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# Simulation of floor heating in a combined solar-biomass system integrated in a public bathhouse located in Marrakech

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**Abstract.** This study was conducted in the framework of the HYBRID-BATH project aiming at improving the energy efficiency of traditional Hammams (Turkish baths) and the reduction of the use of wood energy and therefore of greenhouse gases emissions. The present work focuses on the energetic performance of a two-room Hammam located in Marrakech. The rooms were heated by the ground using a hybrid system Micro-CSP/ biomass boiler. The dynamic simulation of the system (Hammam coupled with the hybrid system Micro-CSP/ biomass boiler) was conducted using TRNSYS18 software. The parametric study was performed on a Typical Meteorological Year data (TMY). This study is devoted to presenting the results of the dynamic simulation of a part of the Hammam investigated, in order to optimize the underfloor heating system. The models and the results of the simulations will be validated by comparisons with experimental results. The main objective is to optimize the operation of such system and to improve its performance.

## 1. Introduction

The number of traditional Hammams in Morocco is on the order of 10,000 units. A traditional Hammam consumes on average 1.5 ton of wood and between 60 and 120 m$^3$ of water per day. This significant consumption is mainly due to the low performance of the systems used for heating that generate considerable losses and contribute to over-exploitation of forests. Any approach to reducing this consumption will contribute to the preservation of these two resources that are more and more stressed in Morocco. In this context, it becomes more and more urgent to put in place innovative solutions for the Hammams to limit their impact on the environment.

In this work, we focus on developing other techniques to produce heat and hot fluids based on solar and biomass energy technologies, as Morocco has significant solar resources of about 5 kWh.m$^{-2}$.day$^{-1}$ and over 3,000 hours of the sunshine per year [1] and undeniable biomass from various agricultural residues. In particular, the Parabolic Trough collector (PTC) will be hybridized with the biomass boilers in order to provide a reliable heat supply to the various components of the Hammam. The biomass boiler will use local resources (olives pomace, walnuts, almonds and argan shells...).

Indeed, the objectives of the HYBRIDBATH project (Hybrid solar / biomass systems for the production of hot water and heating in traditional Hammams) are two-fold. 1) to improve and standardize the combined solar-biomass heating systems ; 2) to advance the research in the technical interaction between the biomass boiler, the water storage system, the solar thermal collector, and floor heating. The overall aim of the project is to improve the energy efficiency of traditional Hammam (Turkish baths) and to reduce the consumption of wood energy and therefore of emissions of greenhouse gases.

Many studies available in the literature evaluated the contribution of some hybrid solar-biomass heating system through simulations and experiments. In this regard, D. Chasapiset al. [2] presented a complete cycle of the operational results of a thermal solar-biomass hybrid system for space heating in Greece. They found that the results are promising with respect to the technology and energy requirements: the daily coverage of the heating from the solar collectors often exceeded 40%. The CO2 emissions avoided by the use of this system from November 2005 until the end of April 2006 have been calculated as 1.016 tons. A similar study based on a dynamic simulation by TRNSYS was conducted by Florian Stift et al. [3] who studied the combined biomass-solar thermal system for heating and domestic hot water supply, designed for small residential applications. The system consists of a thermal storage with an integrated pellet burner and a heat exchanger to feed solar energy from a small collector field into the storage. They have reduced the use of biomass by 17% and an increase of 11% of the solar energy supply could be achieved.

A detailed study of combined solar and pellet heating systems have been carried out by Fiedler [4]. In the study 4 solar and pellet heating systems were studied with the help of annual dynamic simulation. Two of the systems comprised a pellet stove and two systems were solar combisystems; one with a store integrated pellet burner, the other with a separate pellet boiler. The biomass stove and boiler model developed by Nordlander were used in these studies [5].

