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The principles of sauna physics

K. Nore*, D. Kraniotis, C. Brückner

Norwegian Institute of Wood Technology, Forskningsveien 3B, 0373 Oslo, Norway

Abstract

The interaction of the wood surface and indoor climate has been of increasing interest the last decade. The fluctuating air humidity reacts with the wood surface to seek equilibrium moisture content. This reaction is crucial when experiencing a sauna. The instant heat contribution of the latent heat from the released damp when pouring water on the oven gives the intense perceptible sauna experience. This paper shows a set of measurements and calculations conducted in a Norwegian sauna. One sauna event includes in three parts. The heating of the sauna, increasing the temperature and drying out the wood. Then when visiting the sauna is, with the changes between warm and cold, like taking a cold bath in between being heated in the sauna. Usually also this heating includes pouring water on the oven. The physics around this moistening of the sauna is of special interest in this paper. Finally, the visitors leave the sauna and it cools down.

The focus in this paper is on the increase of temperature when pouring water on the oven in the sauna. Different moisture protocols are ran with varying amounts of moistening. The protocols follow real sauna experiences. Surface temperature is carefully measured and recalculated. The key role of the wood surface sorption, providing this latent heat phenomenon, is presented in the results. The sensible heat increase is not due to the change of humidity, as often stated. The heat conductivity is actually higher in dry air compared to moist air. The damp transport energy from the sauna oven through high enthalpy in the air. The damp is absorbed in the dried wood surface and consequently emits latent heat energy back to the room. That is, the surfaces becomes substantial heating panels. The heat release due to wood surface sorption is an extreme employment of the potential of the latent heat. The authors believe that this effect may be significant also in other cases, with smaller water potentials. This is elaborated in the paper.

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* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: kristine.nore@treteknisk.no

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Nomenclature

V	internal volume of sauna room
t	time
T_r	room temperature
RH	room relative humidity
T_s	surface temperature
T_{sp}	surface temperature of the plain surfaces
ε	emissivity of the interior wooden surfaces (*picea abies*)

1. Introduction

The awareness of influence of hygroscopic materials use in buildings is growing. The moisture buffer capacity of such structures has been analyzed in several studies [e.g. 1, 2, 3, 4]. The results showed that hygroscopic materials, as wood, hold the potential for energy savings through reduction of ventilation rates. Beyond this fact, moisture buffering reveals an interesting area of the building physics that has been barely explored so far: the latent heat. Latent heat is the sorption energy released or used in the open pores of materials during the exothermic or endothermic process of phase change from vapor to liquid water or vice versa. Even though relevant studies have displayed the advantageous role of hygroscopic materials by defining their hygrothermal behavior, the energy potential is very often neglected from the calculation methods and the simulation tools. This raises an important question; is it possible to take advantage of the effect of latent heat in order to save energy?

Since heat and moisture phenomena are coupled, the surface temperature will increase when moisture accumulates in the hygroscopic structure and decrease when moisture is dried from the structure, both also resulting in lower air enthalpy. The increase of the surface temperature arises the potential of direct energy gains by increasing the indoor temperature as well. A hygrothermal model accounting for the moisture and heat transport in a solid wood envelope directly exposed to an indoor climate has been presented [5]. The heat provided equals 2.5 kJ/g at 0 °C. This amount is somewhat lower in higher temperatures. Recently, thermography techniques were employed to detect the increase of surface temperature in Norwegian spruce samples (*picea abies*) [6]. The results showed that when the RH of the climate chamber increased, the surface temperature increased by 2.4 °C, while when the same samples were covered by a transparent low-density polyethylene foil the increase was only 1.1 °C.

This paper employed the example of a sauna room in order to study further the buffer capacity and consequently the latent heat phenomena. By operating a sauna, one means pouring water on the sauna stones-oven, resulting in increasing the humidity in the sauna volume. A typical sauna is operated at 75-90°C and with 20-35 % relative humidity (RH) [7]. The materials subjected to this climate dries out, and the wooden moisture content (MC) is expected to be around 4 %. When increasing the RH with damp from water poured on the sauna oven, the dry material absorb and bond with the excess moisture to create equilibrium. The energy form the bonding is radiated mainly back to the room, heating the room instantly.

This paper shows results from thermography of three moisture protocols, i.e. 1lt, 2lt, and 3lt in a sauna. The indoor RH and temperature are recorded and presented as well. In addition, a comparison between treated (normal) and untreated (plain) spruce wood panels surfaces are shown, by means of the surface temperature increase.

