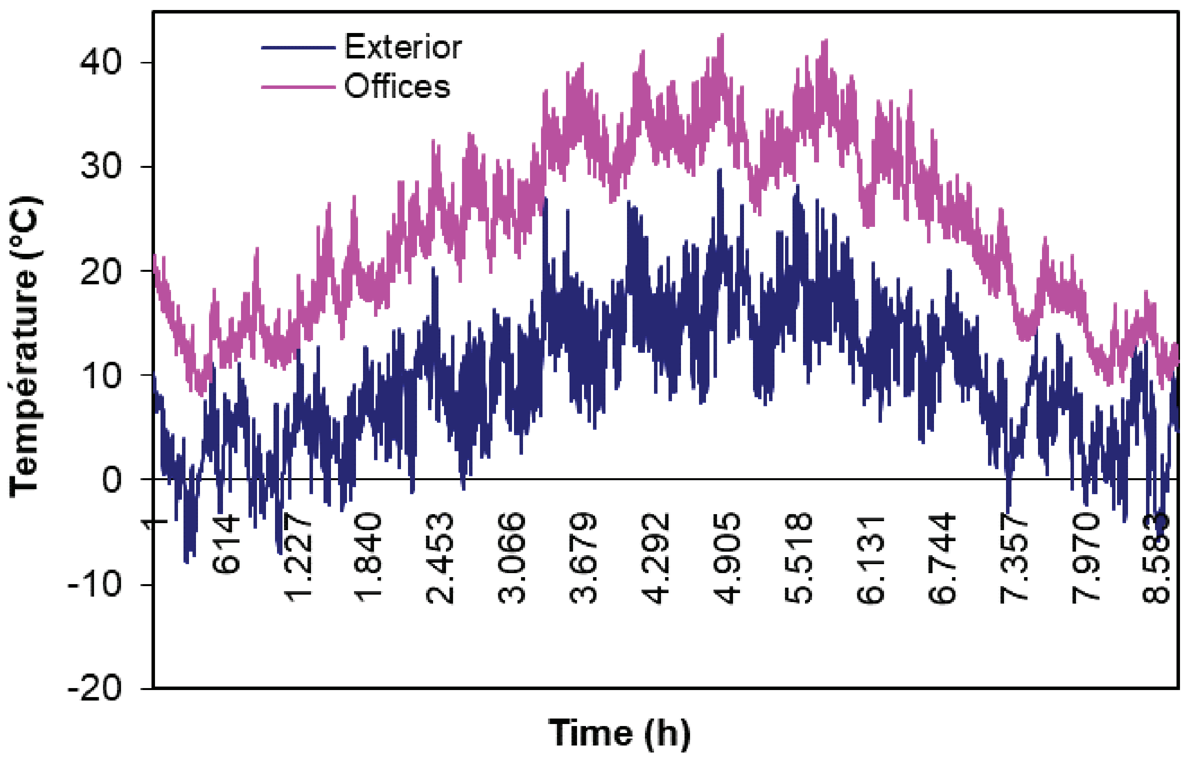

Figure 9. Annual variation of the outside temperature of Arlon city and that of the offices.

10 show a remarkable effect of ventilation on the temperature of offices in night-time operating mode. As it can be seen, there is an average decrease in temperatures of about 3°C compared to offices unventilated; this is due to the high ventilation speed and the supply of fresh air that comes from outside.

Analysis of Different Mechanical Cooling Strategies

The academic building has two installations to maintain a comfort temperature: the night cooling mechanical ventilation system, and the heat extractor. A sensitivity study of the operating mode of these two installations was established. As seen before, the ventilation in the building has a considerable effect only on the temperature of offices and auditoriums. While the heat extractor has a direct and considerable effect just on the temperature of the Hall_1.

In the following, we first study the reduction in the night ventilation threshold. Then we carry out a series of modifications concerning the airflows injected into the different zones of the building according to the closing of the two valves are realized.

Modification of ventilation and extraction thresholds

During the night, ventilation is activated when the temperature in the office exceeds 23°C and stops when it drops below 21°C. Decreasing the night ventilation threshold: 21°C for start-up and 19°C for shut-down (as proposed limit values) leads to the result given in Figure 11. The curve's evolution corresponds to a typical 72 h period of summer (23 and 26 July). It is observed that this modification does not have a remarkable effect on the temperature of the offices. For the three days considered, the temperature of the offices hardly ever dropped below 20°C, which means that the ventilation of the offices never stops. Energy consumption increases as a result.

The heat extractor which only influences the temperature of the Hall_1 has two operating modes: opening the two shutters as soon as the temperature of Hall_1 exceeds 25°C (fan off) and triggering the fan at a temperature of 27°C (shutters closed). The reduction in extraction thresholds was tested as follows:

- Shutters open from 21 to 23°C and the fan starts from 23°C;
- Shutters open from 19 to 21°C and the fan starts from 21°C.

It should be noted as described in Table 4, that the initial situation corresponds to the case where the mechanical ventilation system operates at low speed during occupied periods (8 a.m. to 6 p.m) or at high speed at night (6 p.m. to 8 a.m) with two valves A and B open.