Other studies focusing on the technique of solar heated floor were conducted in the literature. Martinopoulos and Tsalikis [6], studied the active solar heating systems for energy efficient buildings. They performed a technical and economic evaluation of a solar space heating system, installed in a house of 88 m² surface. The analysis was performed for each of the four climate zones designated in the thermal regulation in Greece. They found that the solar system covers at least 45% of the total heating load whereas the recovery period was less than 4.5 years with an annual reduction of more than 50 tons of CO2 in the worst case. Sobhy et al [7] worked on improving the energy performance and thermal behavior of a solar system for heating a single Family Hammam through a heated floor in Marrakech. Two configurations with or without thermal storage, were compared. The dynamic simulation with the TRNSYS software was used to optimize the solar floor heating system.

Furthermore, the experimental study on floor heating was made by Kharchi et al. [8] who studied the thermal behavior of a system with direct solar floor in Bouzaréah (Algeria). Twenty thermocouples were installed at various points of the slab as well as in the inlet and in the outlet of the slab. The authors found DSF (direct solar floor) lowered the temperature of the zone by 1 to 2 °C. In addition, the DSF avoided the phenomenon of cold zone, and the heat was evenly distributed. The dynamic simulation of solar heating floor system by TRNSYS was done by Sobhan-sarbandi [9]. He carried out a comparative study of the effectiveness of two type of solar collectors to heat the floor of a house in Gazimagusa in northern Cyprus under the same conditions during the five coldest days of winter. The first is composed of solar flats collectors in series with a total surface area of 8 m². The second was a compound parabolic collector (CPC) of an area of 2 m². The results showed that the CPC collector provided an equivalent performance to all of the flat collectors in series, and it was able to maintain the desired comfort floor temperature of 25 °C.

The aim of this work is to analyze the energetic performance of Hammam (Turkish bath) situated in Marrakech heated by underfloor heating system. The Dynamic simulation of the Hammam coupled with the hybrid Micro-CSP/ biomass boiler system was conducted using TRNSYS software.

## 2. Description of the hybrid heating system installed

### *2.1. Parabolic trough collectors*

The increase in the use of solar collectors in recent years for domestic hot water preparation has shown that solar heating systems are a mature and reliable technology. Motivated by the confirmed success of these systems for hot water production, an increasing number of home builders are considering solar energy for space heating as well.

In this work we will use the Parabolic Though Collectors (PTC) (TREVELLI, Italy) to pre-heat the water for the Hammam. The PTC collects beam radiation, within a critical angle called the half-acceptance angle and focusses it on its focal line where receiver is placed. Technical characteristics of Parabolic Trough collectors used in this study are presented in Table 1.

**Table 1.** Technical characteristics of parabolic troughs.

| | |
|---|---|
| *Number in series (PTC)* | *6* |
| *Area* | *8,25 m² * 6* |
| *Fluid used* | *Eau + glycol* |
| *Maximum Temperature* | *250°C (programmable)* |
| *Tracking* | *Mon-axial* |
| *Peak Power (at DNI 1000 W/ m²)* | *6 Kw* |
| *Life expectancy* | *20 years* |

### *2.2. Biomass boilers*

The Biomass boilers (Klorina 22, TATANO, Italy) used in this work run at an efficiency of 89 – 91% compared to 28 to 32 % for traditional ones used in public Hammams, with a thermal power output of 2*115 kW. The Biomass feed and air flow can be readily controlled. We plan to use a renewable biomass as feed that have a minimal impact on the environment, such as:

- Pellets,
- Olive pommace,
- Almond shells,
- Argane shells
- Nut shells, etc.

### *2.3. Floor heating*

Under-floor heating is a method heat is provided through the floor. The floor heating system is installed in the three rooms (hot, warm1 and warm2) of each compartment. It covers a surface of 29.6 m² in the hot and warm rooms, and 33 m² in the second warm room, as shown by the Figure 1.


**Figure 1**.Three different underfloor heating systems, (a) hot room, (b) the first warm room, (c) the 2nd warm room.

## 3. Description of the hybrid system studied with TRNSYS

The essential idea is to couple the heat emission device used for space heating to both the boiler biomass and the solar collectors in such a way that the users of Hammam can benefit from the heating floor comfort throughout all the day. The system is modelled in TRNSYS, and the model includes collectors, collector loop, storage, boiler biomass, building (floor heating), pumps, and control system. A schematic diagram of the system is shown in Figure 2. As shown in this Figure, the buffer tank for space heating is heated by the heat exchanger of the parabolic trough collector. When solar energy is not adequate, the temperature in the top of the buffer tank drops below the set point and the system will be backed up by the biomass boiler. Furthermore, the boiler will be operated at the maximum set temperature, which is 80 °C.

