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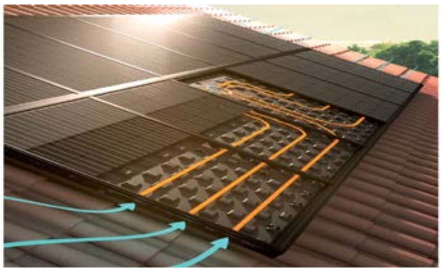
Effect of solar ventilation on thermal improvement and energy efficiency of buildings using phase change materials



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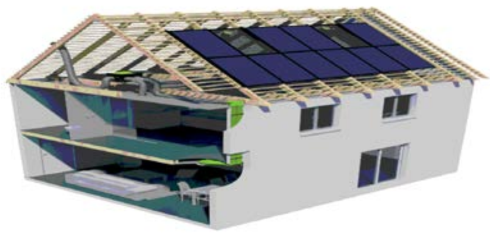
Abstract:

The article presents the design approach of a house using the simulation software of the thermal behavior in dynamic regime TRNSYS, this project aims at the design of a single-family house whose energy balance over one year of operation.
In this first phase of the project the main focus was on the design of the envelope with MCP type 204 systems and mechanic solar ventilation (MSV) are integrated in the overall model. The energy consumption related to the specific uses of electricity is taken into account in the annual energy balance. The whole project is modeled under TRNSYS V16 for the climate of CASABLANCA NOUASSEUR . The results show that the mechanic solar ventilation (PCM+MSV) reduces the operating temperature of the house significantly. Indeed, the mechanic solar ventilation has decreased its average operating temperature by about 2.6°C-3.88°C. It is concluded that ventilation (PCM+MSV) is an interesting passive technique to improve comfort and decrease energy consumption.



The house studied in this project (unoccupied) is located in (CASABLANCA NOUASSEUR). Its total surface is 110 m2 and it rises on: a basement, a first floor,the main facade faces south.

Keywords: **Phase change material ; Mechanic solar ventilation ; Thermal performance; Energy efficiency.**

1.Introduction

Recently, concerns about the thermal load of buildings have received increased attention, as buildings are the largest consumers of energy in most countries. Numerous investigations have shown that many problems are due to the indoor environment of inhabited premises. In the 1980's the first insulated buildings were built according to thermal regulations. As a result, the number of parasitic air intakes has decreased. On the other hand, there was an increase in the rate of pollutants inside the buildings (e.g.: paint, varnish, cleaning products, ...). This is why it was necessary to remedy this problem by imposing a ventilation of the inhabited parts. A house must be well ventilated. We often forget this, because we want to insulate. But insulation does not exclude a healthy air! Today, there are adapted solutions that allow you to take advantage of ventilation for the house while saving energy. Heat recovery is an approach for HVAC (heating, ventilation and air conditioning) [14], which protects the environment and reduces the energy used in buildings. It improves energy efficiency and reduces energy consumption, as energy losses due to ventilation account for up to 50% of total energy losses in buildings.It is important to ensure adequate air circulation for moisture reduction when renovating a house, it is essential to ensure that the air can circulate and that there is sufficient ventilation to allow for moisture regulation in the home. The fight against mold also contributes to the comfort of the home. When insulating exterior woodwork is installed, it must have an integrated ventilation slot in all rooms where there is no mechanical solar ventilation such as MSV. Several solutions are available to ensure air quality in your home.

The air purifier is designed to clean the air inside your home. However, it is important to invest in a CMV, whether it is single flow or, better still, double flow. Both models ensure air renewal, but the double flow CMV allows to preheat the incoming air thanks to the action of the outgoing air, which makes it an ecological and economical solution. Today, there are other alternatives, which focus on ecology. The solar ventilation allows to renew the air of the habitat. Thanks to the sun's energy, this new air is also warm! The air is healthier! The MSV, is a device that automatically forces the extraction of air to ensure its renewal and its quality inside a home. The reduction of energy consumption to preserve the environment is one of the main objectives for the future. Energy losses in ventilation have a huge impact on energy consumption in buildings. In this work, the energy performance of a heat recovery wheel system equipped with an air handling unit was tested throughout the year, and the results were compared with the results of the system simulation using TRNSYS . An energy analysis is performed at the whole building level by Dynamic Thermal Simulation (DTS) [4], onTRNSYS[1],and DesignBuilder Software [2]. The analysis includes all end-use energy for the following items, Heating, Cooling, Air conditioning, Ventilation The purpose of the DTS is to assess the primary energy consumption of the building. The DTS [4], integrates the following parameters: The thermal performance of vertical and horizontal walls; The airtightness of the building; The heating system for the treatment of premises; Cooling system for the treatment of premises; Ventilation system for the treatment of premises.

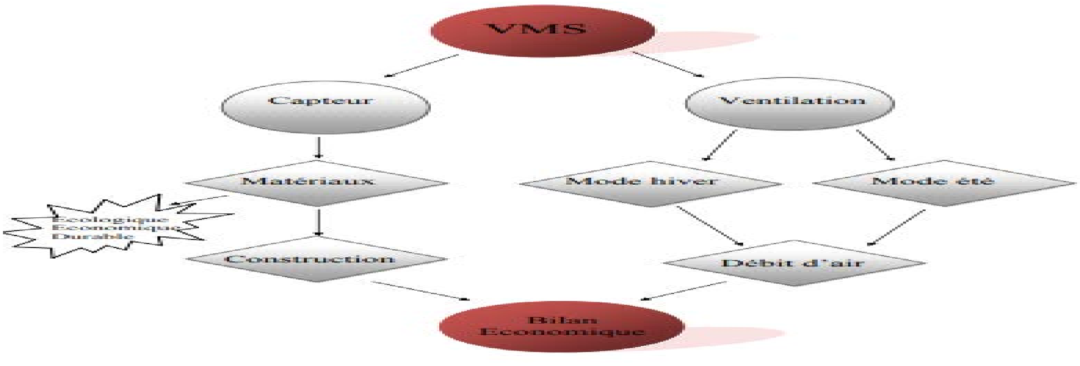


Fig.1. Global balance of solar mechanical ventilation.

Various researchers have performed an energy saving calculation using simulation. Often, the conventional approach cannot be done under different environmental conditions. Energy saving has been studied by several researchers under different climatic conditions. Jamil and al [5]. developed a TRNSYS [1]. model to simulate a desiccant dehumidifier. Experimental measurements

were obtained and compared with the simulation results. The simulation results showed that the coefficient of performance of the system had a critical influence when the regeneration temperature and relative humidity were varied. Walling and al[6]. studied the improvement of the energy performance of a building using a heat pump . The heat pump system was simulated using TRNSYS[1]. They found that it is possible to increase the heat exchange rate of the air handling unit by coupling a heat pump to the air handling unit with a mechanical ventilation . Other studies have focused on the energy performance of a building using THE TRNSYS[1] simulation software, to calculate the payback period when an energy recovery system is implemented. López , al[7],by using TRNSYS[1], simulated an experimental opaque ventilated façade module, indicating that the opaque ventilated façade has potential to achieve free ventilation and air preheating and its performance could largely be dependent on the wind speed and direction, as well as the intensity of solar radiation. Aparicio-Fernández and al [8], made the combined use of TRNSYS and TRNFlow to simulate the performance of an OVF, and compare the simulation results with experimental data. The study indicated that the collection of the hot air from the façade for the use in the building helped to reduce the building's heat demand. Some authors[9,10,11,12,13], conducted the numerical investigation of the performance of the OVF by comparing it with the same sized unventilated façade (without the air cavity) or sealed façade. The results show that the OVF can achieve more than 40% energy saving during summer period due to the reduction in heat gain and ventilation of the air cavity. In this work, a complete system of an existing air handling unit with a rotary air-to-air heat wheel was modeled for simulation using TRNSYS[1]. The operating ventilation system studied was designed to provide fresh air and ensure proper indoor air quality in the conditioned space. The heating and cooling demands are covered by an independent system, the studied ventilation system, which includes indoor air units connected to additional outdoor units and does not affect the energy consumption of the ventilation and has not been studied by our research and investigations. The main objective and novelty of this study was the development of a simulation model suitable for determining the energy consumption of solar ventilation systems. The simulated results were validated with the other experimental studies. The effects of ambient parameters, such as regeneration temperature, temperature and relative humidity (RH), on the energy performance were investigated. The electrical energy consumption was calculated to obtain the impact on the electrical energy consumption of the MSV of electrical energy of the MSV.