According to Figure 12, there is generally a remarkable decrease in the temperature of Hall_1 if the threshold drops. With the extraction threshold of 23-21°C, there is a drop in temperature compared to the initial situation. The extraction threshold of 21-19°C, gives a better result than the previous one since it makes the Hall_1 temperature more comfortable. The heat extractor (installed under the roof of Hall_1) has then a direct and considerable effect on

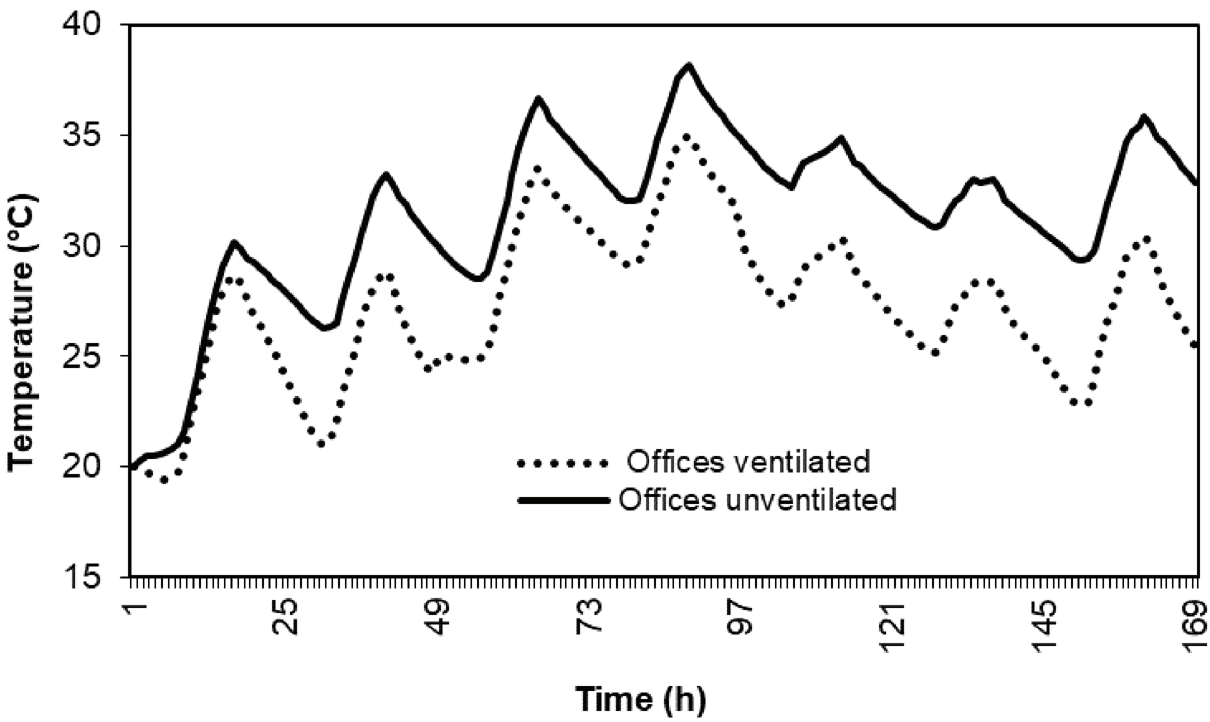

Figure 10. Effect of mechanical ventilation on the offices' temperature during the period of 19 to 26 July.

Table 4. Result of closing valves A and B on the office flow rate in the case of low and high-speed ventilation

	Flow rate (m^3/h) (Low-speed ventilation)		Flow rate (m^3/h) (High-speed ventilation)	
Configurations	**Initial situation***	**A and B closed**	**Initial situation***	**A and B closed**
Large auditorium	778.46	0	2289.6	0
Small auditorium	25.56	0	43.452	0
Offices	230.04	**1020.6**	562.32	**2918.6**

*Initial situation: The mechanical ventilation system operates at low speed during occupied periods (8 a.m. to 6 p.m) or at high speed at night (6 p.m. to 8 a.m) with two valves A and B open.

the temperature of Hall_1 because it facilitates the evacuation of hot air to the outside. We can also observe that the temperature evolution corresponding to the two thresholds is in the thermal comfort range and that the 21-19°C threshold is the most suitable. However, if we reason in terms of operating time, the threshold of 23-21°C is preferred, because its operating time is less than the threshold of 21-19°C, and therefore saves the energy stored in the batteries of the solar cabinet that powers the fan.

Modification of flow rates

The mechanical ventilation system can operate at low speed during occupied periods or at high speed at night [see Table 4]. We first analyze the influence of closing the two valves A and B in night mode. Secondly, we study the effect of closing these two valves all day. The results presented in Figure 13 show the effect of these changes on the offices and large auditorium temperature during the period from July 23 to 26.

