Impact of the moisture buffering effect of wooden materials on energy demand and comfort conditions

Matthias Winkler, M.Eng. [1]
Kristine Nore, PhD [2]
Florian Antretter, M.Eng. [1]
[1] Fraunhofer-Institute for Building Physics, Germany
[2] Norwegian Institute of Wood Technology, Norway

KEYWORDS: *Latent heat exchange, moisture buffering, wood, energy demand, comfort conditions, building simulation*

SUMMARY:
This paper assesses the effects of moisture buffering and related latent heat exchange in wooden surfaces on energy demand and comfort conditions in rooms. A parametric study on basis of an exemplary room varies surface material properties and areas, moisture production cycles, climatic conditions and air change rates for the zone. The study was conducted with the help of hygrothermal whole building simulation, which allows modelling all physical effects related to moisture buffering and latent heat exchange that occur in the surfaces that enclose spaces. Both long and short term simulations were performed, with time steps of one hour or one minute, to assess the associated influences on indoor climate and energy demand.
The study shows a distinct influence on indoor relative humidity. Moisture buffering effects of wooden materials reduce the fluctuation of relative humidity and lead to a more stable indoor climate. Because of that energy demand for humidification and dehumidification can be reduced clearly. Long term simulations show little or no impact for mean indoor and surface temperatures and herby connected energy demand for heating and cooling. Simulations with high temporal-resolution show temporary increase of room and surface temperatures coming with the application of wooden materials as long as moisture loads are available inside the room.

1. Introduction

The project Wood – Energy, Emission, Experience (WEEE) (NFR 216404, 2011) researches influences on energy demand, emissions and health effects coming with the application of wood surfaces. As contribution to the WEEE-project, this paper assesses the effects of moisture buffering and related latent heat exchange in wooden surfaces on energy demand and comfort conditions in rooms. Latent heat exchange happens when surrounding relative humidity changes and the wood needs to establish new moisture equilibrium. To do this, it takes up or releases water from the surrounding air to achieve equilibrium. When moisture is produced in a room, e.g. by cooking or showering, the indoor relative humidity rises slower if the interior surfaces are built of wood, as these surfaces interact with the room and store some of the additional moisture (Holm 2008). In terms of energy this storage process requires to transform the water vapor into liquid water. Due to the phase change, energy is released which heats up the surface and increases therefore the surface temperature. Preliminary studies showed a distinct increase of surface temperature (see Korsnes (2012) and Nore et al (2014)) and energy savings (see Korsnes&Nore (2011) and Antretter et al (2012)).

A parametric study on basis of an exemplary room is conducted to assess the influence of wood surfaces on energy demand and comfort conditions. For this purpose surface material properties and areas, moisture production cycles, climatic conditions and air change rates for the zone are varied. Hygrothermal building simulation software is used for this study.

1.1 Hygrothermal Whole Building Simulation

Hygrothermal whole building simulation is used to explore the possibilities which arise from the utilization of the effects related to the moisture buffering of wood. It allows modeling all physical effects related to moisture buffering and latent heat exchange that occur in the surfaces that enclose spaces. It also accounts for the impact of those effects on the energy demand of and comfort conditions within the space. For this study the hygrothermal building simulation software WUFI® Plus from Fraunhofer IBP is used. Its capabilities and verification is described in Lengsfeld (2007) and Antretter (2011).

1.2 Statistical Methods

Hygrothermal building simulations gives time-series of data with correlating simulation results. In this paper, the statistical distribution of relevant parameters is described by several values. These are minimum, maximum, mean, median and the 25% and 75% quantiles. They will be displayed as boxplots.