2. Methodology.

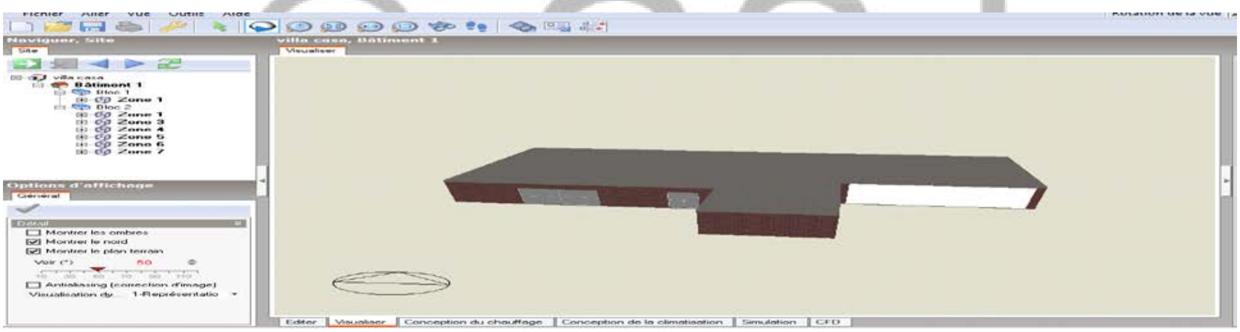


Fig.2 . 3D view

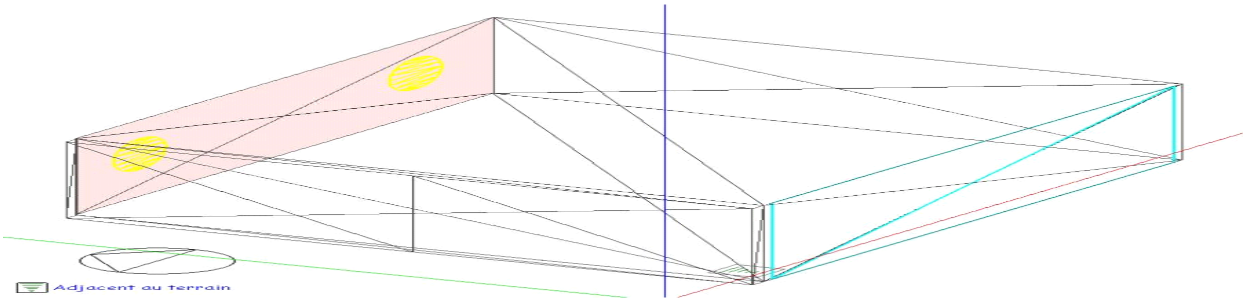


Fig.3 . 3D view of the area

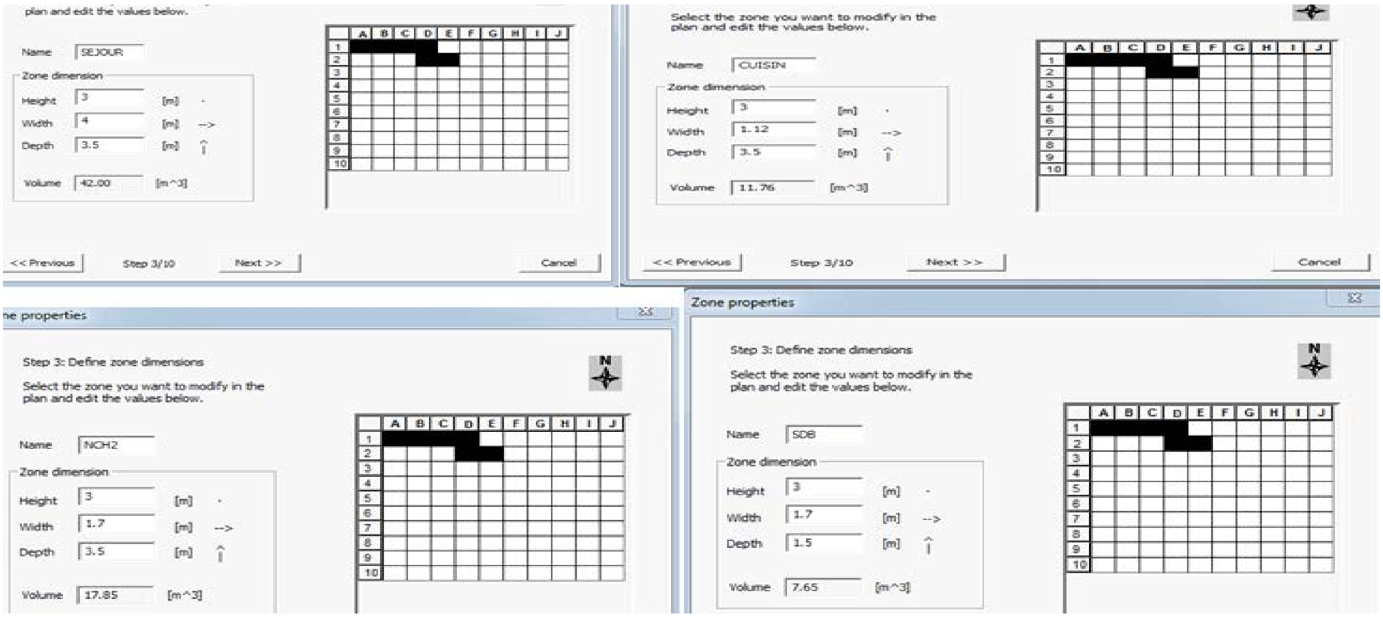


Fig.4. Definition of thermal surfaces.

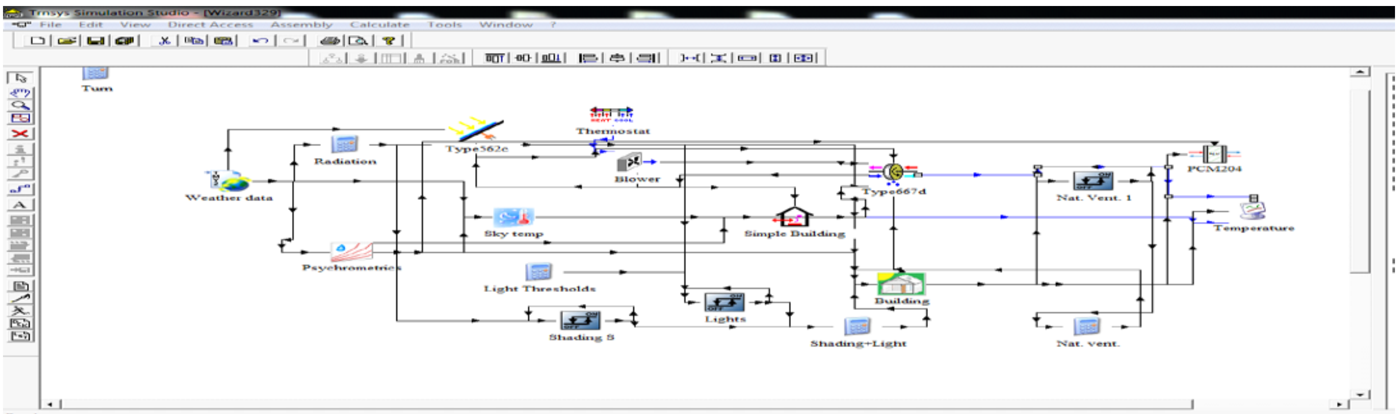


Fig.5.Representation of the building subsystem in the TRNSYS interface.

The simulation was run for one year to avoid errors in the initialization of the simulation and the results were exported in (xls) format. Then the graphs were elaborated by the program "Origin" during the warmest and coldest periods according to the climate file. The 6 days selected during each period corresponding to the hours of the year are January 3.4.6 (180-250 hours) for the cold period and July 20, 21 and 22 (4805-4877 hours) for the hot period. In the area, the heat transfer between walls and air is quite low, 2- 4 W / m²K. Therefore, the heat transfer between the air and the MCP area must be as close as possible to the interior surface to ensure a good heat transfer. A dynamic thermal simulation was performed with TRNSYS 16 software, using type 204, and a VMS to compare the behavior having brick zones and without VMS with zones incorporating phase change materials (PCM) and VMS. The simulation was performed for the climatic zone of (Casablanca Nouasseur).

2.2 TRNSYS Applications :

TRNSYS is a commercial software package developed by the Solar Energy Laboratory at the University of Madison in Wisconsin, USA.TRNSYS is dedicated to the dynamic thermal simulation of buildings and solar systems from simple hot water production to the design and simulation of single or multi-zone buildings, depending on their location, construction materials, architecture, etc. TRNSYS also allows the visualization, at a user-defined time step, of the energy consumption in terms of heating, cooling etc., as well as the annual energy production of solar and/or thermal equipment for a given building (solar water heater, photovoltaic panel, etc.). TRNSYS is based on a block diagram approach. This modular approach allows both to reduce the degree of complexity of the problems to be treated and to work in an environment allowing to add new components and new concepts using several programming languages (C, C++, Pascal, Fortran, etc.). In addition, TRNSYS can be easily connected to many other applications, for pre- or post-processing or through interactive calls during the simulation (Microsoft Excel, Matlab, etc.)TRNSYS has a rich and diversified set of components (Types) (single or multi-zone building, heating/cooling equipment, solar panels, meteorological data, online plotters, controllers, calculators, object management scenario). The creation of the TPF file (TRNSYS Project File), the main phase of a

simulation project, consists in linking the different elements necessary for the desired simulation: multi-zone building (Type 56), meteorological data (Type 99).

2.3.Building model in DesignBuilder V4.

TRNSYS and DESIGNBUILDER allow for accurate modeling of systems in order to best perform the design phase of a building and thus be able to propose solutions for improvement and optimization. They are adapted to users with knowledge in the field of modeling. A good command of these tools is necessary to obtain coherent results. DesignBuilder V4 is used to model the 3D geometry of the building defining the different spaces and HVAC zones. The energy simulation is based on the energy simulation program to model the performance of the building under study. The modeling of the building takes into consideration its geometry as well as the topology of the land and its geographical location.

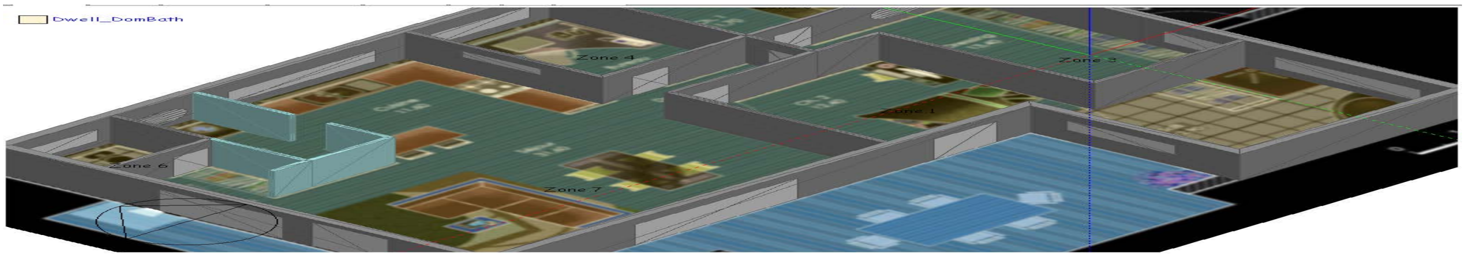


Fig.6. 3D plan.

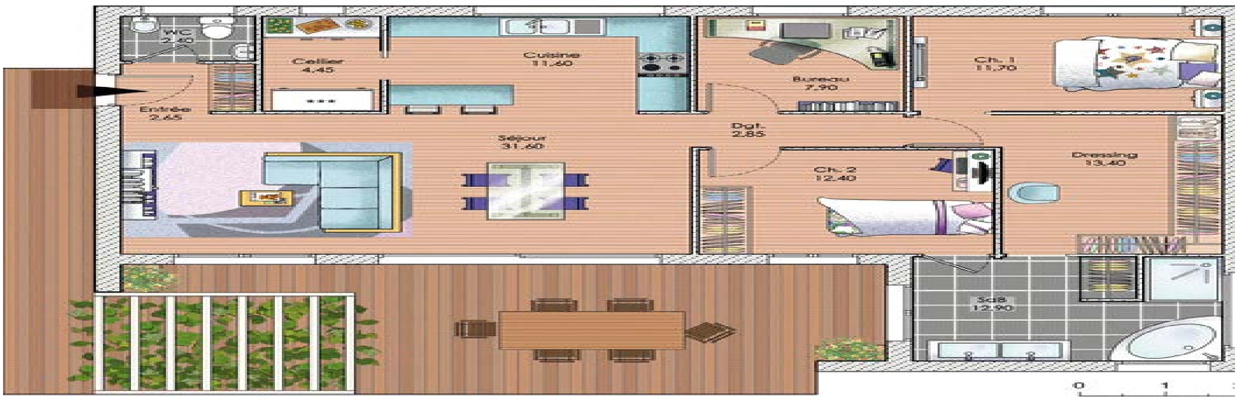


Fig. 7: Plan of the house

The detailed results were generated directly from the DesignBuilder software used for the Dynamic Thermal Simulation recognized a house (occupied by 4 people) is located in (CASABLANCA NOUASSEUR). Its total area is 110 m2 and it rises on: a basement, a first floor and the main facade is oriented to the south.

2.4.Mathematical description of the components used in the simulation :

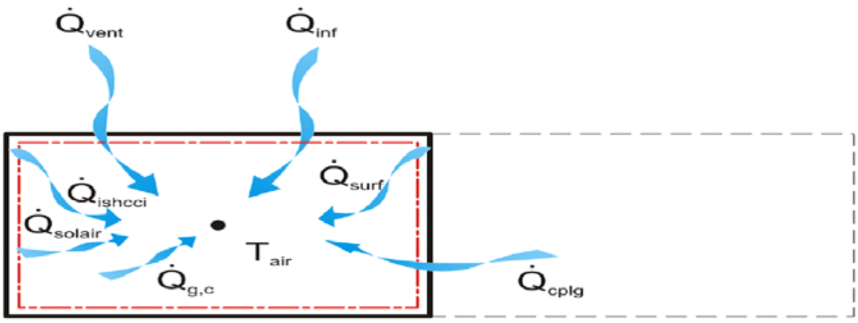


Fig. 8. Convective heat fluxes on an air node (TRNSYS)

The convective flows shown in Figure 8 are defined by the following equations:

$$Q_i = Q_{surf,i} + Q_{inf,i} + Q_{wind,i} + Q_{g,c,i} + Q_{cplg,i} + Q_{solair,i} + Q_{ISHCCI}, \text{ with :}$$

$Q_{surf,i}$: Convective gains from interior walls.

$$Q_{surf,i} = U_{w,i} A_{w,i} (T_{wall} - T_{air})$$

$Q_{inf,i}$: Infiltration gains (airflow from the outside).