The temperature of the large auditorium varies according to the closing of valves A and B. We notice according to Figure 13 (a) an increase in the temperature of the large auditorium compared to the initial situation if the two valves A and B are closed due to no air pulse. This increase is between 0.7 and 3.8°C if the valves are closed at night, and between 1.07 and 4.1°C if the valves are still closed. However, as we can observe in Figure 13 (b), a clear decrease in offices temperature was observed in both cases:

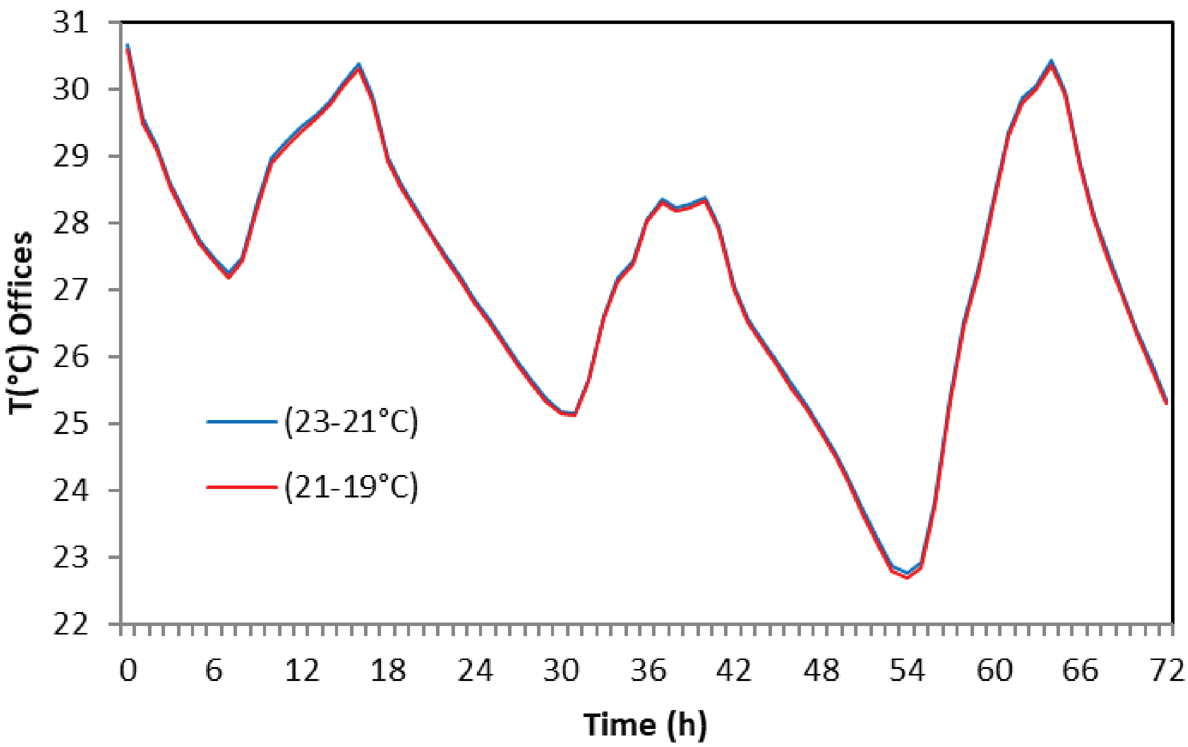

Figure 11. Effect of varying ventilation threshold on the offices' temperature.

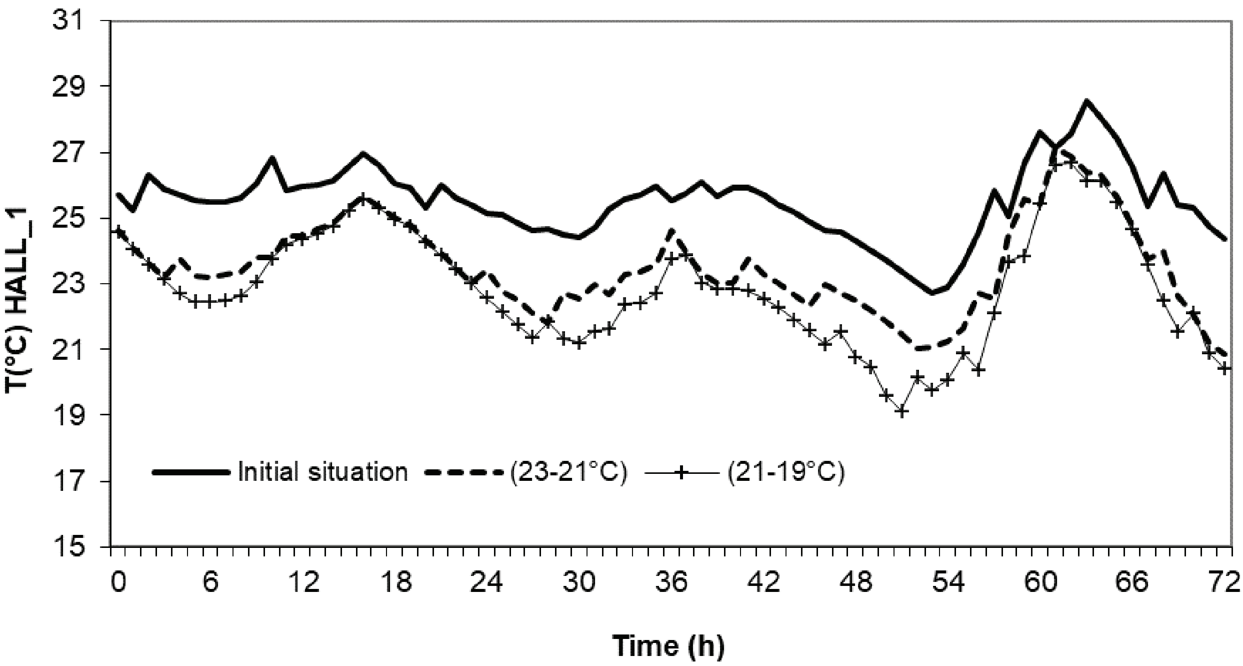

Figure 12. Effect of varying extraction threshold on the Hall_1 temperature.