2. Simulation Study Set-Up

2.1 Geometrical Model

This parametric study is based on a rectangular room with a length of 5.0 m, a width of 4.0 m and a height of 2.5 m, see FIG 1. Both floor and ceiling as well as the eastern and northern wall are set against rooms with the same inner conditions. Exterior walls are located on the eastern and southern side. The latter one contains two windows, each measuring 1.5 x 1.2 m. The walls are modelled as wood frame constructions. Ceiling and floor consist of reinforced-concrete with $CaSO_4$-screed as top-layer. Painted gypsum plaster is applied to all inner surfaces, except the floor which is covered with tiles.

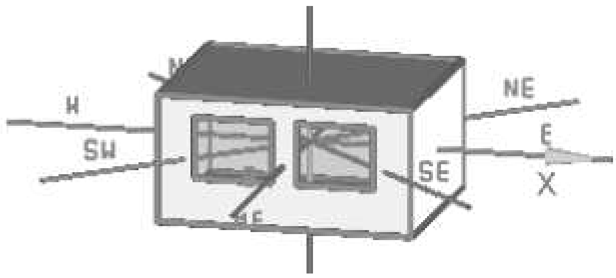


FIG 1. View of the exemplary room modelled in WUFI®plus

During this study the above described indoor surface material gypsum plaster is replaced with wooden materials with higher moisture buffer capabilities: Woodfibre and spruce, painted as well as unpainted. In this process each material is applied step-by step, starting with the ceiling until all surfaces, except the floor, consist of the same wooden material. Hygrothermal building simulations are performed for every application-step, so the resulting influence can be quantified. The materials used in this study were taken from the WUFI® Plus material database.

2.2 Climate Conditions

To assess different climatic conditions each variant of the exemplary room is simulated for four European locations: Oslo, Lund, Holzkirchen and Madrid. TABLE 1 shows an overview of their outdoor temperature and relative humidity. The climate data was taken from the WUFI® Plus climate database.

2.3 Boundary Conditions

Both temperature and relative humidity are controlled. The set-points for temperature are determined with 20 °C and 25 °C, the accuracy of the simulation is set to 0.1 K. These minimal and maximal temperatures are maintained by using ideal heating and cooling devices. Relative humidity is controlled within 30 and 65 %-RH, with an accuracy of 0.1 %-RH. Underrunning or exceeding these set-points results in humidification or dehumidification.

Ventilation is set to constant values, which vary between 0.3 – 1.0 h^{-1}. Infiltration is included in those values. Hygrothermal building simulations are performed for different ventilation cases.

2.4 Inner Loads

The usage of a room has a huge influence on its hygrothermal behaviour. To assess different impacts, four daily profiles with a time step of one hour were created which represent typical usage-types: Office, kitchen, living room and sleeping room. Bathrooms will be assessed in a separate study with another smaller exemplary room. These profiles incorporate heat-, moisture- and CO_2-production cycles as well as occupancy and human activity. Heat sources are based on EN ISO 13790 and moisture production is built from IEA ANNEX 41. CO_2-sources are derived from occupancy by using an internal WUFI® Plus calculator. These four usage-profiles are divided into a weekday- and a weekend-profile.