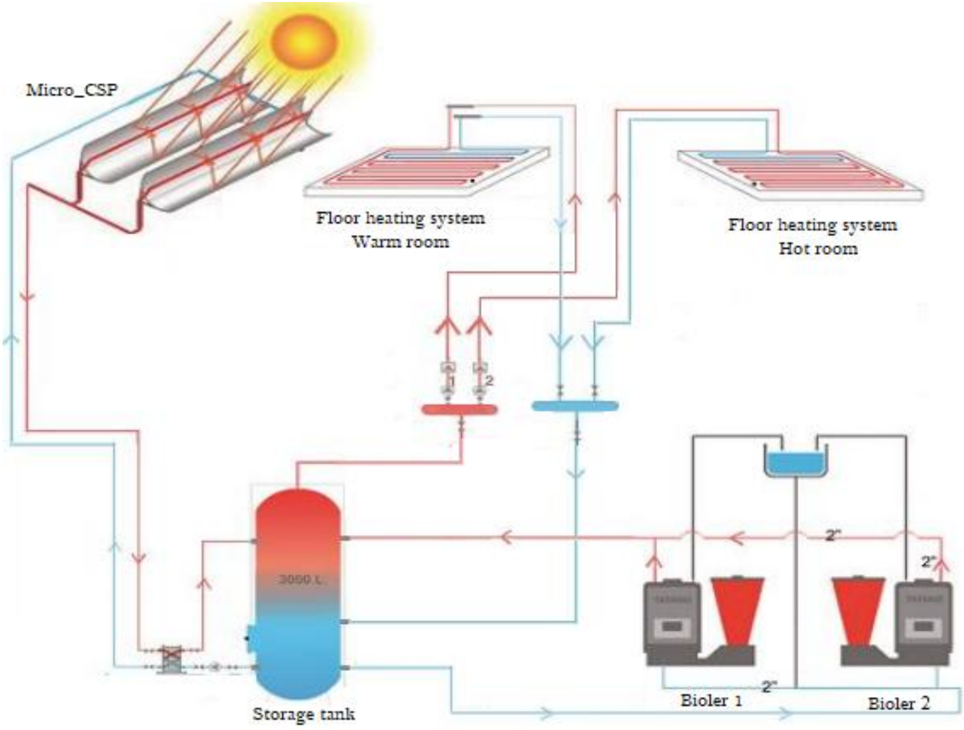


**Figure 2.** Hydraulic schematic for the simulation of the solar combisystem

## 4. Dynamic simulation

The thermal behavior of the part of Hammam studied with heated floor coupled to the hybrid solar/biomass system is modeled through the dynamic simulation software TRNSYS 18 using the model of building (Types 56) [10] as shown in Figure 3.

Transient Systems Simulations (TRNSYS) software is a complete and extensible simulation environment for the transient simulation of thermal systems including multi-zone buildings. It is widely used around the world by engineers and researchers to investigate alternative energy applications, from some simple systems such as domestic hot water system to the design and simulation of buildings and their equipment, including residents behavior, control strategies, alternative energy systems (wind, solar, etc.) [11].

The simulation of the building was carried out using standardized meteorological data (TMY) from Meteonorm [12]. TMY reads the weather information regularly, and checks the solar radiation data to find tilted surface radiation and angle of incidence for an arbitrary number of surfaces. Marrakech climate conditions are used for simulation. The weather data are given on hourly basis.

## 5. Results and discussion

The studied system is located in Marrakech, Morocco (31°38'N latitude, longitude 8°03'W, altitude 426 m), 200 km from the Atlantic coast. The climate of Marrakech is characterized by approximately cold winters and very hot summers, as well significant differences between day and night temperatures. The climate is classified as semi-arid with 3000 h/year sunshine [1]. Figure 4. shows the average hourly temperature of the ambient air for a typical meteorological year in Marrakech.