Q inf,i=V ρ Cp(Text,i-Tair)

Q wind,i: Ventilation gains (airflow from a user-defined source, HVAC system).

Q wind,i=V ρ Cp(Tvent,i-Tair)

Q g,c,i : Internal convective gains (by occupants, by equipment, by etc.).

The change in thermal energy in a zone is equal to the net heat flux "Qi" exchanged by that zone according to the equation. (TRNSYS 16). The temperature of a thermal zone within a building (thermal node) is calculated by $Ci * \frac{d}{dt} Ti = Qi - Pi$ **Where Pi is the thermal load of the zone i.**

Fig.9.Reflection and transmission through a transparent wall.

2.5)Modeling and simulation

After retrieving the data needed for the modeling, it is important to choose the right components from the different libraries available. As we can see in figure 7, under TRNSYS this system is composed of 4 components: Meteonorm (type 15-6), photovoltaic panels (type 562e), inverter (type 48a) and printer (type 65d).

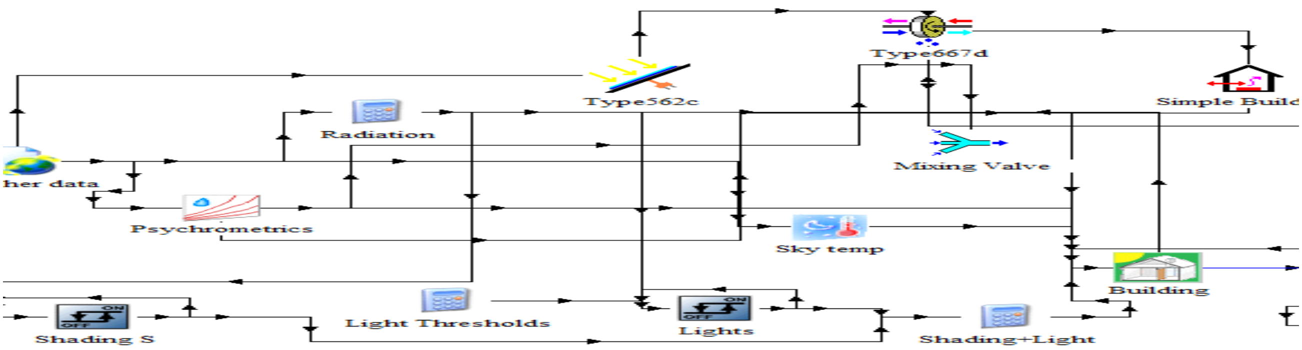


Figure.10. Simulation model inTRNSYS.

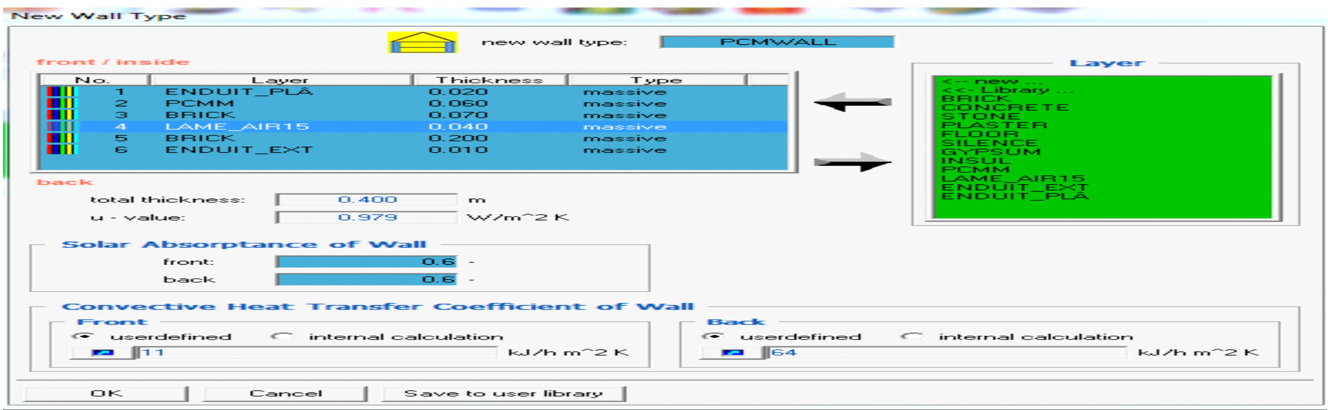


Figure. 11. Exterior wall parameters.

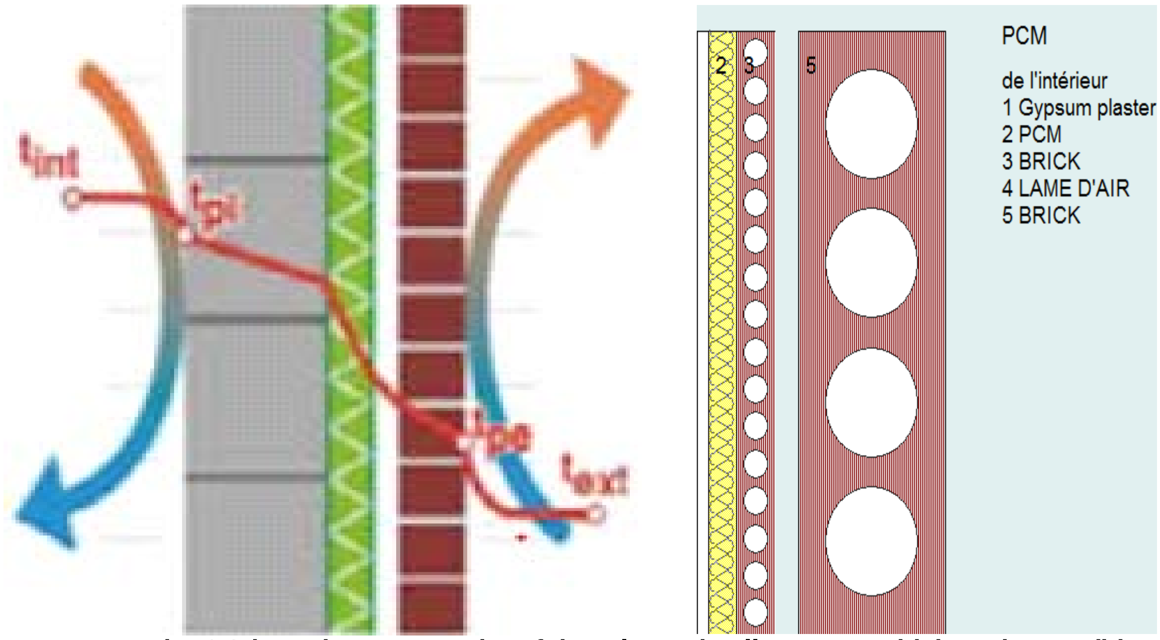
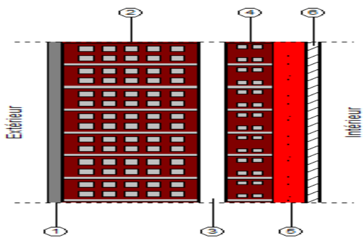


Fig.12.Schematic representation of the N-layered wall structure with boundaryconditions.

Modeling of photovoltaic panels

The photovoltaic solar panels are installed on the roof of the house. There are 5 of them, inclined at 15° to the south. such as the inclination to the sun or the weather variation. But these are directly informed from modules integrated into the library, such as Meteonorm which simulates meteorological data (weather, temperature, inclination of the sun as the day progresses, air humidity, ...). An inverter is also integrated to alternate the direct current that is recovered from the photovoltaic panels

After retrieving the data needed for the modeling, it is important to choose the right components from the different libraries available. As we can see in figure 10, under TRNSYS this system is composed of 4 components: Meteonorm (type 15-6), photovoltaic panels (type 562e).



Couches
1 - Mortier (Masse volumique sèche 2300): 2 cm
2 - Brique rouge 6 trous (0.196 W/(m·K)): 20 cm
3 - Lame d'air faiblement ventilée: 4 cm
4 - Brique rouge 6 trous (0.196 W/(m·K)): 7 cm
5 - PCM: 5 cm
6 - Plâtre courant d'enduit intérieur, masse volumique nominale 1100: 2 cm
Épaisseur totale: 40.0 cm
Caractérisation thermique
Coefficient de transmission thermique: 0.70 W/(m²·K)

Figure. 13. Exterior wall parameters.

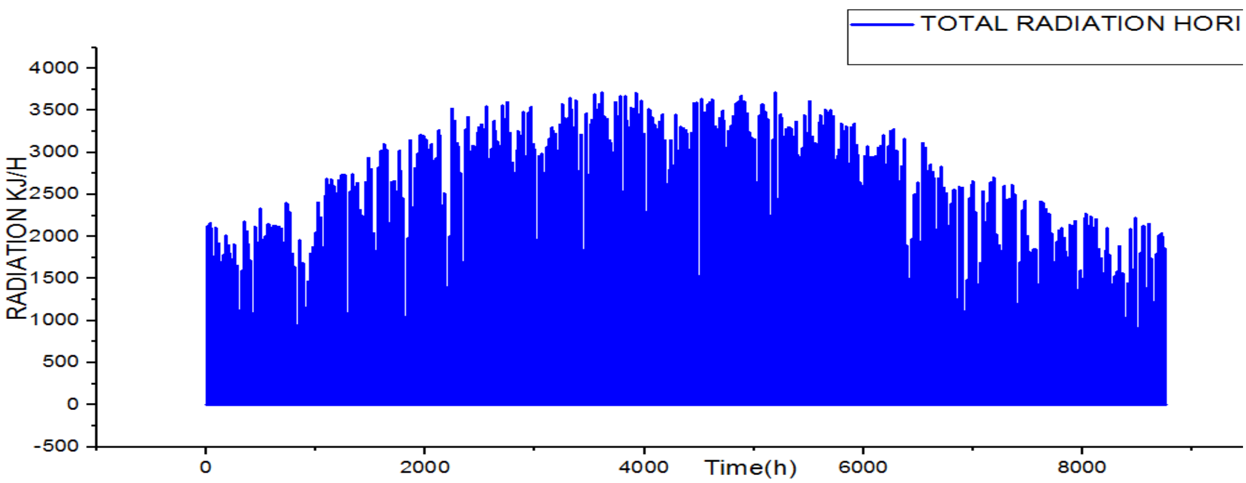


Figure. 14. Power produced by photovoltaic panels.

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The power recovered by these panels varies between 1850 kJ/h (0.514 kW) for the least sunny days in winter and 3600 kJ/h (1.08 kW) for the sunniest days in summer. From a simulation point of view, the resulting values are valid.

Heating / cooling set point: The setpoints for the calculation of the thermal loads of the apartment were set at 20°C and 26°C for heating and cooling respectively according to the Moroccan standard (NM ISO 7730 2010).

Ventilation scenarios: The house is mechanically ventilated when the outside air temperature (All) is below the cooling set point (26°C) during the warm season or above the heating setpoint (20°C) during the cold season. The amount of air introduced was between 0.4 ACH and 1 ACH in summer and between 1.2 and 2.2 ACH in winter respectively and an invariable infiltration rate of 0.5 ACH is considered throughout the year.