with the permanent closure of valves A and B or single closure at night. This drop in temperature of approximately 2.5°C compared to the initial situation is accompanied by a variation in temperature which is less comfortable during working hours (8 a.m. to 6 p.m.). This drop in temperature in the offices is due to the increase in airflow which goes from 230.04 to 1020.6 m^3/h during the day and from 562.32 to 2918.6 m^3 / h at night, due to the closure of the two valves A and B. This closing of the valves prevents the importation of fresh air into the large auditorium, which goes from 778.46 to 0 m^3/h during the day and from 2289.6 to 0 m^3/h at night, which explains the increase in its temperature. The same observation for the small auditorium.

Modeling of Natural Ventilation Circuit in the Building

Airflows in the building are calculated with a multi-zone airflow model. Such a model idealizes the building as a network of nodes and air circulation links between them (Figures 14 and 15). Nodes represent rooms and building surroundings. Links between nodes represent openings, doors, cracks, window seals, as well as ventilation components such as air inlets, outlets, ducts, and fans. So, the wind direction is done through links that represent the openings between the zones (nodes).

Figure 14 gives the model of the natural ventilation circuit on the ground floor and upstairs, while Figure 15 shows a model of a mechanical ventilation network in the building. Auxiliary nodes are linked by airtight conduits, shaping the air paths between the outer and inner nodes.

From the previous paragraph, it was found that the extraction threshold temperature 21-19°C (Figure 12) is the right choice to keep the temperature of Hall_1 lower, and to make the building temperature more comfortable, when natural ventilation circuits are considered. One can exploit the relatively low temperature of the large auditorium. Indeed, the auditoriums are the coolest zones of the building, and the temperature is perfectly regulated by the mass wall. The western facade of the academic building has an emergency door allowing a possible rapid evacuation of the large auditorium. If this door remains open, and the main entrance to the building is closed, we can imagine the natural ventilation circuit represented by circuit 1 in Figure 16. We can also consider opening the office doors and also a window to the East Roof (Circuit 2). The east facade of the academic building has an emergency door allowing a possible rapid evacuation of the small auditorium. If this door remains open with the opening of the office doors, and the main entrance to the building is closed, we can imagine the ventilation circuit 3 shown in Figure 16.

In the mechanical ventilation simulated on TRNFLOW we have defined the characteristics of the fans, with the different types of ducts that create the pressure drops. The airflow is calculated automatically while with TRNBUILD the airflows are measured at the supply point, and then entered into the software. Figure 17 represents a comparison of natural and mechanical ventilation and its effects on the temperature of areas in the building. It is about comparing the mechanical ventilation imposed by the 21-19°C threshold