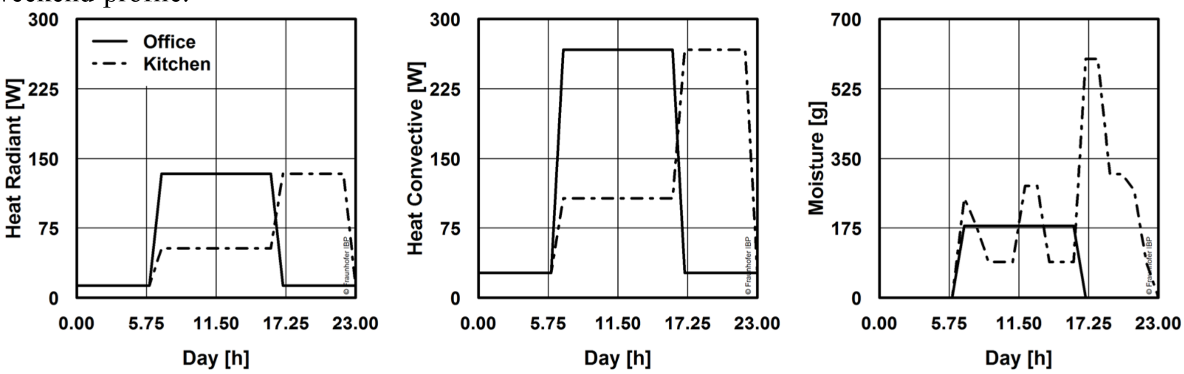


FIG 2. Inner loads for profiles "Office" and "Kitchen" during weekdays (Monday – Friday)

The hygrothermal-building simulations are performed over a year for all four profiles with a time step of one hour, to quantify the long-term effects of moisture buffering materials. In addition, more detailed simulations with a time step of one minute were performed to observe the short-time effects. These simulations cover a timespan of nine months from January to September and focus only on two profiles, which are shown graphically in FIG 2:

- Office: A profile which describes average usage with constant inner loads during weekdays. On weekends only small heat loads and no moisture- or CO_2-production occur.
- Kitchen: Cooking results in abrupt increase of inner moisture production, mainly during dinner time. This profile shows the highest moisture-loads, peak as well as daily sum. It is used both for weekdays and weekends.

2.5 Assessed Variables

Long term effects on the indoor climate are assessed with the statistical methods described in chapter 1.2 with focus on temperature and relative humidity inside the exemplary room as well as mean surface and mean ceiling temperature.

Comfort conditions for temperature are evaluated by using operative temperature, which describes the combined effects of convective and radiant heat transfer. For relative humidity, categories 1 and 2 defined in DIN EN 15251 are used. Category 1 represents a high standard for indoor climate, with an acceptable range for relative humidity between 30 and 50 %-RH. Values below or above these thresholds are defined as “too dry” or “too wet”. Category 2 describes an average standard; its tolerable maximum and minimum are defined with 25 and 65 %-RH.

For energy demand, the yearly sums of heating and cooling energy are compared. Also humidification and dehumidification are taken into account.

TABLE 1. Outdoor climate conditions of the observed locations

Parameter	Min	Mean	Max
Holzkirchen – Temperature	- 20,1 °C	+ 6,6 °C	+ 32,1 °C
Madrid – Temperature	- 2,0 °C	+ 14,4 °C	+ 36.4 °C
Lund – Temperature	- 10,1 °C	+ 9,2 °C	+ 28,3 °C
Oslo – Temperature	- 14,8 °C	+ 6,8 °C	+ 29.3 °C
Holzkirchen – Relative Humdity	24,0 %	81,2 %	98,1 %
Madrid – Relative Humdity	16,0 %	63,0 %	99,0 %
Lund – Relative Humdity	25,0 %	81,0 %	97,0 %
Oslo – Relative Humidity	15,0 %	73,1 %	100,0 %