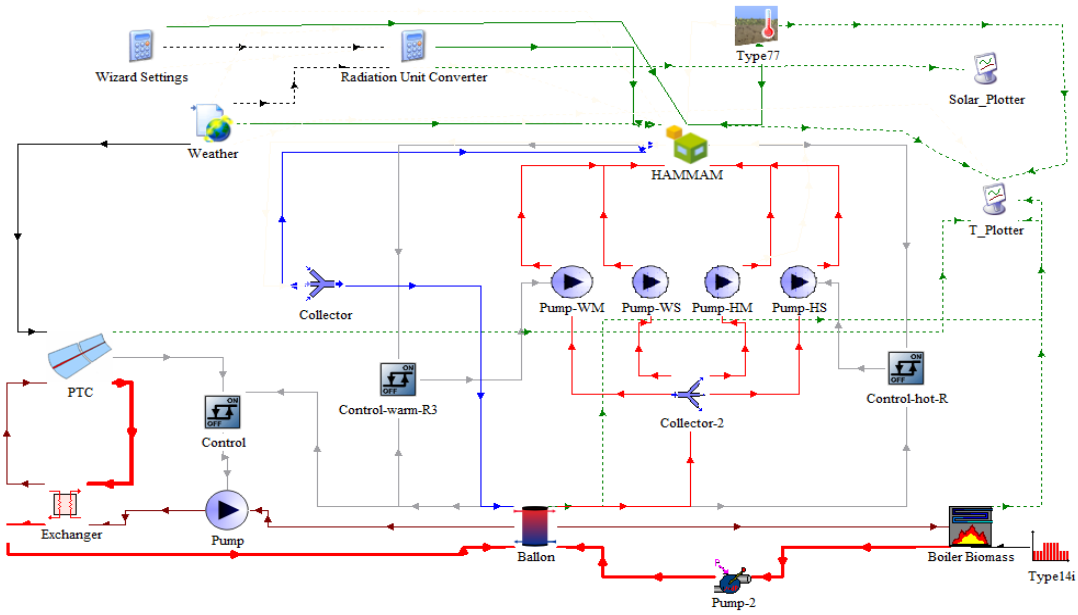


**Figure 3.** Thermal TRNSYS simulation model

The main objective of this work is to study the influence of solar combisystem on the thermal behavior of the part of Hammam during the winter period when heating is needed, in order to achieve the comfort temperature for a Public bathhouses. The simulations were done during the month of December because it is one of the coldest months of the year. As shown in Figure 4. January and December are the coldest months with an average air temperature of 12 °C and 13 °C respectively. The results are obtained during the last week of December.
The hourly ambient temperature (Ta) of Marrakesh and also the total radiation, direct horizontal and direct on the aperture of the collector from the 24th to the 31st of December are presented in figures 5 and 6. It can be observed that, during the night, Ta can be as low as 16-18 °C, while during the day it is between 28 and 33 ° C. The total solar irradiation in Marrakech on a horizontal plane ranging from 3 to 3.6 kWh $m^{-2}$ $day^{-1}$.

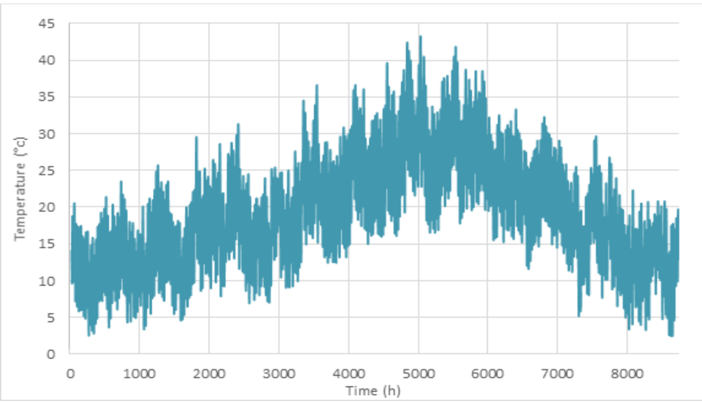


**Figure 4.** Outside temperature variation during year in Marrakech (TMY data)

A reasonably accurate knowledge of the solar radiation is necessary for solar energy systems such as solar thermal. In this regard, it is important to be able to predict the angle between the sun radiation and a vector normal to the aperture or surface of the collector. In this study we used the two axis-tracking mode for the PTC, because the angle of incidence is equal to zero in this case. Therefore the maximum amount of the direct solar radiation is collected as the collector aperture points directly towards the sun.