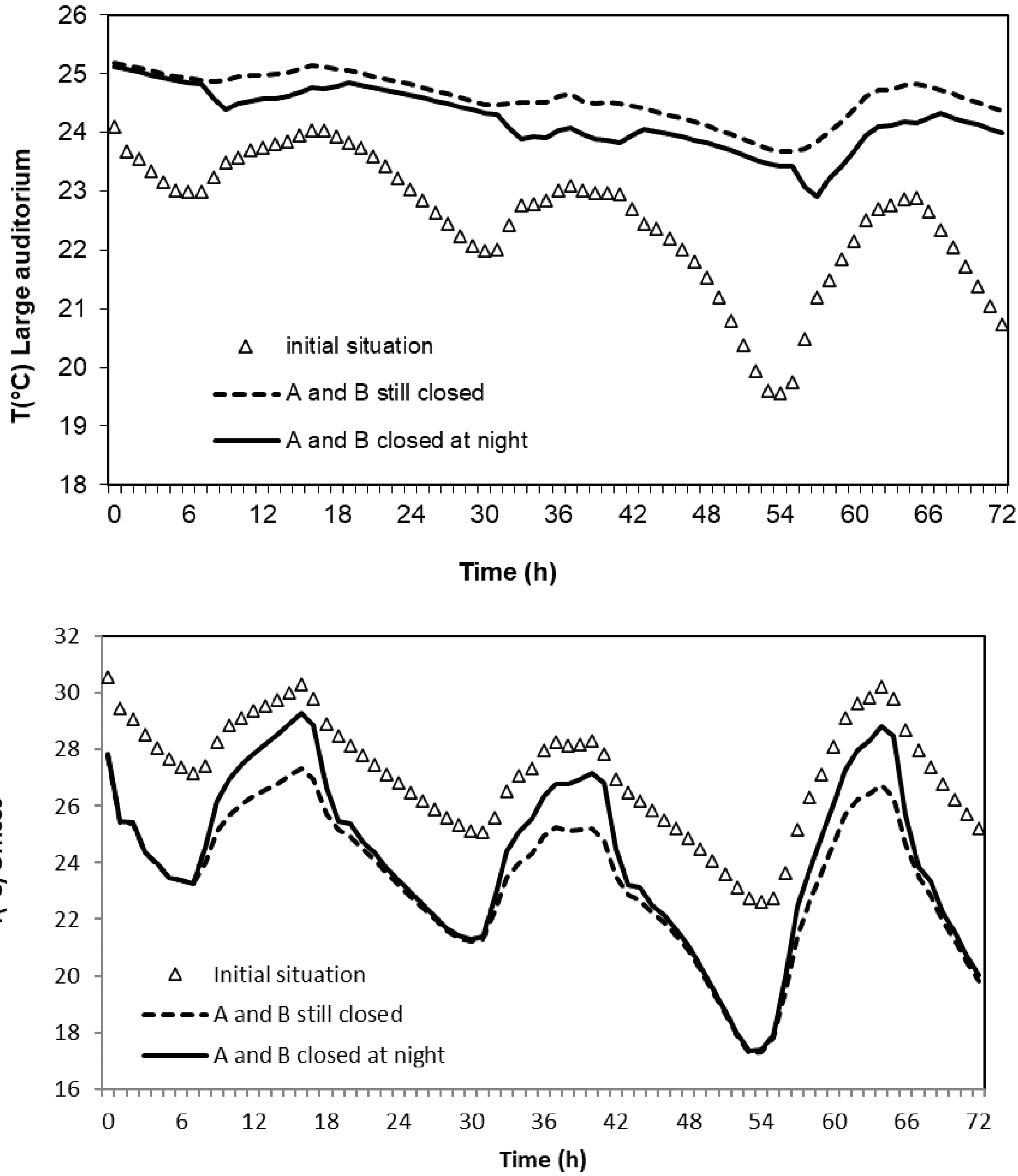

Figure 13. Effect of varying flow rate (due to the operating mode of the two valves A and B) in (a) the large auditorium, and (b) the offices - Period from July 23 to 26.

with natural ventilation which is defined by three circuits and its effects on the temperature of different building areas. In the offices (Figure 17 (a)), natural ventilation with circuit 2 and circuit 3 lowers the temperature by 4°C compared to mechanical ventilation. Therefore, circuits 2 and 3 give a temperature variation within the comfort range. In the large auditorium (Figure 17 (b)), circuit 2 lowers the temperature remarkably, followed by mechanical ventilation. The two methods make the auditorium very comfortable thermally compared to circuit 1. Hall 1 (Figure 17

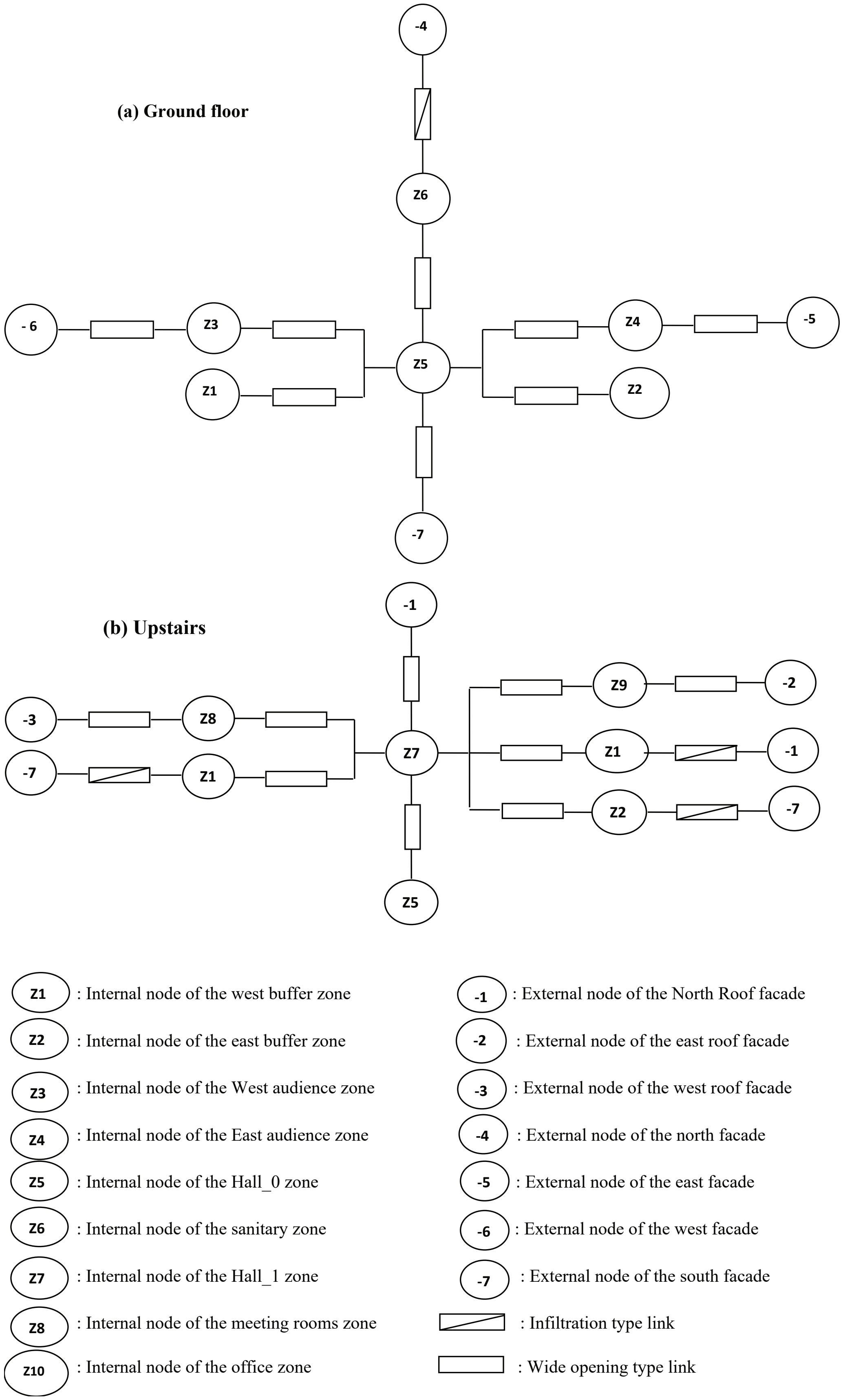

Figure 14. Simple model of the natural ventilation circuit, (a) ground floor, (b) upstairs.