2. Experimental setup

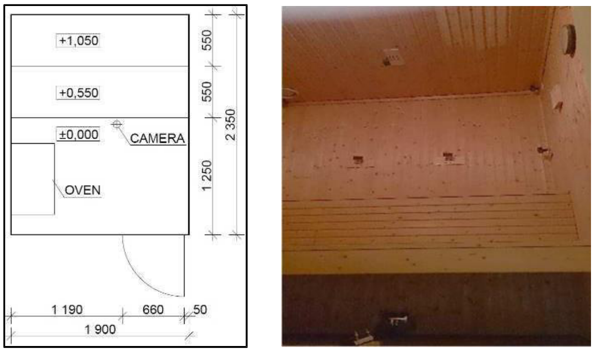
The experiment took place in one of the sauna rooms located in the building of the Norwegian Institute of wood Technology. The internal volume of the sauna is V = 10.26 m^2; the dimensions are: 1.9 m x 2.3 m x 2.45 m. The whole room is encladded with spruce panels (*picea abies*), including floor and ceiling. A two–level bench is facing the door side. The door has an opening of 1.11 m^2 (1.85 m x 0.6 m). In order to eliminate the leakages through the opening, the frame of door was sealed throughout the measurements. A duct is located at the corner of the ceiling of the room and was closed during the measurements. All light sources remained switched off during the test in order to avoid additional heat sources.

The heat source is a typical sauna oven with a power of 6.6 kW and it is mounted on the wall. According to its manual, it is dimensioned for rooms with floor area from 6 to 8 m^2. The electric resistors are covered by stones. During the experiment, the oven was covered by a common aluminum foil in order to decrease the factor of environmental radiation and consequently to reduce the impact on the thermography pictures. The left and the lower right side of the oven were uncovered to ensure the air circulation. The top side of the oven was temporarily uncovered when pouring the water on the sauna stones and immediately afterwards covered again.

A part of the ceiling was chosen as ‘control area’ for the thermography, as the vapors -after pouring water in the oven- would mostly move upwards. The Thermography camera was placed on the floor facing up to the measuring area. The measuring distance was 2.4 m. The camera used employs the long wave range, i.e. 7.5 – 13 μm, while the sensitivity of instrument is ⩽ 0.05 °C. The uncertainty is ±2 °C. Regarding the emissivity, based on the supplementary material of the thermography camera a value of $\varepsilon = 0.9$ was chosen. This is the highest value for wood surfaces in the range of temperatures between 20 and 70 °C. In each measurement-test the reflective apparent temperature was measured before in order to correct the recorded values.

A hand-held humidity and temperature meter was placed in 1.6m height near the opposite wall of the oven. The probe used has accuracy T = ±0.18 °C and RH = ±1.2 % at an atmospheric temperature of 70 °C. At a RH range between 0 and 40 % the uncertainty is RH = ±0.6 %.

Wood moisture meters were installed to record the change of surface moisture content. These measurements are not included in this short version of the experiment.



(a) (b)

Fig. 1. (a) Plan view of the sauna room; (b) View of the thermography camera and the measuring area at the ceiling (taken from the floor level).

3. Methodology

The experiment represent a typical usual sauna process. Before the recording started, the room was heat up to roughly 70 °C. Due to instability of the oven thermostat, the room temperature was fluctuating between 64 and 72 °C approximately, within a period of nearly 20 min.

Each measurement lasted for t = 20 min, i.e. 1200 s. At the beginning of the each measurement, the door was opened in order the person executing the experiment to enter the sauna and then closed again and sealed. This was determined as t = 0 s. In order to let the room to reach an equilibrium, approximately five minutes were spend until the first moistening. The second moistening was taking place at a time period of 10 min after the first one. The logging stopped after five minutes, at time t = 1200 s.

In total, four measurements were executed; Test A, B, C and D. Water amounts of 1, 2, 3 liters were poured on the sauna stones respectively for Test A, B and C, at t = 300 s and t = 900 s. The Test D is as the Test A, i.e. pouring 1liter of water twice, but the difference is that a part of the wooden panel surface was planed in order to study potential differences in the moisture absorption as well as in the surface temperature compared to the old sauna panels. In additions a known reference wood piece was included.