The results obtained in Figure 6. show that during the day, the temperature of the water flow increases as solar energy is absorbed by the solar collectors. The outlet fluid temperature for the PTC is between 52-190 °C. During night time water will be stored in storage tank.

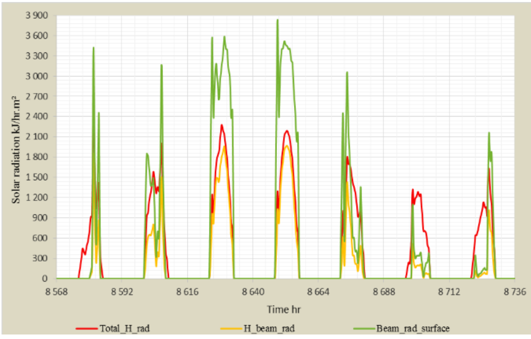


**Figure 5.** solar radiation -24th until 31st of December

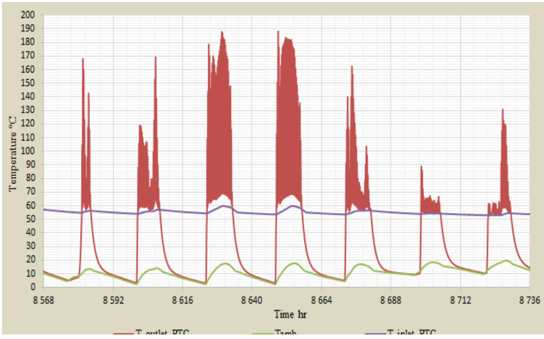


**Figure 6.** the hourly variation of inlet and outlet water flow temperature - PTC collector -24th until 31st of December

## 6. Heating the Hammam by the combined system in cold winter period.

### *6.1. Building temperature evolution*

The studied Hammam composed of two Rooms (Hot and Warm), each one is a monozone building (6×3×3 $m^3$). The maximum performances from the combined system is achieved by use of 8,25 m² of parabolic trough collector, a 100 kg/hr of collector mass flow rate and a 3000 l of hot water storage tank. The heating system is embedded in the floor and some parts of the walls at 0.8 m height, the mass flow rate of water circulated through the radiant floor $\dot{m}$=300 kg/hr, and the simulation time step $\Delta$t=0.125 hr.