3. Results

3.1 Indoor Climate

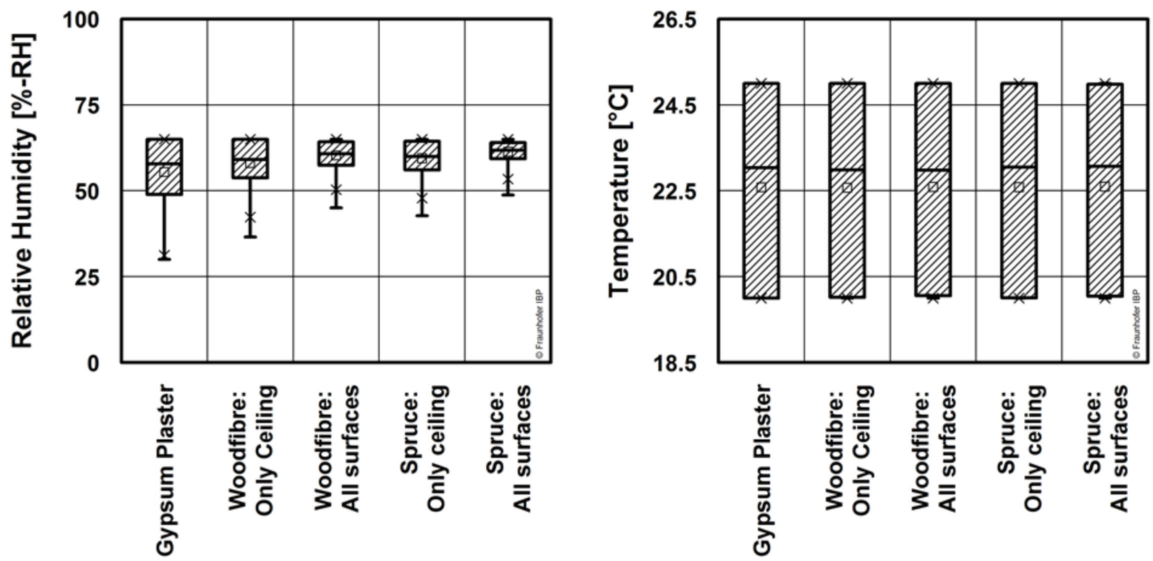


FIG 3. Lund, Kitchen, Ventilation 0.5 h^{-1}. Boxplots showing yearly relative humidity (left) and temperature in the middle of the exemplary room (right).

The application of wooden surface areas affects the indoor climate. Thereby, relative humidity experiences the highest impact: With increasing wooden surface areas the fluctuation of relative humidity declines and stabilises, see FIG 3 (left). Spruce shows a higher buffering-effect than woodfibre. For an air-change rate of 0.5 h^{-1} relative humidity stabilises around 50 %-RH for all inner-load profiles except kitchen. This profile implies the highest moisture production and stabilises around 60 %-RH. Increasing ventilation minimizes the influence of wooden surfaces and broadens the relative humidity spectrum. This buffering effect can be witnessed at all observed climatic locations.

For temperature inside the exemplary room, the statistical parameters of all simulated yearly variants vary on a small scale, see FIG 3 (right). Applying woodfibre areas increases the 1st quarter about 0.05 – 0.10 K in comparison with gypsum plaster faces. Also the temperature median drops around 0.10 K for woodfibre. Spruce and gypsum plaster behave nearly identical. The statistical parameters of the long term simulations for mean surface temperatures also show very little effect.

Assessing the effects of moisture buffering materials on short term indoor temperature fluctuations needs more detailed building simulations with a time step of one minute. These short time simulations are only performed for two climatic locations, Holzkirchen and Lund, and two inner load profiles, kitchen and office. Ventilation is set to a constant value of 0.5 h^{-1}. Higher air-change would influence the moisture buffering effects too much, as described above. The simulations only use fully applied unpainted wooden surface areas. From the simulated data, three months were assessed in detail: January, representing cold winter climate with high heating demand, August, a typical summer month with high cooling demand, and March, with varying climate between summer and winter. This paper will focus on weekly results from Lund in March, where heating and cooling show low influence.

The detailed simulations show a short-term increase of indoor room, surface and ceiling temperatures comparing wooden materials with gypsum plaster surfaces. This applies to both inner load profiles. FIG 4 displays weekly temporal plots of room (left) and ceiling temperature (right) for the surface materials gypsum plaster (grey) and woodfibre (black). The peaks which are visible for both surface types appear simultaneous to peaks from inner moisture loads. So they can be linked directly to latent heat exchange effects. Surfaces applied with woodfibre show more distinct temperature peaks, with differences up to 1.5 K compared with gypsum plaster faces. The rises in surface temperatures are smaller for cold outdoor climate, where heating is necessary. This can be seen in the first three days of FIG 4. For a warmer climate and without any climate control, the impact grows. This can be seen in the last four days in FIG 4. Higher moisture loads lead to a higher increase of surface and indoor temperatures.