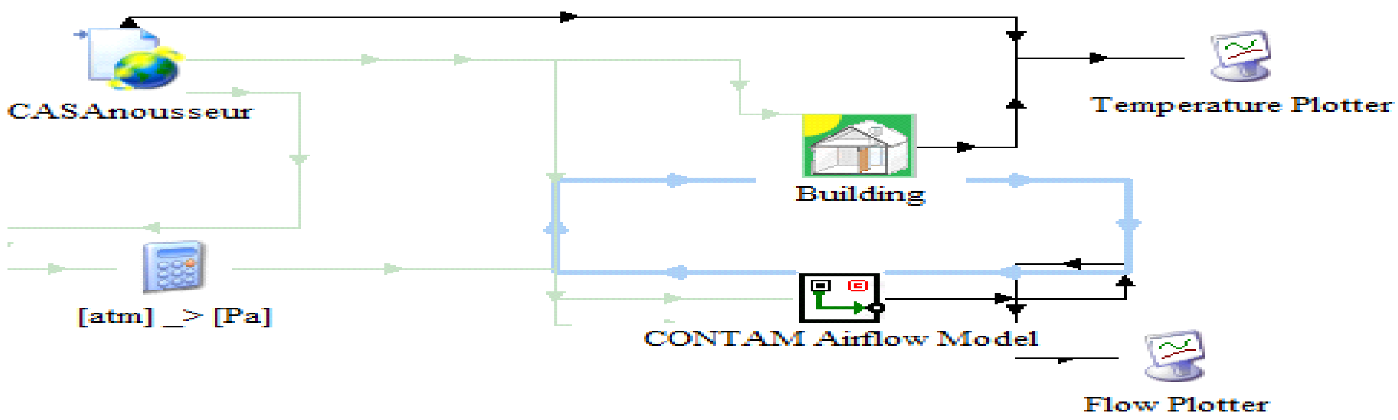

Fig. 15.Simulation with TRNSYS 17 and CONTAM AIRFLOW.

3)Results and Discussion

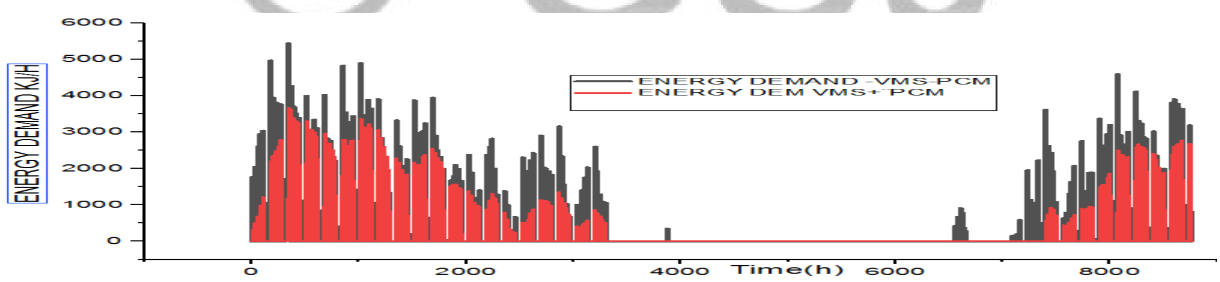

Fig.16. Annual energy requirements(MSV+PCM)and without(MSV+PCM).

Simulation results under DESINGBUILDER:

The results are presented in detail in the HTML reports attached to this report. However, this section visually represents the temperature and humidity curves for each zone in order to guide the team towards a choice of equipment that combines comfort and energy savings. The results of the sizing and the power required to cover the comfort needs are also detailed in the comfort section.

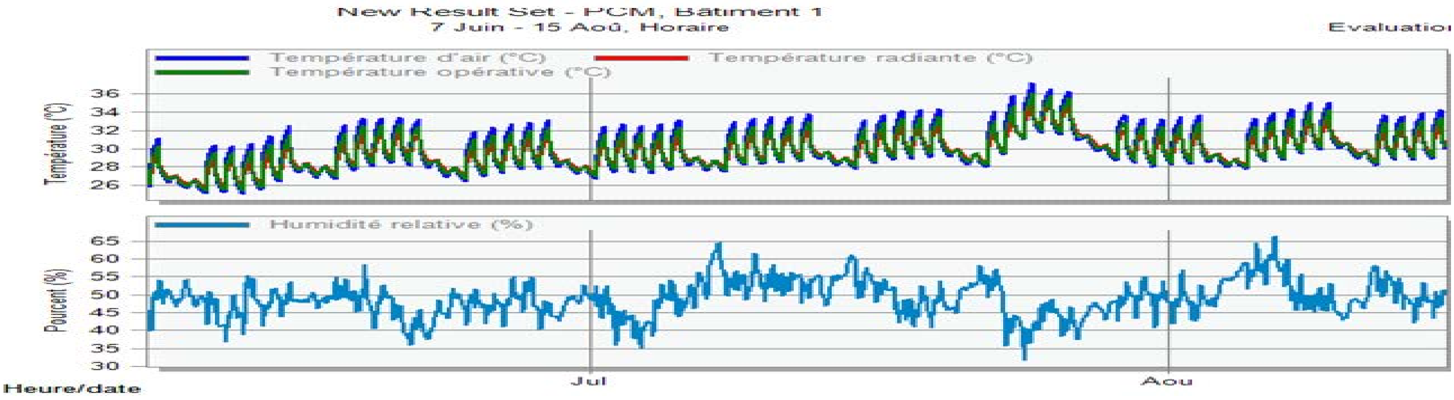

Figure .17. Temperatures and humidity without(MSV+PCM)in summer.

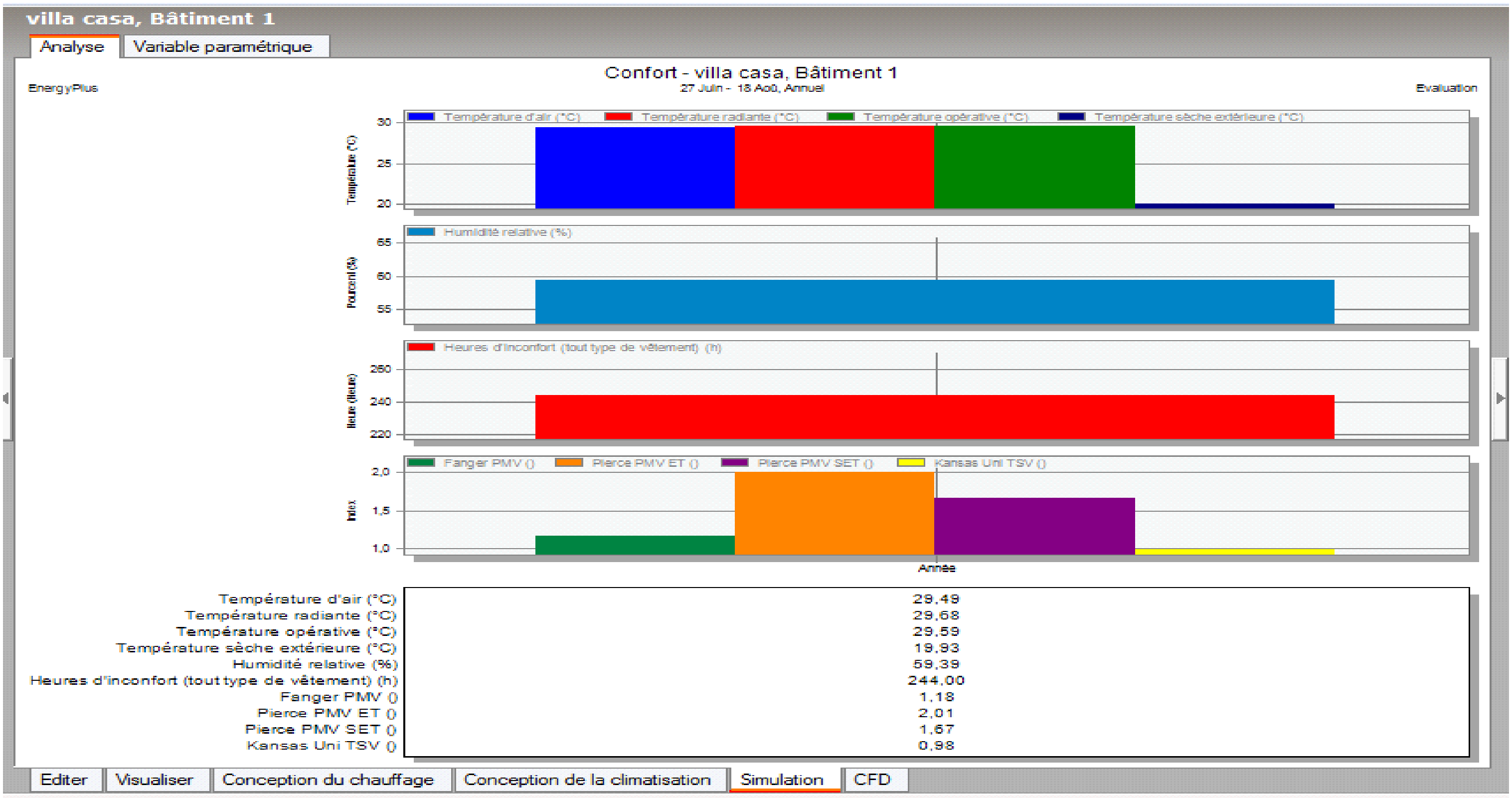

Figure.18.Annual temperature and humidity without(MSV+PCM).

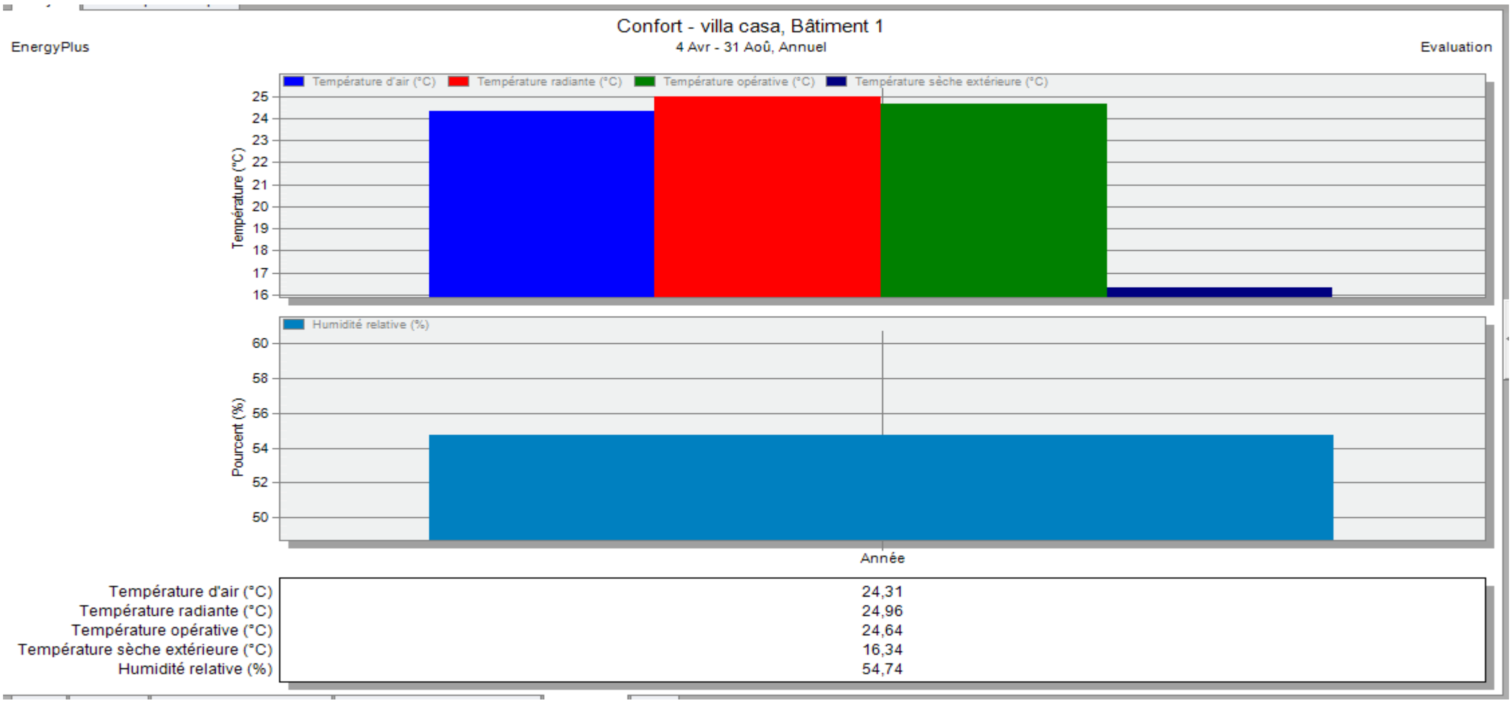

Figure. 19. Annual temperature and humidity with(MSV+PCM).