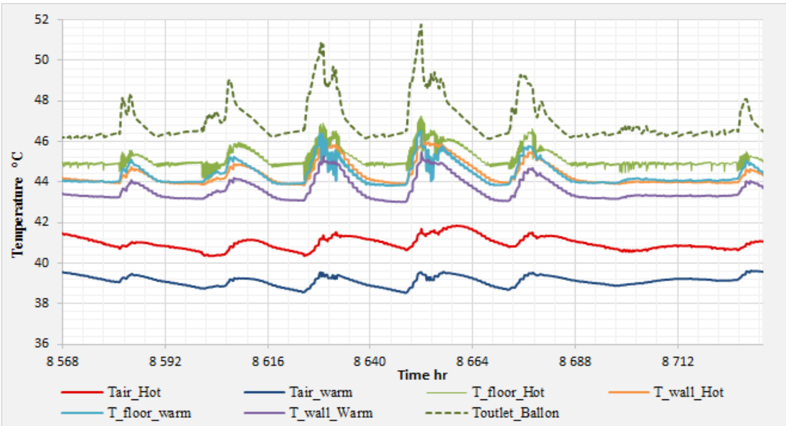


**Figure 7.** Evolution of different temperatures inside the hot and warm rooms - 24th until 31st December.

The results show that during the whole day the boiler is turned off and only heat from the solar collectors is used. At night or during a cloudy day; if the temperature in the hot water tank gets below the set temperature (60 °C), the controller will turn on the biomass boiler to keep the top of the tank at the needed temperature.
The analysis of the Figure 7. shows that the operating temperature does not exceed 43 °C in the hot Room and 40 °C in the warm room. In addition, the temperatures of the floor and wall surfaces in the warm and hot rooms are between 43 and 46 ° C. Further, this range represents the temperature of comfort inside the traditional Hammams in Marrakech.

### *6.2. The effect of tubing materials on the floor temperature*

The thermal properties of under floor heating tubing can play an important role in the efficiency of the heating system. In this study, a comparison between the two tubing materials commonly used as floor heating coil, namely copper and crosslinked polyethylene (PEX) was carried out. The thermal conductivity of copper tubes and PEX are 328 $W.m^{-1}.K^{-1}$ and 0.45 $W.m^{-1}.K^{-1}$ respectively. The figures below present the temperature of the heated floor surface with copper and PEX pipes and the operative temperatures of the two rooms in the presence of water flow regulation.
Figure 8 and 9 shows the difference between the temperature of the heated floor with copper and PEX tubing in the hot room as well as in the Warm room.

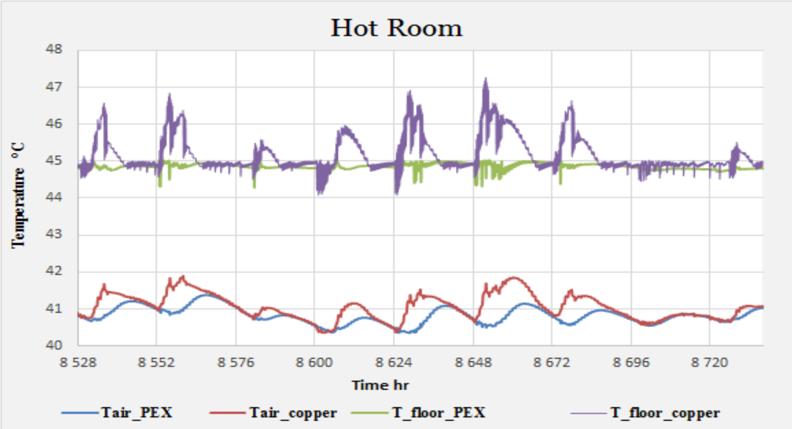


**Figure 8.** The operative room temperature and floor heating surface temperature for copper and PEX tubes in warm room-22th until 31st of December

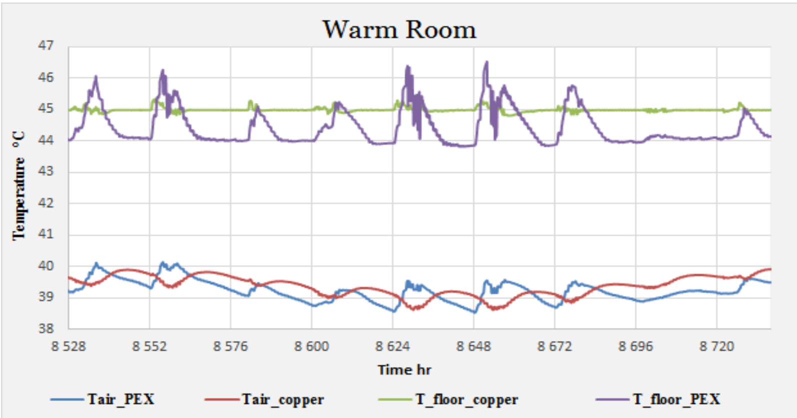


**Figure 9.** The operative room temperature and floor heating surface temperature for copper and PEX tubes in warm room-22th until 31st of December

As shows in Figure 8, the temperature of the heated floor surface has the same behavior, the maximum surface temperature difference between the two serpentine types is 2 °C. For the warm room, as shows in Figure 9, the maximum surface temperature difference between the two serpentine types is on the order of 1 °C.
From these results, we note that, although copper tubing has a higher thermal conductivity compared to the PEX one, it has not a significant effect on the heating floor surface temperature. However the cost of Copper tubing is higher than the cost of PEX tubing. The economic solution is to use PEX tubing as a tubing material.