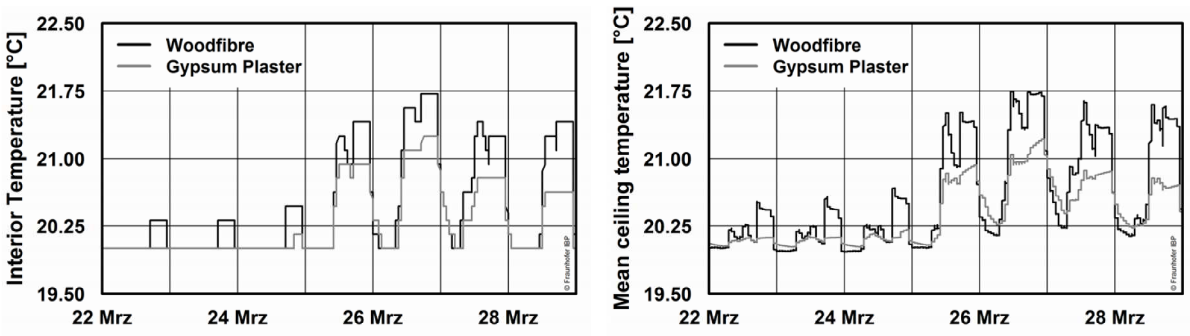


FIG 4. Lund, Kitchen, Ventilation 0.5 h^{-1}. Comparing full applications of woodfibre (black) and gypsum plaster (grey) on the exemplary rooms' inner surfaces. Temperature in the middle of the room (left) and mean ceiling temperature (right).

The simulations show higher temperature peaks for woodfibre surfaces than for spruce faces. The latter ones' surface temperatures are still about 0.1 – 0.2 K higher than for gypsum plaster surfaces. During summer the spruce variants show the lowest surface and indoor temperatures, being up to 0.1 – 0.3 K below gypsum plaster surfaces.

These observations also apply to the inner load profile office. Because of its smaller moisture loads the temperature peaks are lower than for the kitchen profile.

3.2 Comfort Conditions

Larger wooden surface areas buffer humidity inside the exemplary room in comparison with the original gypsum plaster surfaces, which effects the classification of the comfort conditions of EN 15251. For both categories the inner load profiles office, sleeping room and with reservations living room benefit thereof. Their relative humidity stabilises in all climatic locations around or below 50%-RH, with living room being slightly above. So, larger wooden surface areas result in higher accordance for both categories one and two of EN 15251. Spruce performs better than woodfibre, see FIG 5.

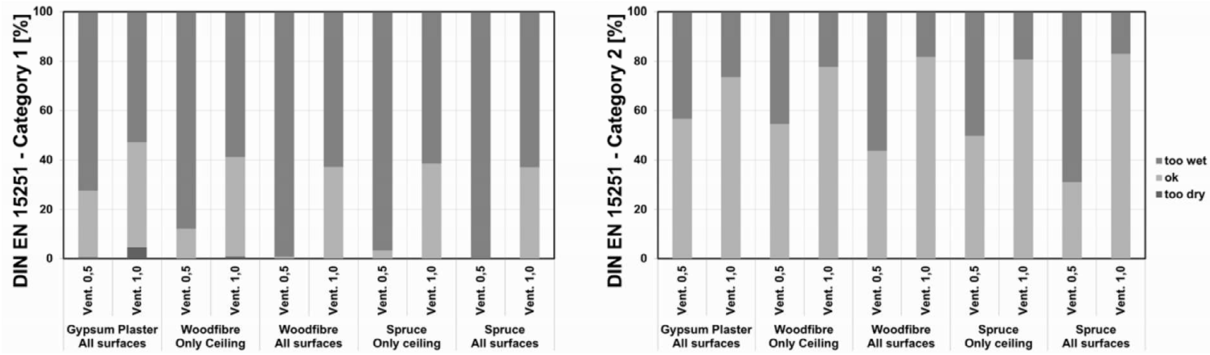


FIG 5. Lund, Kitchen, Ventilation 0.5 h^{-1} and 1.0 h^{-1}. Comfort Conditions of EN 15251 Category 1 (left) and 2 (right).

