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Feasibility of Using Wood Chips to Regulate Relative Humidity Inside a Building: A Numerical Study

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Abstract: The use of bio-based materials in buildings has become more and more significant last years. In most of the cases, their health properties and natural provenance have made them a great solution to face global climate warming and the new policies to reduce building energy consumption. In many thermal problems, bio-based materials can allow to optimize the building thermal behavior according to its energy consumption and inside comfort conditions. So it is when they are used as an insulation material in the building. However, it is not the case in this paper. In fact, the bio-based matter is rather used as a desiccant wheel to control air conditioning inside the building.

The aim of this paper is to numerically verify if it is possible to use a bed of wood chips as a hygroscopic material (or a desiccant matter) in order to modify the relative humidity inside the building in Reunion Island and so improve thermal comfort. A simple model of heat and mass transfer between a bed of wood chips and building inside air has been set up and implemented into a validated building simulation code named ISOLAB.

Numerical simulations were set up for the four climate zones of the island regulations and a focus has been made on the low altitude one (with high, solar irradiation, temperature and relative humidity).

Simulation results give the thermal behavior of the building particularly the temperature and relative humidity of inside air temperature, and temperature and moisture content of wood chips. The obtained results lead to determine if the wood chips bed is suitable for the reference building and to verify its technical feasibility (wood species, size of the bed, integration to the building, etc.). The results show that the use of a WCB help to decrease the building inside air temperature and water content up to 10°C less and 11.6 $g.kg^{-1}$ less. These are the ways to improve inside comfort conditions.

Indeed, comfort analysis have shown the possibility to significantly increase building users' thermal comfort when coupled with a fan and natural ventilation, like the regulation needs for low altitude climate. In this case, a gain of 68% of year time is achieved for a building equipped with WCB system compared to one without it (6308 hours of comfort over a year with the WCB against 350 hours without WCB). So the WCB seems to be able to help reducing cooling loads in tropical climate conditions.

Keywords: Wood chips bed; building inside comfort; bio-based material; desiccant; relative humidity; temperature; building thermal modelling

Nomenclature

C_{pa}	Specific heat capacity of air ($J.kg^{-1}.K^{-1}$)
C_{pl}	Specific heat capacity of liquid water ($J.kg^{-1}.K^{-1}$)

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C_{ps}	Specific heat capacity of dry wood chips (J.kg^{-1}.K^{-1})
C_{pv}	Specific heat capacity of water vapor (J.kg^{-1}.K^{-1})
CMV	Controlled mechanical ventilation
dt	Time step (s)
dz	Space step (m)
F_m	Water rate exchange between air and wood chips in the bed (kg$_{water}$.m^{-2}.s^{-1})
h	Convective exchange coefficient in wood chips bed (W.m^{-2}.K^{-}1)
$h_{cv,p}$	Convective exchange coefficient inside facing of the wall numbered “p”
$\dot{m}_{z,in}$	Air flow rate due to CMV from a building zone (z) to a considered one (in) or to outside
$\dot{m}_{wcb,in}$	Air flow rate due from a wood chips bed to a building zone (in)
N_p	Number of walls of a building zone
N_z	Number of building zones
N_{wcb}	Number of wood chips bed in a building zone
G	Energy appliance charges (W)
P	Building persons charges (W)
Q_{cmv}	Air rate from outside to inside the building
Q_{wcb}	Air rate from outside to inside the building through the wood chips bed
S_p	Surface area of the wall numbered “p”
$T_{a,in}$	Temperature of air inside the building (K)
$T_{a,out}$	Temperature of air outside the building (K)
T_b	Temperature of wood chips (K)
T_p	Temperature of inside surface of building wall numbered “p” (K)
$T_{\infty,in}$	Temperature of air entering the wood chips bed (K)
$T_{\infty,out}$	Temperature of air outgoing the wood chips bed (K)
T_{∞}	Temperature of wood chips bed air (K)
U_{∞}	Air velocity in the wood chips bed (m.s^{-1})
$V_{a,in}$	Air volume of the building (m^{3})
$W_{a,in}$	Building inside air water content or absolute humidity (kg$_{water}$.kg$^{-1}{}_{air}$)
$W_{a,out}$	Outside air water content or absolute humidity (kg$_{water}$.kg$^{-1}{}_{air}$)
W_b	Water content of wood chips (g$_{water}$.kg$^{-1}{}_{wood\ chips}$)
W_{∞}	Water content of wood chips bed air (kg$_{water}$.kg$^{-1}{}_{air}$)
$\dot{W}_G$	Water rate due to appliances (kg$_{water}$.s^{-1})
$\dot{W}_P$	Water rate due to persons (kg$_{water}$.s^{-1})
WCB	Wood chips bed
α_s	Compacity of dry wood chips (m^{-1})
α	Compacity of wet wood chips (m^{-1})
ΔH_v	Latent heat of water (J.kg^{-1})
ε	Proportion of empty space in wood chips
λ	Thermal conductivity (W.m^{-1}.K^{-1})
ρ_a	Density of air (kg.m^{-3})
$\rho^{b}{}_{s}$	Density of dry wood chips (kg.m^{-3})