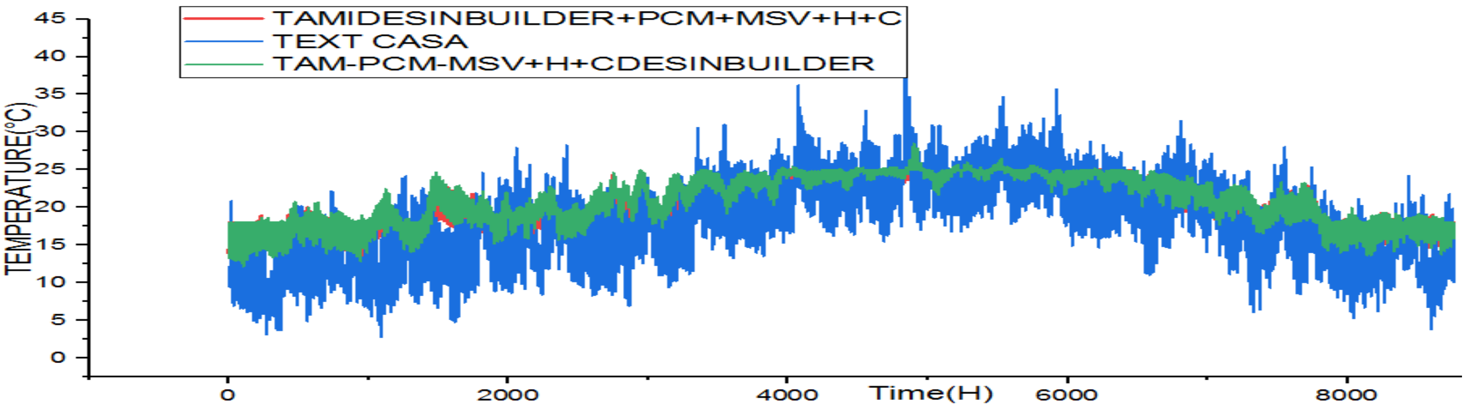

Fig. 20. Evolution of the air temperature with(MSV+PCM)and without(MSV+PCM).

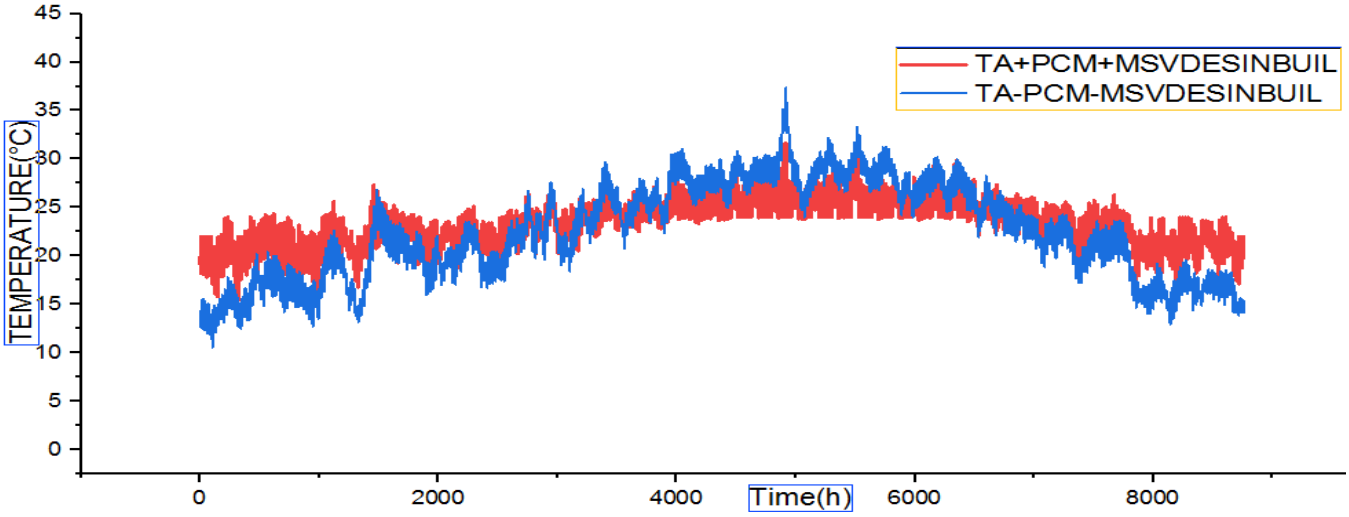

Fig. 21. Evolution of the air temperature with(MSV+PCM)and without(MSV+PCM).

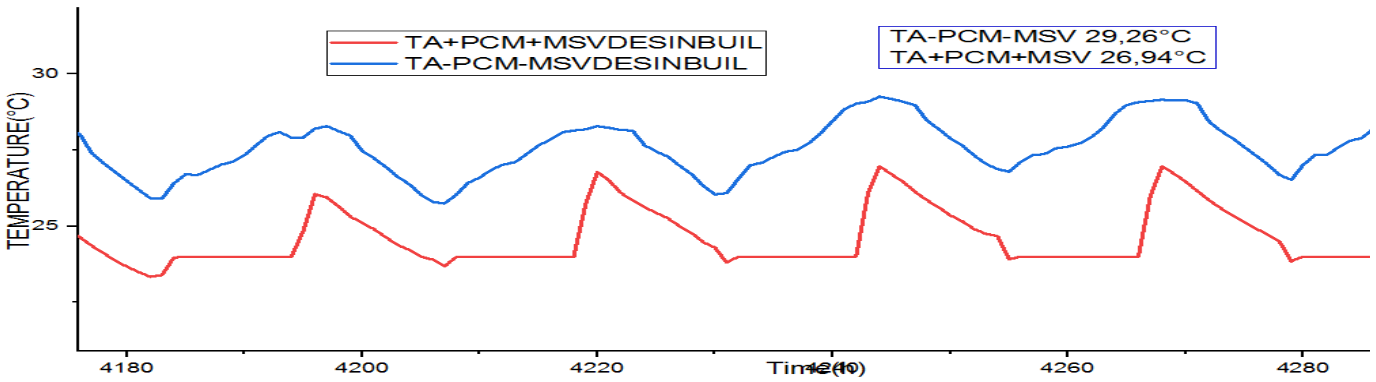

Fig. 22. Evolution of the air temperature with(PCM+MSV)and without(PCM+MSV)in summer

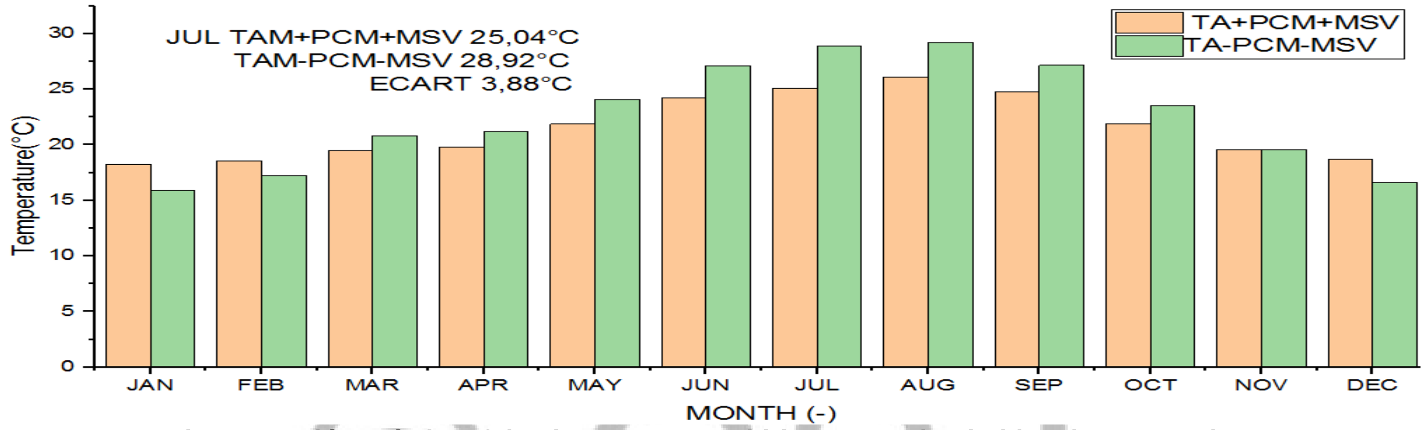

Fig. 23.Monthly evolution of the air temperature with(PCM+MSV)and without(PCM+MSV).

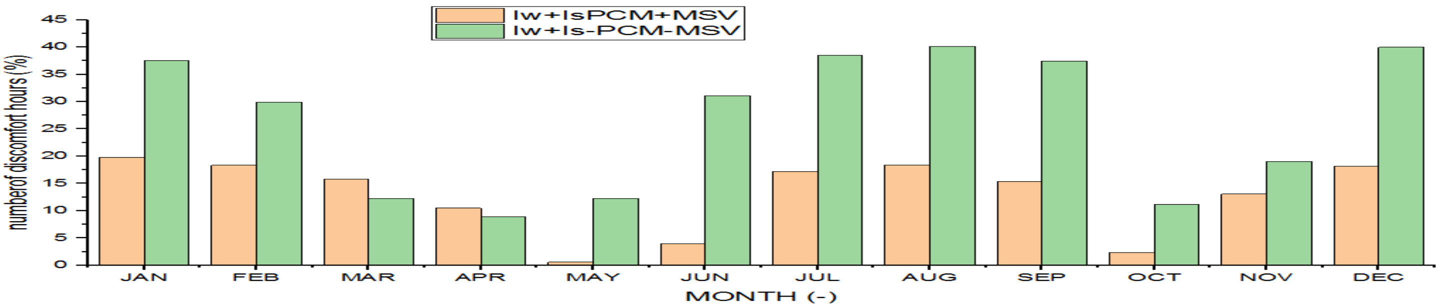

Fig.24. Thermal discomfort indexes with(MSV+PCM)and without(MSV+PCM)

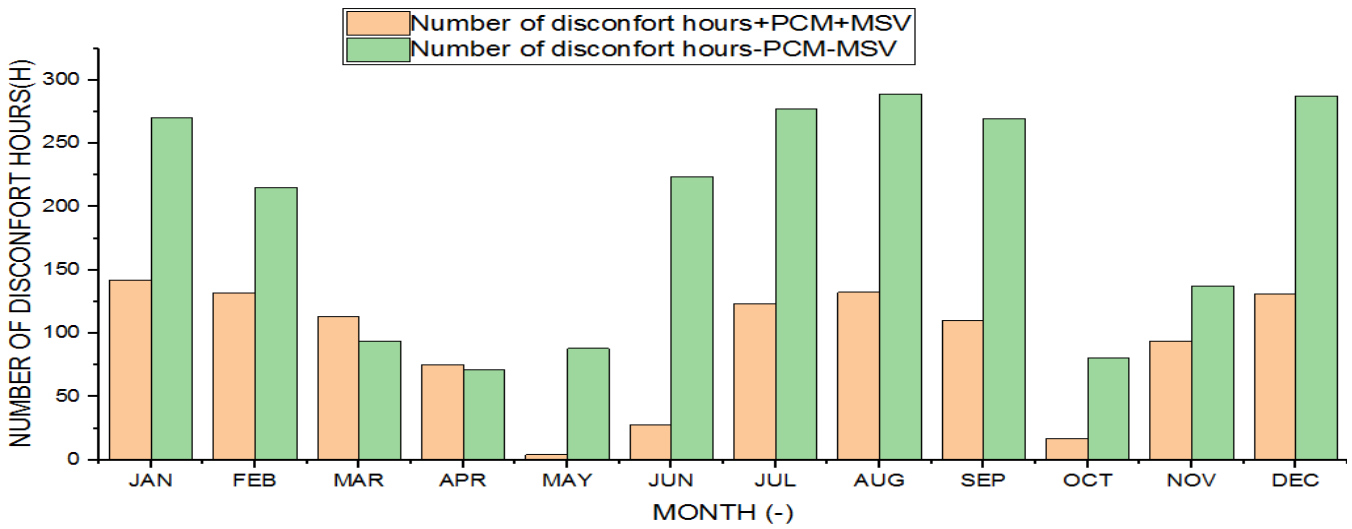

Fig.25 . Number of discomfort hours with(MSV+PCM)and without(MSV+PCM.