Because of the high moisture loads in the kitchen profile relative humidity stabilises between 55 and 65 %-RH. Larger wooden surface areas tend to higher values of relative humidity. In both categories of EN 15251 the upper thresholds are exceeded more often with increasing wooden surface areas, resulting in the classification “too wet”. Higher ventilation rates lead to lower relative humidity, as mentioned above. This results in higher accordance with the comfort categories of EN 15251, which can be seen in FIG 5.

As with indoor and surface temperatures, yearly simulations show hardly any impact on the statistical parameters of operative temperature. The additional simulations with a time step of one minute, as described in chapter 3.1, are necessary to quantify the short time effects on operative temperature. There, surface and room temperatures increase with the application of wooden surfaces. This also leads to higher peaks in operative temperature when compared with gypsum plaster. For woodfibre faces these peaks are about 0.3 – 0.7 K higher during winter and about 0.5 K lower during summer, which improves thermal comfort conditions.

3.3 Energy Demand for Air Conditioning

TABLE 2. Lund, Kitchen, Ventilation 0.5 h^{-1}. Yearly energy demand for heating and cooling, as well as necessary amount of dehumidification.

Surface condition	Heating [kWh/a]	Cooling [kWh/a]	Dehumidification [kg/a]
Gypsum Plaster	386.0 (± 0.0 %)	577.7 (± 0.0 %)	486.0 (± 0.0 %)
Woodfibre on ceiling	386.5 (+ 0.1 %)	604.2 (+ 4.6 %)	372.3 (- 23.4 %)
Woodifbre on all surfaces	388.0 (+ 0.5 %)	607.1 (+ 5.1 %)	287.4 (- 40.9 %)
Spruce on ceiling	388.5 (+ 0.6 %)	576.6 (- 0.2 %)	313.7 (- 35.5 %)
Spruce on all surfaces	398.5 (+ 3.2 %)	573.1 (- 0.8 %)	245.6 (- 49.5 %)

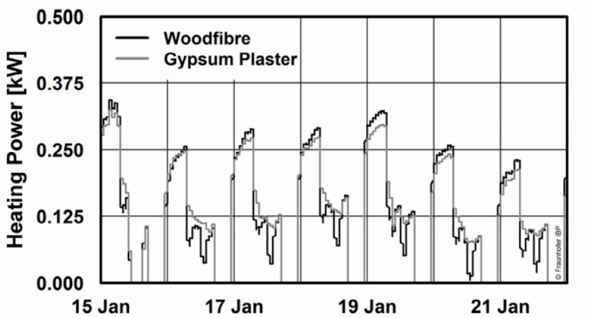
The hygrothermal building simulations over one year with an hourly time step show hardly any long term effects on heating energy demand by increasing the wooden surface areas for the exemplary profile kitchen in Lund, see TABLE 2. This can be stated for all observed climatic conditions. Larger wooden surface areas generally tend to a slightly higher heating energy demand than gypsum plaster, with woodfibre being marginally lower than spruce.

Both wooden surface materials show different, but again small impact on cooling energy demand, see TABLE 2. The highest influences result from changing the ceiling material. Woodfibre tends to a slightly higher cooling demand than the gypsum plaster case, while the application of spruce areas decreases the necessity of cooling. These effects show their biggest impact in the climatic location Madrid.