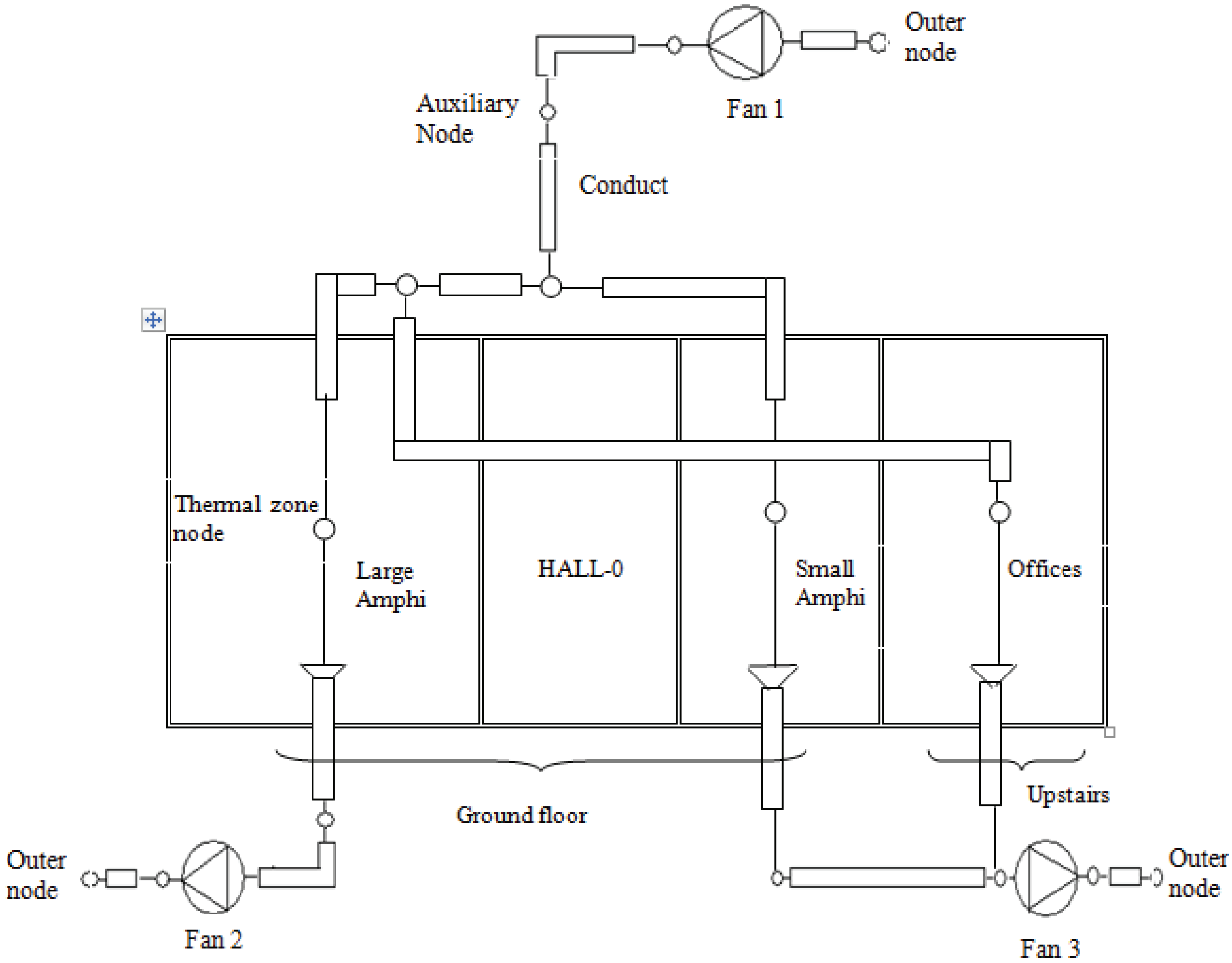

Figure 15. Simple model of the mechanical ventilation circuit that supplies the offices and the two auditoriums.