1 Introduction

Other works have shown that wood chips can help to reduce AC loads, for example in office building in Asia as an insulation of the roof [1-5]. The work presented in this paper is also conducted as a proof of concept study. The main objective is to verify the possibility of using a wood chips bed (WCB) to regulate relative humidity inside the building, as it can be done with desiccant wheels [6-10]. Indeed, such systems can help reducing the building energy consumption by reducing the building latent loads. To do so, the desiccant systems (desiccant wheels or others) modify the air injected in the building through the air conditioning system. The air relative humidity is modified when the air passes through the desiccant system.

This proof of concept study was done by using a validated building simulation code (named ISOLAB [11]) in which a simple model of heat and mass transfers between wood chips and the building has been implemented.

This paper is first described the building, as well as the parameters of the WCB and the meteorological data. Furthermore, the integration of the WCB into the building is proposed with its couplings to the building ventilation system. Secondly, a description of the model of WCB, and particularly its coupling with the building simulation code are presented. Finally, numerical results are shown and discussed.

2 Problem Description

To run numerical simulations three steps are needed: description of the environment (meteorological data), building description and wood chips bed description and operation.

2.1 Environmental Conditions

In La Réunion Island, there are two main issues with regard to the energy behavior of buildings: one related to air conditioning in summer for low-altitude buildings (< 600 m) and another related to heating in winter for high-altitude ones (> 600 m).

To properly solve these issues, local thermal regulation (RTAADOM [12]) plans to divide the island in four climatic zones as it can be seen in Fig. 1. The meteorological data sets that have been used for numerical simulations are also indicated in Fig. 1 by the four numbers. This allowed to simulate the building in the four representative environments of La Réunion for a representative year (based on past 50 years).

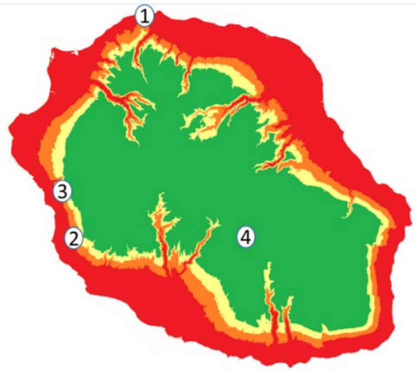

Figure 1: Climate zoning of the thermal regulation in La Réunion island and location of the meteorological data [516]

Altitudes: 0-400m, 400–600m, 600–800m, >800m

Town: 1 Saint-Denis, 2 Piton Saint-Leu, 3 Colimaçons, 4 Plaine des Cafres

2.2 Building Description

To run simulations, the building simulation code also needs the building description. A representative residential building has been described by a local committee composed of industrials, social landlords, building builders and thermal insulation craftsmen [13].

5 persons are in this residential building (2 adults and 3 children). It is composed of 4 chambers, a living room (comprising the kitchen), a bathroom and a toilet. Its surface area is about 115 m^2.