The more detailed building simulations with a time step of one minute show an impact of moisture buffering effects on heating load. As with temperature, woodfibre surfaces show a higher influence than the other materials. FIG 6 (left) displays the heating power demand of an exemplary week during January for the surface materials woodfibre (black) and gypsum plaster (grey). The inner loads profile is kitchen. Rising moisture loads result directly in decreasing demand of heating power. Woodfibre surfaces lead to a higher drop than gypsum plaster. During high moisture loads, for example dinner time in the inner loads profile kitchen, the heating energy demand drops down to zero. These effects can be observed for all surface materials. With lower or no moisture loads, the necessary heating power increases for the exemplary room assembled with woodfibre and exceeds the demand of the gypsum plaster case. These short time effects can be witnessed at the two assessed inner loads profiles kitchen and office.

The simulations with high temporal resolution confirm the observations of the yearly simulations about cooling energy demand. Applying woodfibre surfaces results in more or less the same energy demand as gypsum plaster faces, while spruce reduces the peak loads of cooling demand a little, see FIG 6 (right).

Whereas the influence on annual energy demand for heating and cooling is low, the impact on humidification and dehumidification is distinct and shows the highest savings potential, see TABLE 2. Because of the high moisture buffering capabilities of wooden materials the relative humidity inside the exemplary room is more stabilised with increasing wooden area. This leads to less humidification or dehumidification demand. Simulations show up to 50 % lower necessity of humidification or dehumidification compared with gypsum plaster surfaces. For this purpose, spruce performs better than woodfibre.



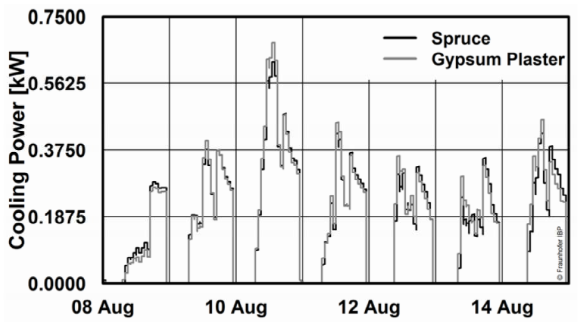


FIG 6. Lund, Kitchen, Ventilation 0.5 h^{-1}. Heating demand of the exemplary room (left) for woodfibre (black) and gypsum plaster (grey) surfaces during an exemplary January week. Cooling demand (right) during an exemplary August week for the materials spruce (black) and gypsum plaster (grey).

An overall comparison of the influence of the surface material on heating, cooling and dehumidification demand on all assessed climate locations is shown in FIG 7. A comparison of rooms completely equipped with either gypsum board, woodfibre or spruce on all surfaces shows the same trend as described above. Small impact is found for heating and cooling demand, the highest saving potential can be achieved for dehumidification.