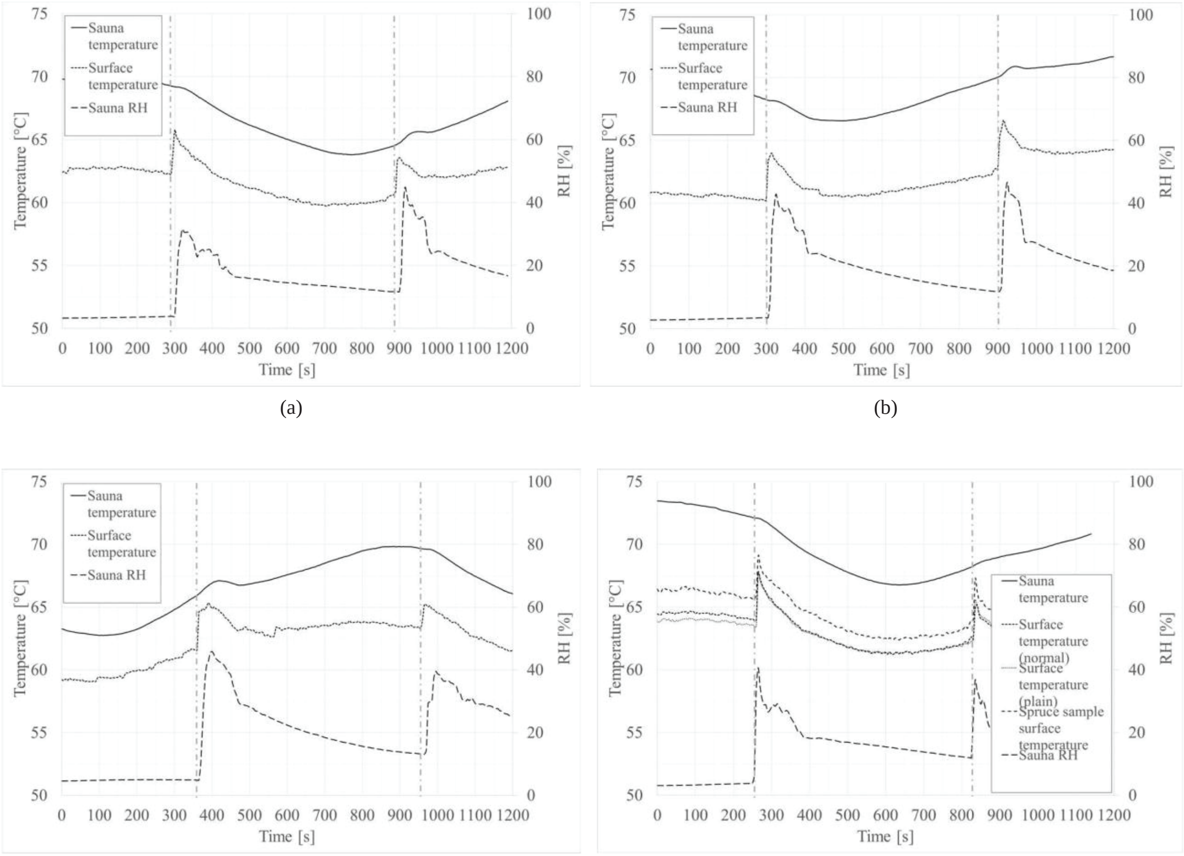
The water has temperature of was around 20°C. Table 1 summarizes the details of each measurement.

Table 1. Overview of the measurements executed.

Measurements	Amount of water poured (twice) on the sauna stones	Surfaces of wooden panels
Test A	1 lt	Normal
Test B	2 lt	Normal
Test C	3 lt	Normal
Test D	1 lt	Plain

4. Results

The results of the sauna air temperature and RH as well as the surface temperature of the spruce panels are shown in Figure 2. The oven in the sauna studied was not able to keep a constant temperature. This is in the solid line, with descending and rising temperatures of the sauna (operating temperature) in all graphs in Fig. 2. Each test start was attempted to hit the top of the oven heating cycle, but not always with luck, as seen in C test which started a bit late. However, all experiments shows one descending and one rising temperature.



(a) (b)

(c) (d)