Its vertical walls are made of woods and all properties except thermal insulation are the same as the wall numbered "P8" and named "Wood frame walls with mineral wool insulation" in [13]. The systems that produce heat in the building have been taken into account by the simulation code through a file comprising meteorological data and the energy appliances power used each meteorological time step.

Its roof is a traditional one in La Réunion consisting of a 0.75 mm galvanized steel sheet, a 100 mm polystyrene insulation and a 13 mm plasterboard. Those parameters are considered in the building modelling [11].

2.3 Wood Chips Bed Description

It is considered as a fixed cluster of wood chips contained in the wall in replacement of other insulation materials. In the case of wood frame walls, it has to be placed between the stiffening structure and the interior cladding consisting of wooden strips on all the length of the walls (see Fig. 2). The vertical walls are 37 m length and 2.5 m height. It was assumed that 35 m of walls can contain the wood chips bed (after deducting the thickness of the frame). So, the wood chips bed was 35 m length, 2.5 m height and 0.12 m width. The proposed wood chips come from a wood species available on the island (cryptomeria japonica) and have a thermal conductivity of about 0.05 $W.m^{-1}.K^{-1}$. Wood chips have a compacity of 2 m^{-1}, a density of 400 $kg.m^{-3}$, a proportion of empty space of 0.7. The sizes of the chips have a diameter ranging from 2 to 20 mm (see Fig. 3).

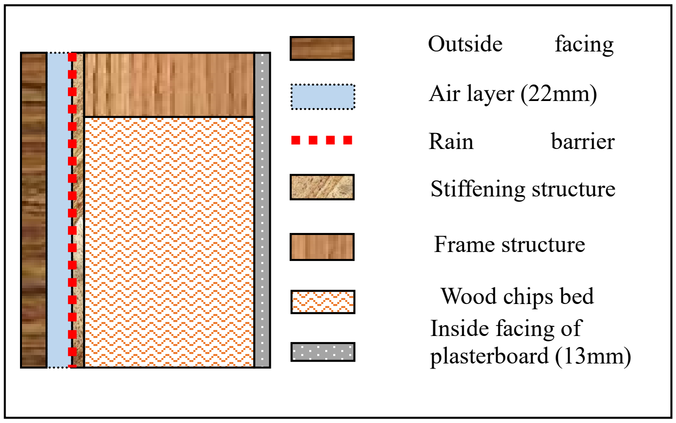

Figure 2: Sectional view of the building vertical wall: integration of wood chips bed into it

To correctly run, and to impact the building thermal behavior and its inside comfort conditions, the WCB has to be connected to the inside of the building. It is proposed to connect it to the air controlled mechanical ventilation system (CMV). In residential buildings, in La Réunion, the thermal regulation does not impose air-conditioning but requires a minimum airflow rate through the use of CMV. So, the outside air will pass through the WCB before through the CMV and enter inside the building. This air gives the drying conditions (temperature and moisture content). The WCB will change the characteristics of the incoming air and so the inside comfort conditions.

Figure 3 : Picture of the wood chips

2.4 Model Description

The building simulation code ISOLAB can simulate the thermal behavior of a building according to its environmental conditions and its use. It considers the dimensions of the building, the thermal properties of the wall, its occupation and the air-conditioning system when it occurs, etc. Numerical simulation results are the building temperature field, the relative humidity and water content ones, the one of heat flux transfer through walls and the ones of particular systems (photovoltaic panels, heat production system, etc.). It has been continually improved since its creation in 2002 with works on thermal modeling of different types of complex walls: photovoltaic panels [14], phase change materials [15] or vegetalized walls [16].

This time, the building simulation code has been improved by implementing a simple model of heat and mass transfer in WCB and coupling it to the one of the building.