Date/Time	Relative humidity	Fanger PMV	Pierce PMV SET	Kansas Uni TSV	Air temperature	Operating temperature	Hours of discomfort (all types of clothing)
	%				°C	°C	h
01	58,1736	-1,982428	-0,51028	-0,520915	18,27263	17,91078	142
02	58,3474	-1,859565	-0,4344	-0,433164	18,56883	18,33627	132
03	56,3276	-1,494739	-0,20737	-0,228366	19,52416	19,63644	113,5
04	56,5131	-2,909025	-0,84401	-0,751193	19,83404	20,05193	75,5
05	57,1063	-2,041002	-0,42024	-0,296155	21,8553	22,2717	4
06	56,8649	-1,035449	3,82E-02	-4,59E-02	24,208	24,64834	28
07	58,5434	-0,231627	0,449985	0,2228894	**25,68607**	26,48121	123,5
08	61,8689	-0,190659	0,495913	0,2441614	26,12629	26,49078	132,5
09	63,7755	-0,759796	0,174005	-1,11E-02	24,79658	25,1402	110,5
10	60,4432	-0,67417	0,269993	-5,66E-02	21,92078	22,23078	17
11	60,2369	-1,469555	-0,18846	-0,227518	19,59113	19,61954	94
12	62,7846	-1,818748	-0,40655	-0,412997	18,67871	18,37238	131

Table.3. Temperatures and heat gains with(MSV+PCM) in DesignBuilder .

Figure 20,21,22,23 shows the maximum difference between the temperatures simulated by the numerical model DesignBuilder V4 with (PCM +MSV) and without (MCP +MSV) in summer a (CASABLANCA NOUSSEUR), and the distribution of this difference. Overall, it is clear that the majority of the differences between the simulated temperatures with (PCM +MSV) and without (PCM+MSV) a difference of 3.88 ° C.

Commitment to sustainable construction: **The house committed to a sustainable development approach, made the choice to carry out its construction project of the house according to an environmental approach with a certification objective"(HQE™ International).**

Table.4.Requirements of HQETM target 4

HQE target 4 requirements ™		Number of points available
Description of the sub-target 4.1.1	Improve the building's ability to reduce its energy needs. Justify the bioclimatic design of the building using : • A notice describing the design of the project (volume, ground plan, orientation of glazed surfaces, bioclimatic components) according to the context and the activity in the premises, • The reduction of energy needs (heating, cooling, lighting) calculated using a Dynamic Thermal Simulation.	**Prerequisites**

Description of the sub-target 4.2.1	Reduce primary energy consumption due to heating, cooling, lighting, DHW, ventilation, and operating auxiliaries, related to user comfort. Justify a minimum gain of 10%.	Prerequisites
	Justify a 20% gain	5 points
	Justify a 30% gain	6 points
	Justify a 40% gain	7 points
	Justify a 50% gain	8 points
	Justify a 60% gain	9 points
	Justify a 70% gain	10 points
	Justify an 80% gain	15 points
	Positive energy building	20 points

CONSUMPTION (MSV+PCM) KWH/m2/year	CONSUMPTION (-MSV-PCM) KWH/m2/year	GAINS KWH/m2/year	Synthesis
(H+C) 16.18 kwh/m2/year	**(H+C) 14.16kwh/m2/year**		
(H+C+INF+G) 47.97 kwh/m2/year	**(H+C+INF+G) 54.6 kwh/m2/year**	**6.78 KWH/m2/year An 13%gain**	**consumption in heating and air conditioning are less than 50 KWH/m2/year therefore conforms by the RTCM**

Table.5.Energy consumption with(MSV+PCM)and without(MSV+PCM).

The maximum annual thermal specific needs for heating and cooling are set by the RTCM according to the climate zone. In climate zone 1 (AGADIR), these annual needs are set at 25 kWh/m²/year for residential buildings [RTCM, 2014]. The results that previous by TRNSYS for a house of 110 m2 clearly shows that the heating and cooling needs are 16.47 kWh/m²/year. These requirements represent only 34.12% of the requirements set by the RTCM.

MONTH	HEATING+PCM+MSV	COOLING+PCM+MSV	INFILTR,+PCM+MSV	VENTILAT,	INT_GAINS+PCM+MSV
-	[KWH]	[KWH]	[KWH]	[KWH]	[KWH]
JAN	382,7	0	-185,9	-11,57	429,3
FEB	319,5	0	-141,9	-10,13	378,9
MAR	226,7	0	-123,4	-11,44	404
APR	117,3	0	-111,6	-11,65	387,5
MAY	75,7	0	-65,23	-14,84	409,4
JUN	1,89	23,36	-35,48	-23,74	385,7
JUL	0	79,22	-28,45	-31,32	400,8
AUG	0	109,7	-28,15	-34,1	408,4
SEP	0	63,22	-62,05	-28,17	380,6
OCT	1,89	7,88	-77,14	-24,88	418,8
NOV	108,1	0	-127,8	-13,12	410,9
DEC	295,3	0	-153,1	-10,71	416
SUM	1529	283,4	-1140	-225,7	4830
SUM+PCM +MSV	5276,7	KWH			
	728.27 KWH				

	12.2%				

HEATING-PCM-MSV [KWH]	COOLING-PCM-MSV [KWH]	INFILTR-PCM-MSV [KWH]	INT_GAINS [KWH]
300	0	-195,5	430
211	0	-155,3	470
106,8	0	-139,1	500
68,95	0	-123,1	520
29,14	6,71	-88,9	530
0,6	81,96	-55,49	560
0	157,7	-34,77	570
0	201,2	-32	500
0	103	-64,85	400
1,48	40,05	-92,26	410
62,9	0,08	-138,2	414
181,1	0	-164	430
961,97	592	-1283	5734
SUM-PCM-MSV	6004,97	KWH	

Table. 6. Requirements obtained with the optimized solution.

The heating requirement over the year is very low13 KWH/m2 and well below the target of 15kWh/m²/year, which validates our model from the heating point of view.

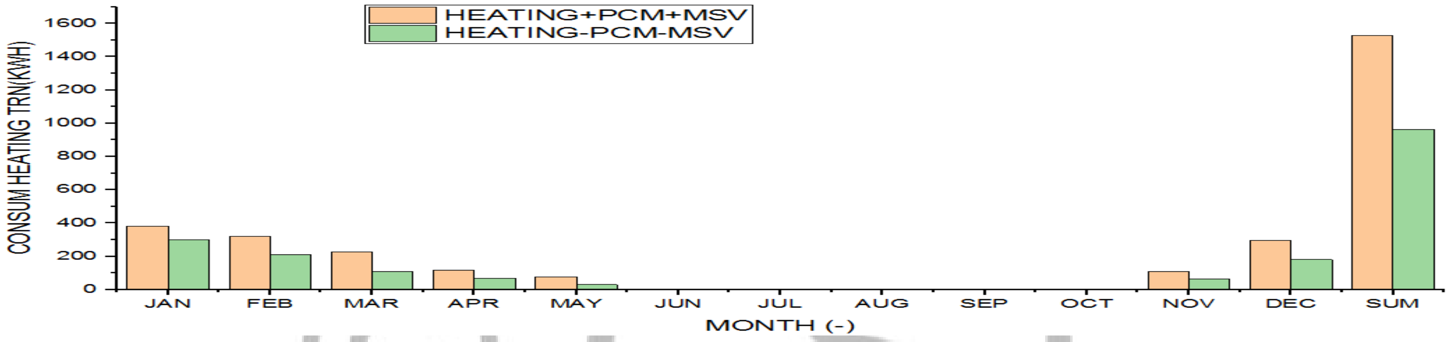

Fig.26.Monthly heating consumption with (PCM+MSV) and without (PCM+MSV) in TRNSYS.

In this section, we have considered that the MSV is provided by a ventilation system for which we will have to calculate the nominal electrical power. By the way, considering an electric fan with an efficiency of 80% and a global pressure in the building of about 50Pa and that the desired fresh air flow is 1120m3/h or 4ACH.

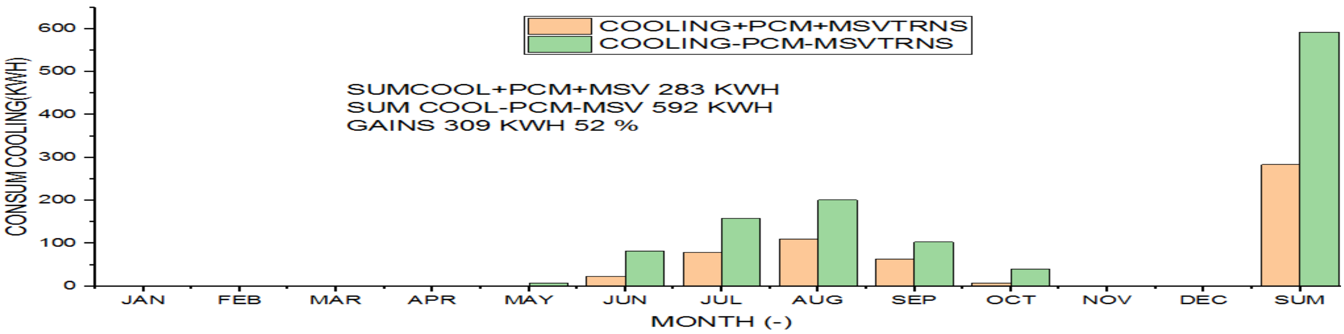

Fig. 27.Monthly consumption of air conditioning with(MSV+PCM)and without (MSV+PCM)underTRNSYS

The Figures 26,27 shows the beneficial effect of the MSV on the energy saving of the building envelope in the climate of (CASABLANCA NOUSSEUR). Indeed this energy saving in terms of electricity consumption is more important in the summer where the MSV saves respectively 592 KWH about 52% of the electrical energy under the TRNSYS 204 system and 2728 KWH about 59% with DesignBuilder . it should be noted that the MSV has no significant effect on the heating load. The maximum annual electrical specific needs for heating and cooling are set by the RTCM according to the climate zone. In climate zone 1 (AGADIR), these annual needs are set at 25 kWh/m²/year for residential buildings [RTCM, 2014]. The previous results clearly show that the heating and cooling needs are about 16.32 kWh/m²/year. These needs represent only 34.72% of the needs set by the RTCM.