*6.3. The effect of the distance between tubes on floor surface temperature*

Figure.10 shows the effect of changing the distance (dx) between the tubes on the floor surface temperatures of the hot and warm rooms in the last week of December. From the figures below we note that the surface temperature of the floors increases with decreasing dx. We also note that for the hot room, the floor surface temperature for dx = 7 cm is between 44 to 47,5 °C and for dx= 16 cm it is between 44,5 to 45,5°C, furthermore, the floor surface temperature of warm room for dx = 7 cm is between 44 to 46,5°C and for dx= 16 cm is between 43,5 to 45°C. We found that with the controllers that are used to regulate mass flow rates, with an even smaller dx, it is expected that the maximum floor surface temperature would exceed the thermal comfort criteria of the Hammam (46 °C) for both hot and warm room.

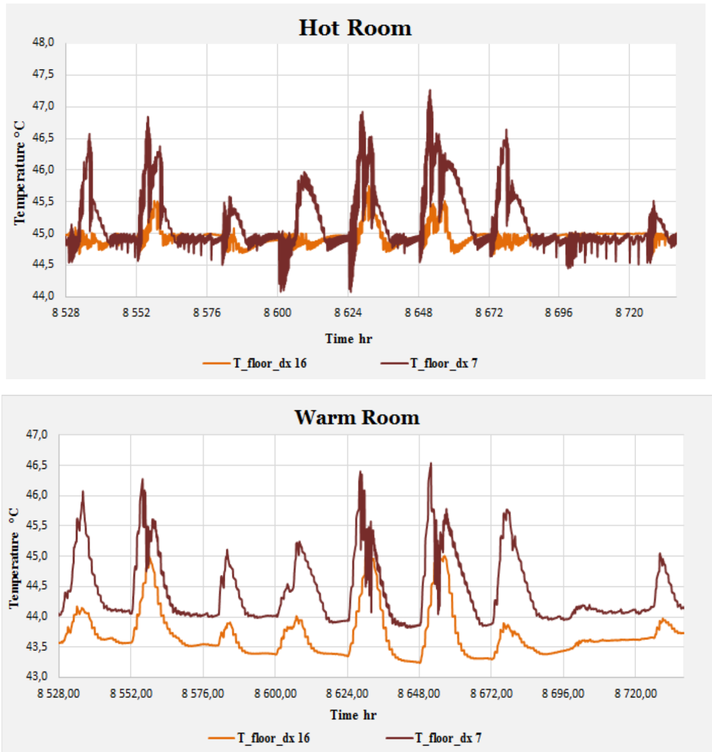


**Figure 10.** Floor surface temperature in the hot and warm room with different distance between tubes-22th until 31st of December.

## 7. Conclusion

In this work, we modelled a combined solar/biomass system for heating two rooms of the Hammam located in the city of Marrakech during the last week of December. Dynamic simulation via TRNSYS software was used in order to optimize the floor heating system. The biomass boiler is required to overcome the shortcomings of solar energy (intermittency), in order to keep the operative temperature at the zone of comfort of a Hammam throughout the day.

The influence of pipe material on floor surface temperature was investigated. It is shown that there is no significant difference of floor heating either temperature when copper or PEX tubing are used. The optimum solution is therefore to use PEX tubing as pipe material. In addition, we studied the effect changing the distance between the tubes on the floor surface temperatures for the hot and warm rooms.

The next steps concern to study a combined biomass-solar system for domestic hot water production and space heating, of a full global model of Hammam coupling of these different models under the environment of TRNSYS 18. The validation of the model will be realized through the comparison with the experimental measurements, which will be carried out. The main objective is to optimize the operation of such system and to improve its performance.