2.4.1 Heat and mass transfer of wood chips bed

The model relies on a simple balance of heat and mass transfers between the WCB and air that is forced through it as the works of [17-19]. It leads to 4 balance equations:

- 2 for the mass balance between the wood chips bed and the air that passes through it,
- 2 for the heat balance between the wood chips bed and the air that passes through it (wood chips bed air),

<u>Mass balance of the wood chips bed:</u>

$$\frac{\boldsymbol{\rho_s^b}}{\boldsymbol{\alpha_s}}\frac{\partial \boldsymbol{W_b}}{\partial \boldsymbol{t}} = -\boldsymbol{F_m} \tag{1}$$

<u>Mass balance of the wood chips bed air:</u>

$$\frac{\boldsymbol{\varepsilon}}{\boldsymbol{1-\varepsilon}}\frac{\boldsymbol{\rho_a}}{\boldsymbol{\alpha}}\boldsymbol{U_\infty}\frac{\partial \boldsymbol{W_\infty}}{\partial \boldsymbol{z}} = \boldsymbol{F_m} \tag{2}$$

<u>Heat balance of the wood chips bed:</u>

$$\frac{\boldsymbol{\rho_s^b}}{\boldsymbol{\alpha}}(\boldsymbol{Cp_s} + \boldsymbol{W_b} * \boldsymbol{Cp_l})\frac{\partial \boldsymbol{T_b}}{\partial \boldsymbol{t}} = \boldsymbol{h}(\boldsymbol{T_\infty} - \boldsymbol{T_b}) - \Delta \boldsymbol{H_v}\boldsymbol{F_m} \tag{3}$$

<u>Heat balance of the wood chips bed:</u>

$$\begin{aligned}\frac{\boldsymbol{\varepsilon}}{\boldsymbol{1-\varepsilon}}\frac{\boldsymbol{\rho_a}}{\boldsymbol{\alpha}}(\boldsymbol{Cp_a} + \boldsymbol{W_\infty} * \boldsymbol{Cp_v})\boldsymbol{U_\infty}\frac{\partial \boldsymbol{T_\infty}}{\partial \boldsymbol{z}} \\ = -\boldsymbol{h}(\boldsymbol{T_\infty} - \boldsymbol{T_b}) + \boldsymbol{F_m}\boldsymbol{Cp_v}(\boldsymbol{T_b} - \boldsymbol{T_\infty})\end{aligned} \tag{4}$$

2.4.2 Coupling of the Building Model with the Wood Chips Bed One

The coupling between the two models is set up through the heat and mass balances of building inside air [11] and the modification of spatial boundary conditions of the WCB model.

Heat balance of building inside air for one zone:

$$\rho_a . C_{pa} . V_{a,in} . \frac{T_{a,in}}{dt} = \sum_{p=1}^{N_p} h_{cv,p} . S_p \left(T_p^{t+\Delta t} - T_{a,in}^{t+\Delta t}\right) + G + P + Q_{cmv} . \rho_a . C_{pa} . \left(T_{a,out}^{t+\Delta t} - T_{a,in}^{t+\Delta t}\right) - \sum_{b=1}^{N_{wcb}} \dot{m}_{wcb,in} . C_{pa} . \left(T_{\infty,out}^{t+\Delta t} - T_{a,in}^{t+\Delta t}\right) \quad (5)$$

This heat balance lead to take into account the air injected inside a building zone through the WCB and that take the place of the same amount of air ejected of it (through the last two terms of the equation).

Water mass balance of building inside air for one zone:

$$\rho_a . C_{pa} . V_{a,in} . \frac{\partial W_{a,in}}{\partial t} = \sum_{z=1}^{N_z} \dot{m}_{z,in} . W_z - \sum_{z=1}^{N_z} \dot{m}_{z,in} . W_{in} + \dot{W}_G + \dot{W}_P + \sum_{wcb=1}^{N_{wcb}} \dot{m}_{wcb,in} . W_{\infty,out} - \sum_{wcb=1}^{N_{wcb}} \dot{m}_{wcb,in} . W_{a,in} \quad (6)$$

As for the previous heat balance, the same amount of water mass that is injected to the zone is also ejected from it (through the last two terms of the equation).

3 Results and Discussion

Numerical simulation results have been analyzed according to three points of view: the impact of WCB on inside building thermal and water content behavior and its impact on building inside comfort. The figures focus on the environment of the town of Gillot (see Fig. 1) which is representative of hot and humid climate. The results are comparable in other areas.