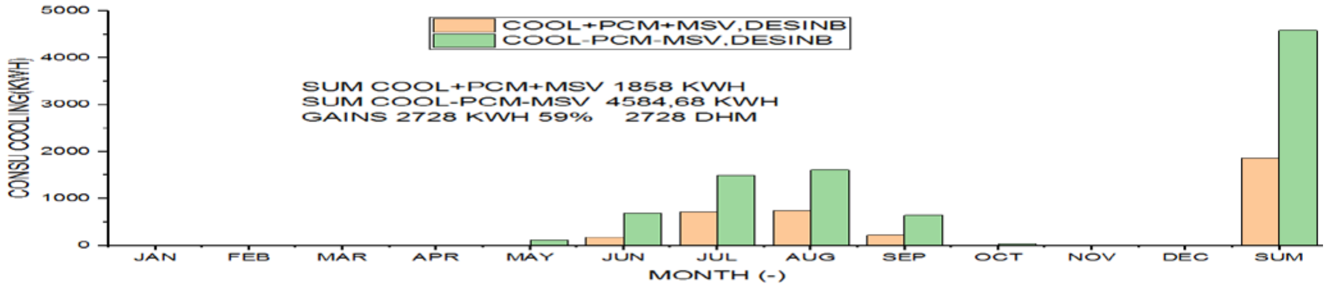

Fig.28.The monthly consumption of the air conditioning with(MSV+PCM)and without (MSV+PCM)in DesignBuilder .

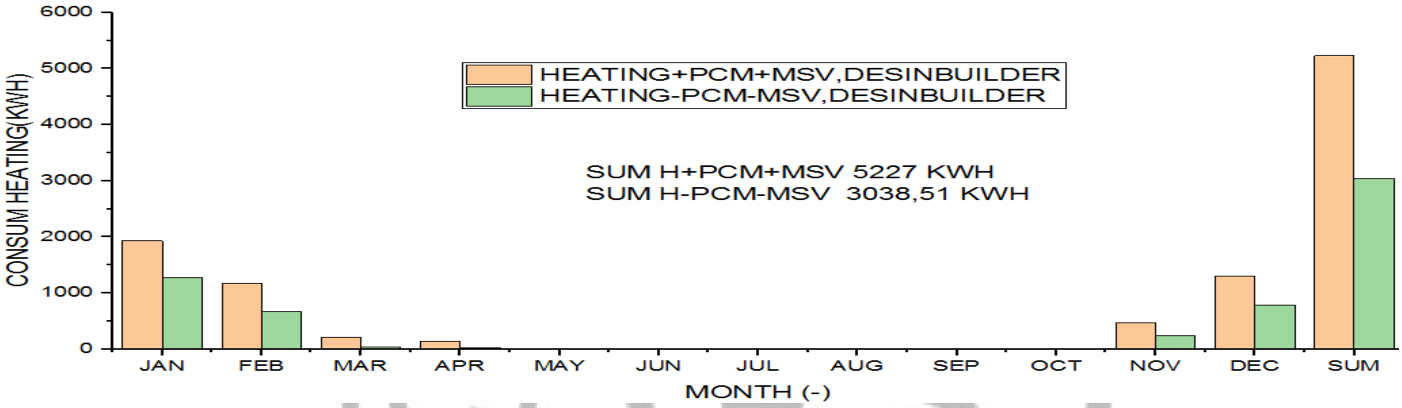

Fig.29.Monthly heating consumption with(MSV+PCM)and without(MSV+PCM)in DesignBuilder .

Sum (H+C+PCM +MSV)KWH DESINBUILDER	Sum (H+C-PCM -MSV)KWH DESINBUILDER	Sum (H+C+INFI +PCM+MSV)KWH DESINBUILDER	Sum (H+C+INFI -PCM-MSV)KWH DESINBUILDER	GAINS (H+C)	GAINS (H+C+INF)
7086,1633	7623,19	14837	17103,47	537.2 KWH	2266,48 KWH **13.26%**

Table.7. The sum of heating and cooling loads with(MSV+PCM)and without(MSV+PCM)in DesignBuilder.

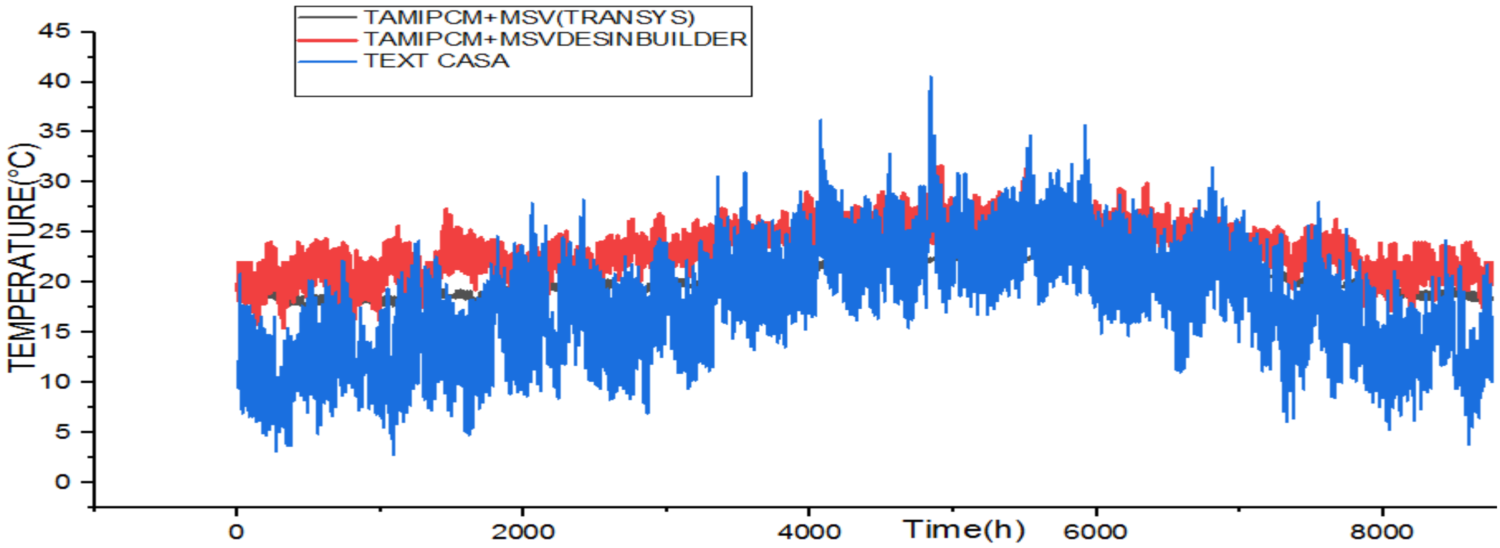

Fig.30. Annual evolution of the internal ambient temperature with TRNSYS and DesignBuilder.

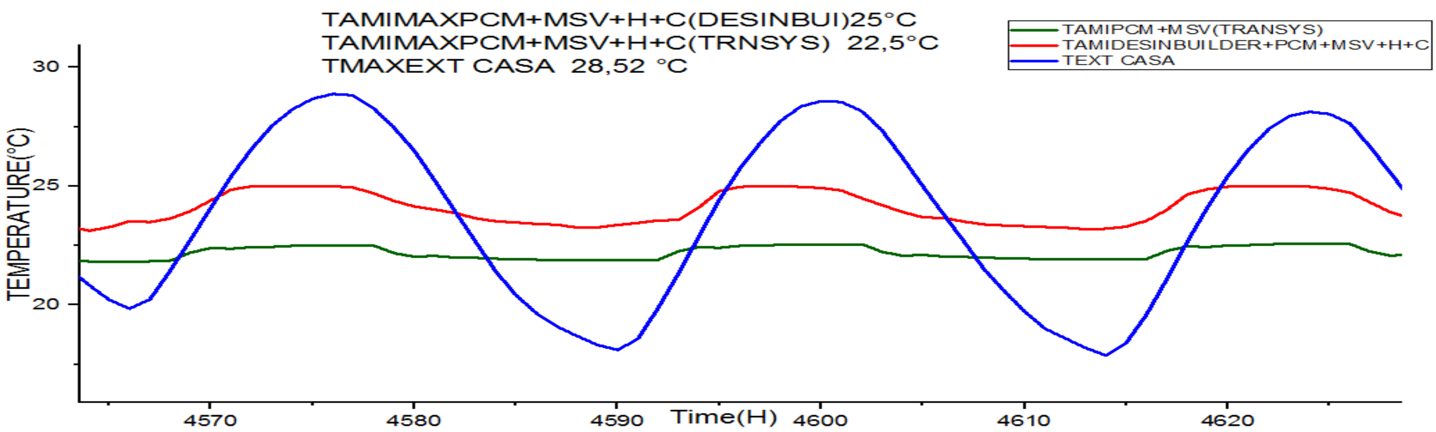

Fig.31.Evolution of the internal ambient temperature with TRNSYS and DesignBuilder in summer.

Material	Wall+PCM+MSV+H+CTRNSYS	Wall+PCM+MSV+H+C DESIN
All,casa Max(°C)	**28.52**	**28.52**
Tin,Max(°C)	**22.7**	**25**
(°C) (wall+PCM+MSVTRNSYS)and (DESINBU) : 2.4°C	**6.02** **2.4**	**3.5**

Table . 8. Maximum amplitudes of the inner surface temperature.

The figure 31 and the table 8 shows the maximum amplitudes of the inner surface temperature between the temperatures simulated by the two numerical models TRNSYS and DESIGNBUILDER, We noticed that TRNSYS could be due to the variety of physical models used or uncertainties on the homogenization of parameters, and also on the internal and external gains that integrate on DESIGNBUILDER . The result shows a deviation of 2.4°C, confirming the great sensitivity of the calculation codes to the variation of physical parameters that are not well identified. This result shows that it is important to work on the definition of the sources of uncertainty in the building, both in terms of the validity of the parameters and the imperfection of the numerical models used. Methods have been developed to identify the influential parameters. An overview of sensitivity analysis methods applied to the building domain will follow.

The effect of the amount of ventilation on indoor temperature and energy consumption:

The indoor temperature and cooling energy consumption would be dissimilar. Apparently, the impact on indoor thermal comfort of solar ventilation provided at night is greater than that of ventilation provided during the day. During the day, the phase change energy storage properties of PCM could improve the thermal inertia of building envelopes and thus prevent the indoor temperature from rising

too quickly and too high. On the other hand, ventilation brings in cold outside air to release the warm inside air as well as the heat stored by the PCM. It is believed that the simultaneous use of PCM and ventilation would significantly reduce the indoor heat load in summer, and the cooling energy consumption could be effectively reduced. In order to investigate how the amount of ventilation improves the performance of PCM on indoor temperature and energy consumption for the climate zone (CASABLANCA NOUASSEUR), the effect of ventilation amount (i.e., air changes per hour) was studied.