## 8. References

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# Corrigendum: Simulation of floor heating in a combined solar-biomass system integrated in a public bathhouse located in Marrakech

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Description of corrigendum e,g,

**Page 2 and 3:**

In order to make the paper homogeneous and more organized, I changed the subtitle ranking:

| *from:* | *To :* |
|---|---|
| *2.1. Parabolic trough collectors* | 2.1. Floor heating |
| *2.2. Biomass boilers* | 2.2. Parabolic trough collectors |
| *2.3. Floor heating* | 2.3. Biomass boilers |

**Page 2:**

In the floor heating part, the following text appears:

*"Under-floor heating is a method heat is provided through the floor."*

This should read:

*"In order to improve the energy efficiency of the Hammam we used the technique of underfloor heating, it's provides an effective control for the bath room's temperature using water as heat transfer fluid, it radiates upward from the ground, moving heat into the air and heating the surroundings gradually and positively without excessive heating. Indeed, it reduces both energy and water consumption. "*

***Figure captions;***

I improved the quality of all the Figures, in order to be like the template of the journal.

*Figure 1*; **page 3.**

*Figure 5, 6 and 7*; **page 6.**
*Figure 8 and 9*; **page 7.**
*Figure 10*; **page 8.**

**Example: figure 8;**

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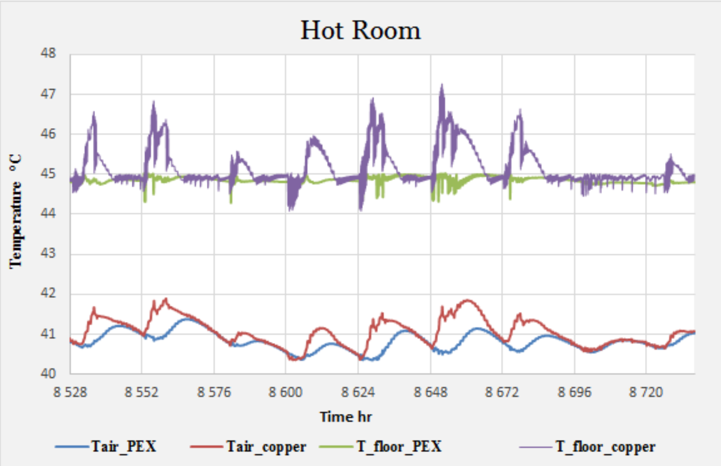


**Figure 8.** The operative room temperature and floor heating surface temperature for copper and PEX tubes in warm room-22th until 31st of December

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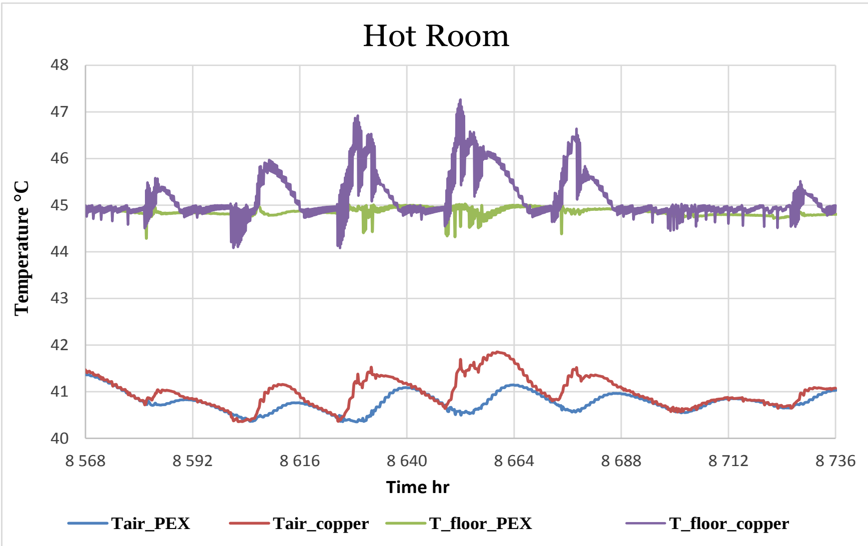


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