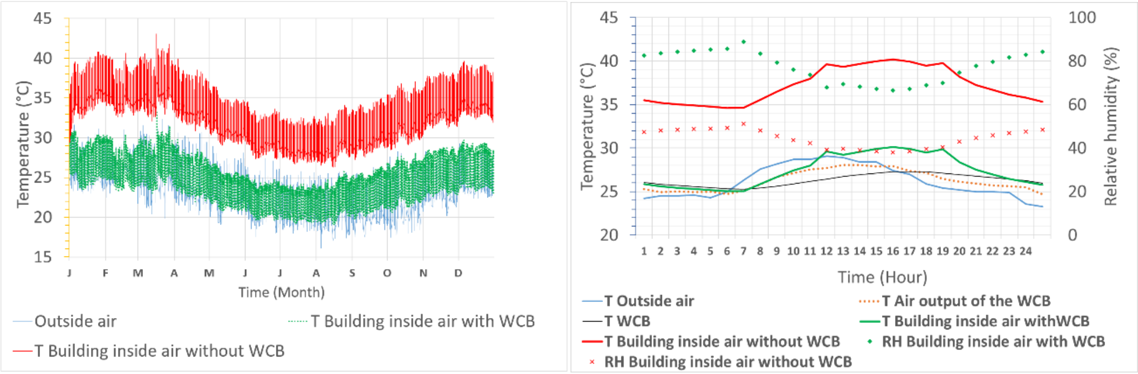

Figure 4: Building thermal field behavior for a year (left) and in February (right)

3.1 Water and Temperature Field Behavior

3.1.1 Impact on Building Inside Thermal Field

Numerical results show that the use of a WCB lead to a diminution of inside air temperature all the yearlong compared to the building without it (see Fig. 4). For example, in February, the diminution of temperature is about 10°C (see Fig. 4).

This can be explained in Fig. 4, with a focus in February. It is shown that as the wood chips bed have a less temperature than the outside air after 7 am, it cools the air coming from outside before injecting it into the building. It is possible because the wood chips bed has been cooled during the night with the colder outside air. So, it reduces the building inside air temperature as an air conditioning system could have done.

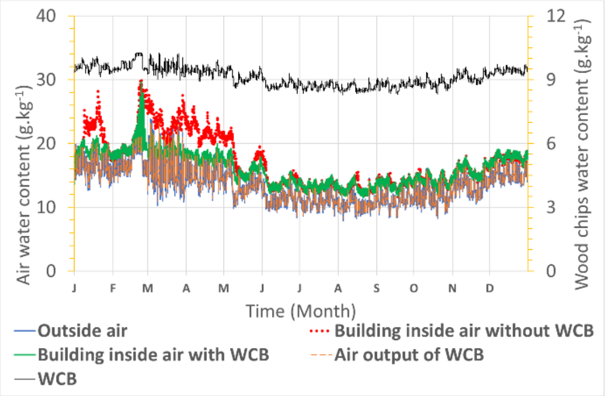

Figure 5: Building inside water contents behavior along a year

3.1.2 Impact on Building Inside Water Contents Field

In Fig. 5, the WCB reduces the water entering in the building with the CMV system at particular times of the year. For example, in February, the diminution of water content is up to 8 g.kg^{-1} (see Fig. 6). Unlike the temperature, water content of building inside air is not reduced all the yearlong. It is the case at the end of February. In Fig. 6, it is shown that in these conditions the wood chips bed can absorb a part of the water coming from the outside when the outside air relative humidity increases. So, the wood chips bed reduces the amount of water transferred to the inside compared to a building without one, from about 27 g.kg^{-1} to 22 g.kg^{-1} during a day.