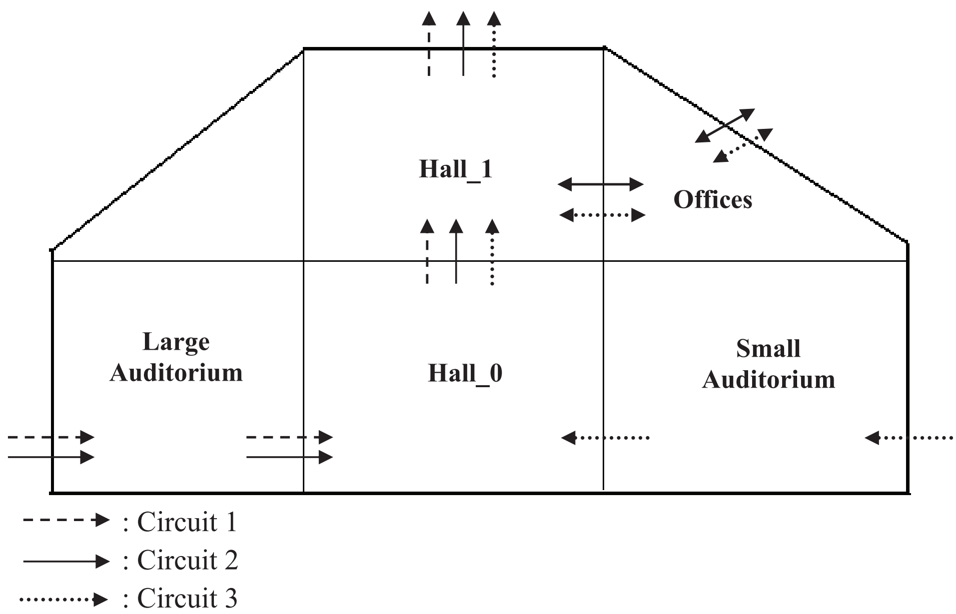

Figure 16. Natural ventilation circuits.

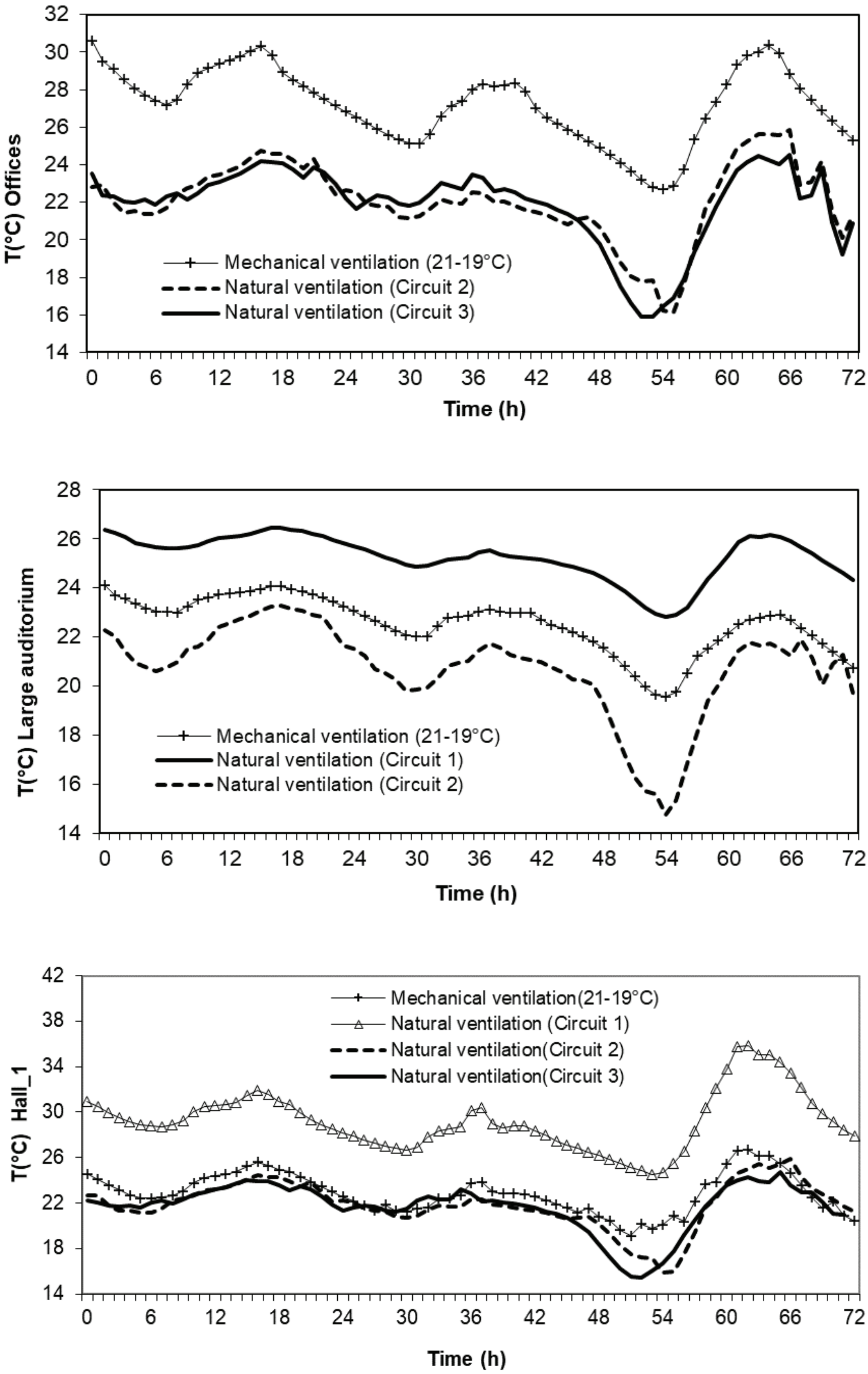

Figure 17. Comparison of natural and mechanical ventilation and its effects on the temperature in (a) the offices, (b) the large auditorium, and (c) the Hall_1.