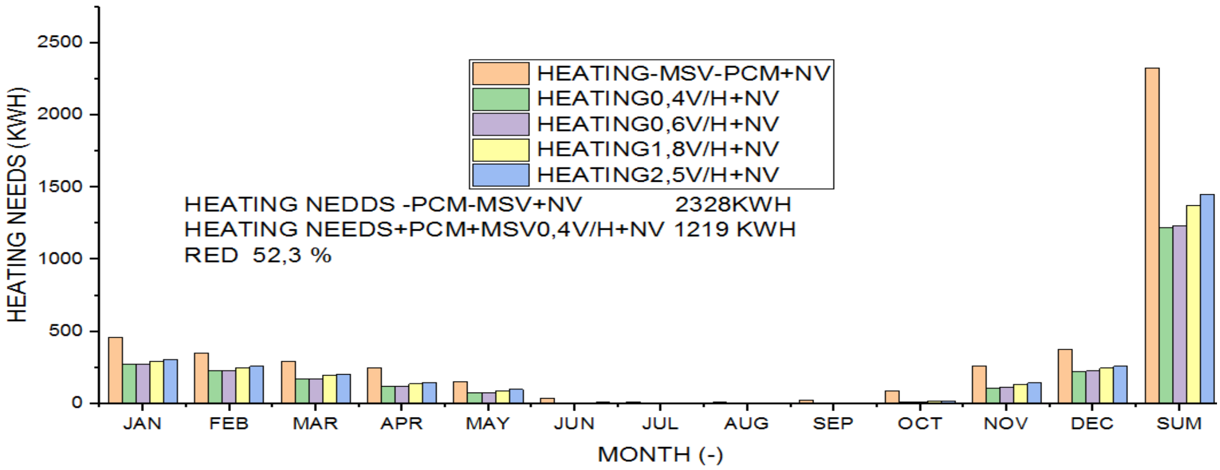

Fig. 32. Energy consumption for different amounts of solar ventilation in summer.

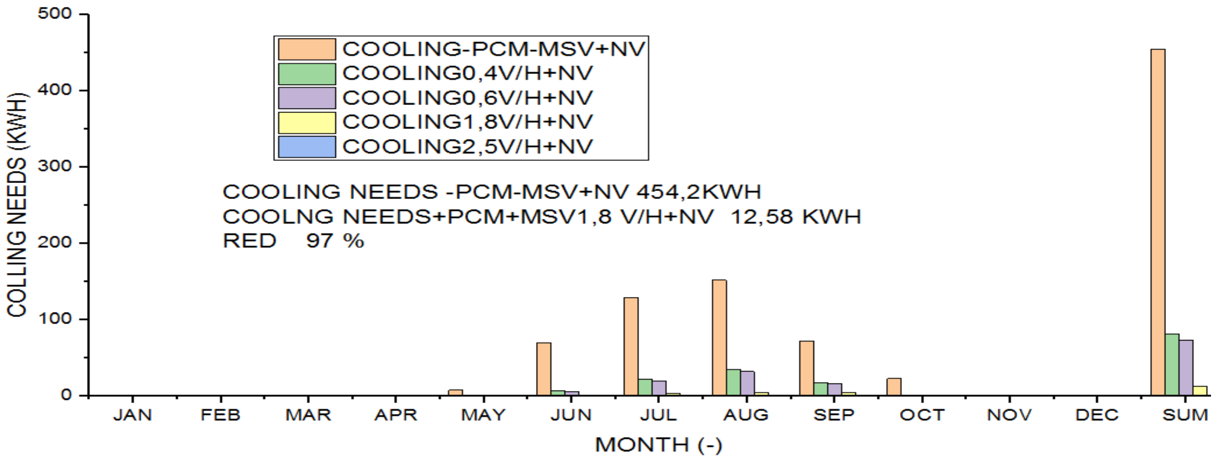

Fig. 33. Energy consumption for different amounts of solar ventilation in winter.

Figures 32, 33 show the effect of the amount of ventilation on the heating and cooling energy consumption for the climate zone (CASABLANCA NOUASSEUR). The cooling energy consumption decreases with increasing amount of solar ventilation. In general, the greater the amount of ventilation provided, the greater the effect of the PCM on energy savings. However, the effect of the amount of ventilation on energy consumption became insignificant when the ventilation was greater than 1.5 AC/h. The cooling energy consumption, ventilation energy consumption and total energy spent for different ventilation amounts in (97.23% reduction), and when decreasing the solar ventilation amount between 0.4AC/H and 1.3 AC/H the energy consumption decreased in winter (52.5% reduction). So we take between 0.4 and 1.3 AC/H in the heating period and between 1.3 and 2.2 AC/H in the cooling period. Which means that the amount of ventilation also played an important role in reducing energy consumption.

Effects of (MSV+PCM) on indoor CO2 concentrations:

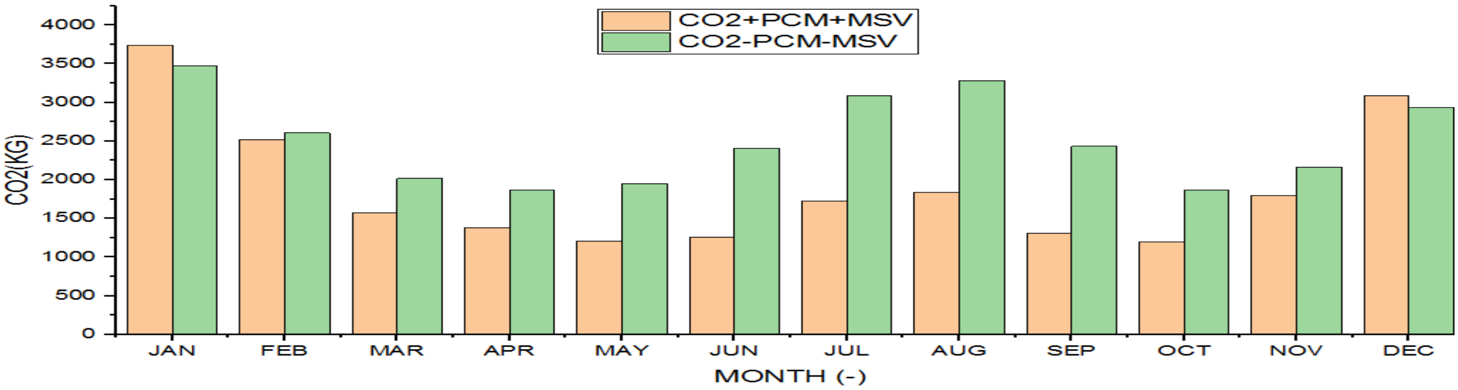

Fig.34.Monthly CO2 concentration with (PCM+MSV) and without (PCM+MSV).

The comparison of the CO2 concentration for the two SENARIOS, shows that the building with (PCM+MSV) requires less CO2 concentration than the building without (PCM+MSV). The annual sum of CO2 concentration with (PCM+MSV) reaches 22625 kg, has low values compared to the annual sum of CO2 concentration without (PCM+MSV) 31073 kg gains of 8448 kg of CO2 (Reduction of 27.19%). Thus, the CO2 concentration in a room of a given indoor environment remains essentially dependent on the CO2 concentration present in the outdoor air, on the intensity of the emissions of the CO2 sources present (e.g number of occupants and types of activities practiced by them in the said room) and on the air exchanges between this room and the other rooms of the building as well as with the outdoor environment, which can be modulated in particular by the natural, mechanical or hybrid ventilation . It should be noted that the processes likely to attenuate the concentrations of CO2 can also lead to the reduction of the concentrations of other gaseous or particulate contaminants of the indoor air.

4.Conclusion

It is concluded that the efficiency of the PCM can be improved if the building can be properly ventilated to release some of the heat gains during the night. In particular when the air temperature is close to the melting temperature of the PCM 22 °C . A global building model consisting of a house modeled and simulated in TRNSYS and EnergyPlus and the modeled solar air/MCP exchanger fan system is simulated under climate (CASABLANCA NOUSSEUR) . In this article, mechanical ventilation with solar energy is proposed according to different ventilation rates between 0.4 and 1.3 ACH in winter and 1.3 and 2.2 ACH in summer.In addition, the mechanical ventilation unit is powered by a solar photovoltaic system; if solar power is not available, the ventilation unit is connected to the national power grid. solar mechanical ventilation can also increase the airflow locally and improve heat transfer. Similarly, solar mechanical ventilation can be used to accelerate the heat release from the PCM at night and the thermal energy storage efficiency of the PCM can be significantly improved. It is believed that the application of PCM on the building envelope with cool and environmentally friendly natural and solar ventilation can be one of the most effective measures to minimize indoor temperature fluctuations and mold and reduce building energy consumption and CO2 concentration.
Indeed this energy saving in terms of electricity consumption is more important where the (MSV+PCM) saves respectively about 55% of the electrical energy of cooling. On the other hand, it should be noted that MSV has no significant effect on the heating load, the results also showed that the higher the amount of solar ventilation, the more the PCM improves the indoor thermal comfort in summer , but the effect of the amount of solar ventilation on the energy consumption becomes insignificant when the ventilation is higher than 1.3 AC/H in summer (reduction of 97%), and when decreasing the amount of solar ventilation between 0.4AC/H and 1.3 AC/H the energy consumption decreased in winter (reduction of 52.5%). So we take between 0.4 and 1.3 AC/H in the heating period and between 1.3 and 2.2 AC/H in the cooling period. This means that the amount of ventilation also played an important role in reducing energy consumption.The best combination of all energy efficiency measures studied for the climate

zone (CASABLANCA NOUASSEUR) was evaluated by comparison with a reference case without (PCM-DISCOMFORT-MSV) . The result is that the recommended techniques lead to an energy- efficient building because its cooling and heating energy is reduced. In addition, the resulting apartment heat load is consistently lower than the RTCM (2014) requirements.

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[14] HVAC system According to the requirements of ASHRAE 90.1-2010 Appendix G, the HVAC system in the base model depends on the building type.

APPENDIX

ABBREVIATIONS

Symbol ACH: Air Changes per Hour IEA: International Energy Agency TI:Température interne
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers CFD: Computational Fluid Dynamics
VMS: Ventilation mécanique solaire. HVAC: Heating, Ventilation and Air-Conditioning PCM : Phase Change Materials
MEMEE: Ministry of Energy, Mines, Water and Environment MSV :Mechanical solar ventilation
PMV :Predicted Mean Vote PPD :Predicted Percentage Dissatisfied Ground floor: Ground floor
RT : Thermal regulation (France) RTCM : Thermal regulation of constructions in Morocco TMY: Typical Meteorological Year
TPF :TRNSYS Project File TRNSYS :TRansient SYstem Simulation

NOMENCLATURE

A : thermal diffusivity (m2/s) Cp :specific heat capacity (J/kg.K) Cel : cost of electricity E : layer thickness (m)
H : heat transfer coefficient (W/m2.K), specific enthalpy(J/kg) i :inflation rate (%)kwh k :thermal conductivity (W/m.K)
n :lifetime of building (years) N : number of layers of the composite wall PCM: phase change material
Qc :yearly cooling transmission loads (J/m2) Qh :yearly heating transmission loads (J/m2)
Qtot :total yearly transmission loads (Qtot ¼ Qh þ Qc) (J/m2) T : time (s) T : temperature (°C) Ta :ambient air temperature (°C)
Tc : cooling set-point temperature (°C) Tsky :sky temperature (K) x :coordinate direction normal to the wall (m)

Greek Symbols

ε :emissivity f :time lag (h) h :reduction rate of annual energy consumption (%) hs: efficiency of the heating system
c :convective i :inside, node numbe j :layer number o: outside r: radiative s :surface, solar
Qi Net heat gain W Q surf Convective gains from interior walls W Q inf Infiltration gains W

Q wind Ventilation gains W Q g,c Internal convective gains (from occupants, equipment, lighting, etc.) W
Q cplg Convective gains due to air flow between zones W Q ISHCCI Solar radiation absorbed by internal shading devices in the area, which is directly transferred as convective gain to the indoor air W
Q r,wi Radiative gains by the wall surface node W Q g,r,wi Internal radiative gains received by the wall W
Q sol,wi Solar gains received by the wall via the windows W
Q long,wi Gains through radiant heat exchange between a wall and other walls in the zone W
QH Heating load kWh/(m^2.a) QC Cooling load kWh/(m^2.a)
Q Total heat load kWh/(m^2.a) RH Relative air humidity %.