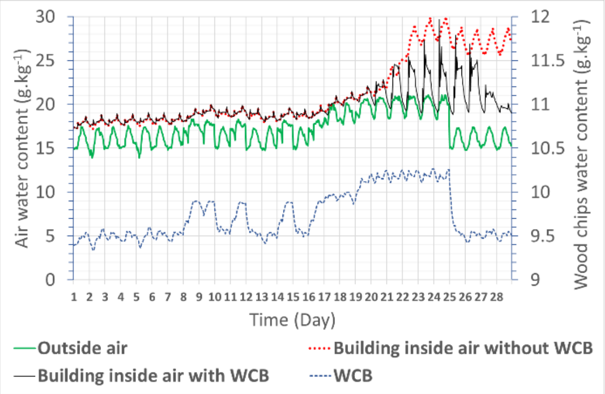

Figure 6: Water contents behavior in February

By looking in February weather data (see Fig. 7), we can see that during the rise of outside air water content, the wind speed and global solar irradiation were lower. However, these particular conditions are not all occurring each time the outside air water content was increasing. We concluded that other parameters can lead to this increase locally (near the weather data collector) like rain, plant cutting or spray.

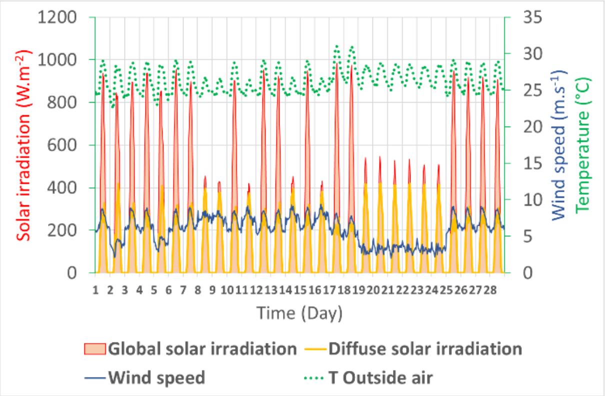

Figure 7: February weather data.

3.1.3 A summary with Some Numbers

Tabs. 2, 3 and 4 present a summary of the results obtained with the simulations. It shows the differences between the inside air of the buildings (with and without WCB) and some statistical data. These tables show that WCB can improve hygrothermal conditions inside the building by significantly reducing both temperature and water content of building inside air.

Table 2: Difference between the inside air temperatures of the building without WCB and the one with (°C)

Altitude (m)	Standard deviation	Average deviation	Maximum difference
0-400	5.31	4.53	10.52
400-600	5.22	4.32	9.44
600-800	4.88	4.01	8.81
>800	4.33	3.57	7.18

Concerning the impact of the WCB on the building inside air temperature, Tab. 2 shows that WCB is decreasing it from about 7.18°C above 800 m to 10.52°C under 400 m. This results are similar to some typical insulation materials used in the building like 8cm of rockwool or a radiant barrier that can lead to a decrease of respectively 7°C and 10°C in same conditions [11].

Table 3: Difference between the inside air water contents of the building without WCB and the one with ($g.kg^{-1}$)

Altitude (m)	Standard deviation	Average deviation	Maximum difference
0-400	3.45	2.84	8.86
400-600	3.52	2.80	13.06
600-800	3.18	2.57	17.81
>800	2.47	2.04	6.25

Depends on climate zoning, the use of WCB can also lead a decrease of water content up to 17.81 $g.kg^{-1}$ (Tab. 3) and an increase up to 45.3% of the inside air relative humidity (Tab. 4). We assumed that the wood chips drying lead to an increase of water content inside the building and so the increase of relative humidity. These reduction of temperature and water content lead to study the impact of the WCB on thermal inside comfort. Indeed, such impacts can lead to better comfort and that the results presented below.

Table 4: Difference between the inside air relative humidity of the building with WCB and the one without (%)

Altitude (m)	Standard deviation	Average deviation	Max difference
0-400	17.59	15.36	45.3
400-600	13.83	11.39	45.29
600-800	13.35	11.12	43.72
> 800	11.18	9.12	23.52

3.2 Impact on Inside Comfort Conditions

We would like to study the link between the use of the WCB device and the thermal comfort conditions. To illustrate this, we will focus on a recurring problem in the coastal areas of Reunion Island (zone 1): ensuring summer comfort conditions in a hot and humid climate. Two configurations are put in parallel: one building equipped with the WCB device and another, without. The analysis will be based on an ideal tool for the climate configuration studied: the Givoni diagram [11,14].