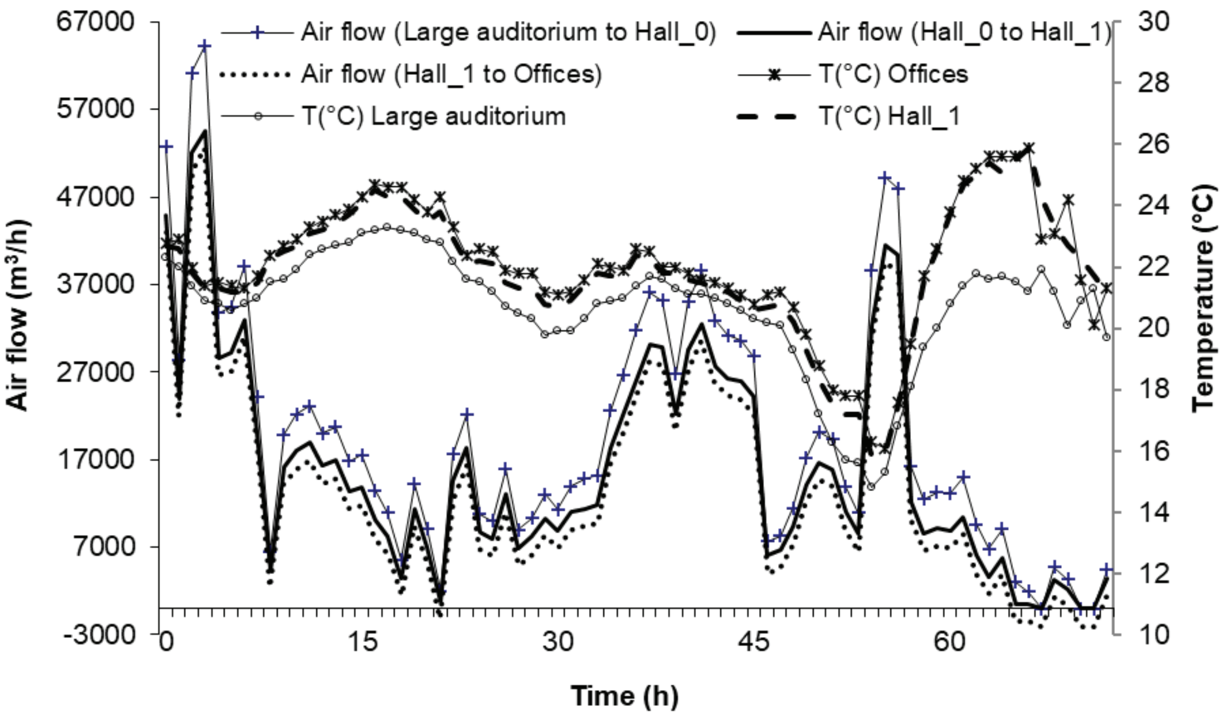

Figure 18. Temperatures and air flows values measured with natural ventilation circuit 2 (between large auditorium, Hall_0, Hall_1, and Offices), period of 23 to 26 July.

(c)) is a zone of interaction of the three circuits. In terms of thermal comfort, mechanical ventilation, circuit 2 and circuit 3 give good results compared to circuit 1.

The simulation on TRNFLOW allows an automatic calculation of the airflow rates between the different openings that separate the zones of a planned circuit. We take the example of circuit 2 of natural ventilation because it is the optimal circuit that makes the different areas very comfortable. Then we established the variation in flow rates between the large auditorium and hall_0, hall_0 and hall_1, and between hall_1 and the offices. According to Figure 18, in general, the flow rates are relatively high, and if we compare the temperature variation with the flow rate, we see that the temperatures are high when the circulated air flow rate is low.

CONCLUSION

In this study case, the aim was to propose ventilation strategies in order to decrease in overheating periods the indoor temperature of an academic building considered a passive solar structure. Using TRNSYS software, with its two components, TRNBUILD and TRNFLOW, different possible scenarios were tested and a comparison between mechanical and natural ventilation was highlighted.

Thanks to the proposed ventilation scenarios, we have shown that we can, thanks to natural ventilation, renew the air inside the different areas of the building and maintain a comfort temperature during overheating periods.

Indeed, in the offices, natural ventilation with circuits 2 and 3 lowers the temperature by 4°C compared to mechanical ventilation. Therefore, circuits 2 and 3 give a temperature variation within the comfort range. In the large auditorium, circuit 2 decreases temperature remarkably compared to mechanical ventilation.

Then, natural ventilation with modeling of air evacuation through office windows and also through the heat extractor was conducted to improve the thermal comfort. It can an alternative to mechanical ventilation if we consider appropriate scenarios. This will strongly reduce energy consumption.

NOMENCLATURE

P	Power density (W/m^2),
ΔP	Wind pressure (Pa),
ρ	Density (kg/m^3),
v	Local wind velocity at a specified reference height (m/s),
C_p	Wind pressure coefficient,
TRNSYS	Transient System Simulation Tool
HE	Heating Exchangers,
H	Humidifier
IEA	International Energy Agency
AIVC	Air Infiltration and Ventilation Centre

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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