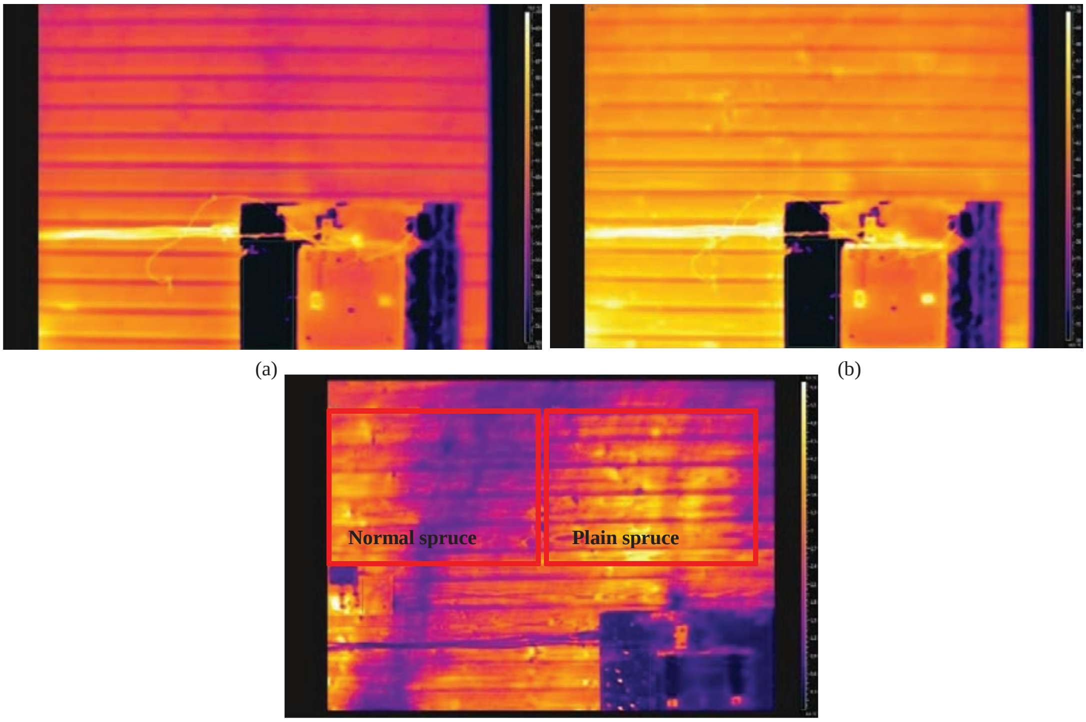
Fig. 2. Time series of sauna air temperature, relative humidity and spruce surface temperature (a) in Test A; (b) in Test B; (c) Test C; (d) Test D.

The RH clearly increase when water is poured, as shown with the bottom lines, and linked to the secondary axis. The RH before pouring the water was at the level of 4-5 %. An incrementing trend is shown with the increasing amount of water, as seen by comparing the Test A, B and C. In particular, in A with 1 liter the RH increase around 30 % in each moistening, B with 2 liters increase around 35 % and C with 3 liters increase over 40% at least the first time 3 liters is poured.

The thermography of the sauna ceiling, presented with the middle dotted line(s) in each graph in Fig. 2, is clearly responding to the change in RH. The curve evidently follows the RH. The surface radiates the latent heat from the bonding water molecules. The surface temperature rise approximately 2.5 °C in all Tests, i.e. A, B and C despite the fact that the moisture protocol is different; 1, 2 and 3 liters of water respectively. The duration of the increase is almost the same as well. It would be reasonable to claim that these two facts imply that a max pulse has been reached. The wood panels is likely not to able to absorb more damp and emit higher radiation.

The operative temperature reflects the temperature increase given from the wooden panels. Clearly, the effect is smaller compared to the increase of the surface temperature, i.e. 0.5 °C or lower. Especially when the temperature of the oven (and consequently of the room) is descending, the phenomenon is even more hard to see. This trend is not well understood by the authors. It is assumed that the high indoor temperature of the sauna is not significantly influenced by the increase of the surface temperature. However, there is an indication that potentially the indoor temperature can be affected by the latent heat exchange.

In experiment D, a part of the ceiling surface that has been monitoring during the previous tests is now 'plain'. This does not give particular changes in the surface temperature measured. Hill explain thermal wood modification [8]. No changes in the cell structure or wood composition are expected prior to reaching to around 150 °C, when the amount of hydroxide ions decrease. Thus, even with high temperatures in the sauna the wood should react like normal, untreated wood. In this experiment (Test D), a known spruce sample was included, showing somewhat higher surface temperature, but with the same temperature change achieved (Fig. 2d).



(a) (b)

(c)

Fig. 3. Thermography images of the control ceiling area (a) before first moistening (Test C); (b) right after moistening (Test C); (c) temperature difference between the normal (treated) spruce surface (left) and the plain (treated) one (Test D, second moistening).

5. Conclusions

The sauna physics have been studied and presented in this paper in order to understand in a better way the latent heat exchange when moisture is absorbed in a hygroscopic surface. The results showed that there is a significant increase of surface temperature in the spruce panels when the RH in the room increase by pouring water on the sauna stones (oven). The increase was the same in all the moisture protocols studied, indication that the moisture capacity of the specific cladding had been reached even with the lowest amount of water added. The increase in the room temperature was lower compared to the ones of the wooden surfaces. However, a reason could be that the high temperature of the sauna cannot be significantly affected by the radiation emitted by the hygroscopic surfaces through the latent heat exchange. In a conventional room, the phenomena ought to be more clear. Finally, a comparison between treated and untreated spruce surfaces confirmed that no changes in cell structure or wood modification are expected in temperatures below 150 °C, as the surface temperature of the two are tested behaved similarly.

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