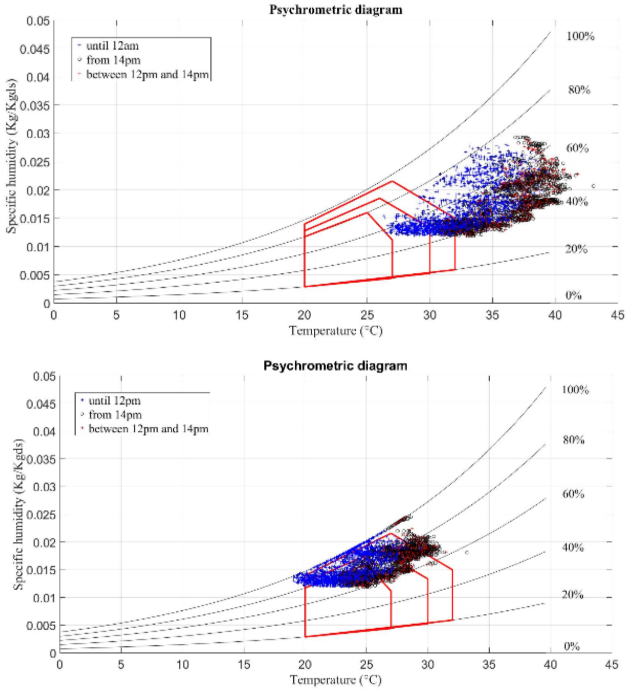

Figure 8: Psychrometric diagram of Givoni zone 1 (up without WCB, below with WCB)

Baruch Givoni [20] established a link between the thermo-hygrometric conditions within a room and the level of thermal comfort for different ventilation scenarios. These elements are placed on a psychrometric diagram in which he evaluates the physiological requirements of comfort. On the basis of the main environmental parameters (temperatures, relative humidity and air speed), Givoni analyses comfort situations by taking into account physiological evapotranspiration phenomena for a sedentary activity (1.2 met) and a summer clothing (0.5 clo). Three comfort zones are identified and associated with 3 different air speeds from 0 to 1 m.s^{-1}. The results obtained make it possible to quantify the percentage of points in each zone, and thus to deduce the number of hours of thermal discomfort over the period studied.

Simulations were carried out throughout the year (8760 h) for a building (T5 type) with a high user presence (family of 5 people) with almost constant presence (scenario described in the insulation guide [13]).

Table 5: Analysis of psychrometric diagram of Givoni zone 1

THERMAL COMFORT ZONE OF GIVONI			WITH WCB	WITHOUT WCB	DELTA
0 M/S	20°C-27°C 20%-80%	Percentage of time in thermal comfort	0%	0%	0%
		Time hours in thermal comfort	0 h	0 h	0 h
0.5 M/S	20°C-30°C 20%-90%	Percentage of time in thermal comfort	14%	0%	14%
		Time hours in thermal comfort	1227 h	0 h	1127 h
1 M/S	20°C-32°C 20%-95%	Percentage of time in thermal comfort	72%	4%	68%
		Time hours in thermal comfort	6308 h	350 h	5958 h
USE OF AN ACTIVE COOLING SYSTEM	> 32°C	Hours required	2452 h	8410 h	5958 h

On the psychrometric diagrams (see Fig. 8), we can see that the mass of the points changes both in temperature and relative humidity according to the presence or not of WCB. The absence of the device shows that indoor thermal conditions are characterized by temperatures above 32°C and an average relative humidity of 55 ± 15%. The presence of WCB allows the indoor temperature to be regulated with a variation range between 24°C and 31°C for an average relative humidity close to 80%. By looking at the moisture content of the air, we can see that the device allows to pass from 20 ± 5 g/kg dry air to 17 ± 3 g/kg dry air. The moisture content has therefore decreased by more than 15%.

The overall shape of the point cloud obtained also gives an indication of the envelope: the exploded shape of the point mass shows an average thermal inertia against high in the case of the use of WCB.

In the morning (blue spots), the relative humidity inside the building is high. This is not acceptable as it can lead to water condensation in the building. Condensation can shorten the life of the building with the appearance of pathologies such as fungi, mold, material chips, etc.

In the absence of any ventilation (0 $m.s^{-1}$), we find that the indoor conditions do not allow a sufficient level of comfort to be achieved. To be in this first zone of Givoni, temperatures must be between 20°C and 27°C, and the relative humidity must be higher than 20% and not higher than 80%. Beyond that, the feeling of comfort is limited by the strong presence of water in the air. This configuration reflects the case of a closed building with a high presence of steam generators (users). Relative humidity and temperature cannot be reduced because there is no air flow to evacuate internal loads.

At 0.5 $m.s^{-1}$, the air speed is similar to a natural ventilation from the front opening. We note that the WCB allows users to be in a situation of thermal comfort no less than 1227 hours per year, or nearly 14% of the year.

The scenario where the air speed is 1 $m.s^{-1}$ could correspond to the presence of a fan coupled with natural through ventilation. In this case, the building equipped with the WCB device shows its full strength: 6308 hours per year in a situation of thermal comfort compared to 350 hours for the building without the device, a gain of more than 68%. This last zone of Givoni shows that the user can feel in a situation of thermal comfort up to an air temperature of 32°C. Beyond that, an active cooling system (air conditioner) can be considered. The results of the study quantify this observation: under the conditions described, and without WCB, air conditioning would be necessary no less than 96% of the time in the lower Reunion Island area. The building envelope using WCB is a significant alternative to maintain a comfortable/consumption ratio consistent with a bioclimatic approach. Of course, in extreme temperature conditions (2452 hours per year for WCB configuration), air conditioning provides this extra to guarantee a comfortable situation all year round. Reducing the number of hours of use of the active cooling system using WCB reduces the energy consumption of the building.

3.3 Impact on Building Energy Savings

Some other studies [10] have shown that desiccant systems can lead to 44% of energy savings when used with the building air conditioning system. But it is not possible to show similar results with this work. Further experimental studies are in progress to be able to evaluate energy saving potential with a WCB wall.

4 Conclusions

This paper has presented a numerical study of a building coupled with a wood chips bed as the building ventilation system. The building and WCB has been presented and their modelling have been proposed.

Numerical simulations have been run with the building simulation code ISOLAB and for 4 different climates of La Réunion Island and a focus have been made on the zone with the highest temperature and humidity (corresponding to low altitudes in La Réunion island).

Results have shown that the WCB is an interesting way to reduce inside air temperature and water content depending on climate zoning, respectively from 7 to 10°C and from 11.6 $g.kg^{-1}$ to 10.6 $g.kg^{-}$. Numerical results of WCB building have also shown an impact on inside air relative humidity compared to a one without WCB (from 23 to 45%). Even if inside comfort conditions can be improve by the use of a WCB, this one lead to the increase of inside air relative humidity and this can lead to some building pathologies (fungi, mold, etc.).

Nevertheless, comfort analysis has shown the possibility to significantly increase building users' thermal comfort when coupled with a fan and natural ventilation, like the regulation needs for low altitude climate. In this case, a gain of 68% of year time is achieved for a building equipped with WCB system compared to one without it (6308 hours of comfort over a year with the WCB against 350 hours without WCB). So the WCB seems to be able to help reducing cooling loads in tropical climate conditions.

Concerning flammability and durability (to the climate or to the local fauna), as for bio-based insulation materials, more studies have to be done to be able to verify the compliance of such materials in such uses to the building regulations. Future studies should focus on the way to protect the bio-based material from the local fauna or to identify one that is not impacted by it, especially with regard to termites.

To correctly use a WCB as a system of building inside air quality improvement, it will be necessary to study other coupling modes to the building. It will also be interesting to study how to optimize its coupling and its control in order to be able to use it when it's needed and so avoided humidity pathologies.

It will also be interesting to study its design from a technical point of view to verify the feasibility of its coupling to the building.

Future works will focus on the study of other coupling modes in order to optimize WCB operations and performance. A design study will also be conducted to set up an experimentation able to measure all the parameters needed to better understand its physical behavior.

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