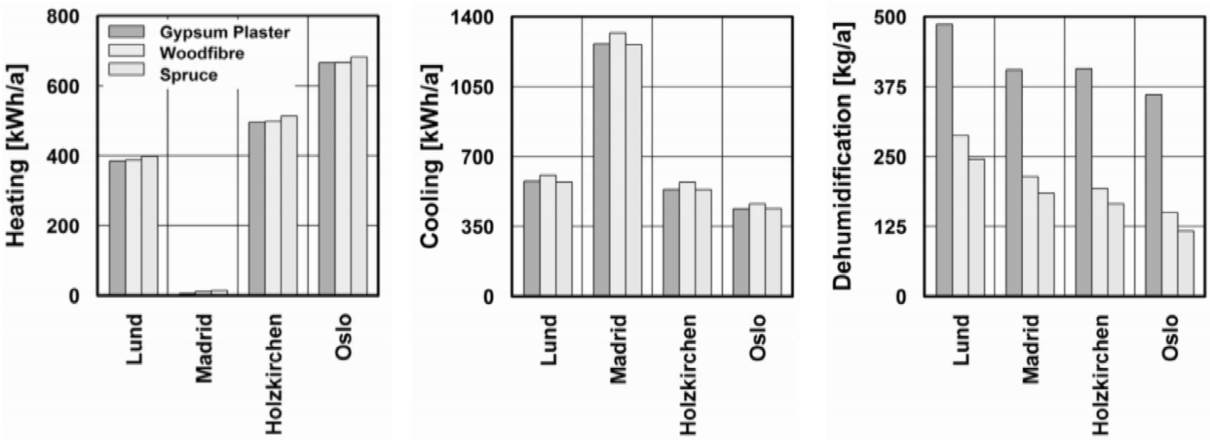


FIG 7. Kitchen, Ventilation 0.5 $h^{-1.}$ Effect of moisture buffering on heating (left), cooling (middle) and dehumidification (right) demand for all climate locations. All inner surface areas covered with the related material.

4. Summary, Conclusions and Outlook

This paper gives a short overview on the effects of moisture buffering and related latent heat exchange in wooden surfaces. The highest influences on indoor climate can be observed for relative humidity, where fluctuations decline and stabilize with increasing wooden surface areas. This improves comfort conditions and clearly reduces energy demand for humidification and dehumidification. Room and surface temperatures show no long-term impacts. But short-term simulations indicate increasing peak temperatures which correlate with rising moisture loads and can therefore be connected to latent heat exchange effects. This also influences comfort conditions positively by increasing operative temperature.

Humidification and dehumidification show a high energy saving potential. The application of wooden surface materials had negligible long term effects on heating and cooling energy demand, but resulted in better comfort conditions. The higher the surface area where wooden materials are applied, the higher is the effect.

This paper shows potentials which arise from latent heat exchange effects. For a more detailed knowledge of these impacts further studies will be necessary. Simulations with high temporal resolution should be extended to other inner loads profiles and climatic conditions. The approach described in this paper will be applied to a smaller exemplary room, representing bathrooms, where high moisture loads should have a distinct impact on indoor climate. Furthermore ventilation should also be considered more detailed, for example the influence of non-uniform and rapid air exchanges.

It is shown that the application of moisture buffering materials on inner surfaces improves comfort conditions and energy demand for humidification and dehumidification. These effects can be assessed with a hygrothermal whole building simulation software, which models all buffering and latent heat exchange processes. It is to be researched, how an extrapolation to a verified real-scale building affects its performance.

5. Acknowledgements

The authors highly acknowledge the Research Council of Norway for funding the project WEEE together with the industry partners. Innovation Norway is acknowledged for funding part of the test house erection at Søråsjordet in Ås.

References

Antretter F., Sauer F., Schöpfer T., & Holm A. 2011. Validation of a hygrothermal whole building simulation software. Proceedings of Building Simulation 2011.

Antretter F., Mitterer C. & Young S.-M. 2012. Use of moisture-buffering tiles for indoor climate stability under different climatic requirements, HVAC&R Research, 18:1-2, 275-282

EN ISO 13790. 2008. Energy performance of buildings - Calculation of energy use for space heating and cooling. European Committee for Standardization.

EN 15251. 2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. European Committee for Standardization.

Holm A. 2008. ANNEX 41 Whole building heat, air and moisture response (MOIST-EN), Volume 4: Applications: Indoor environment, energy, durability. Final Report International Energy Agency.

Korsnes S. K. 2012. Moisture and heat transfer of indoor surfaces. Master Thesis, in Norwegian. Norwegian University of Science and Technology, Trondheim, Norway.

Korsnes, S. K. & Nore, K. 2011. Potential energy savings due to latent heat exchange in indoor exposed wooden surfaces. CESBP 2013.

Lengsfeld K. & Holm A. 2007. Entwicklung und Validierung einer hygrothermischen Raumklima-Simulationssoftware WUFI®-Plus. Bauphysik 29 (3).

Nore K., Englund F., Aurlien T., Nyrud A. Q. 2014. Wood construction: Energy, Emissions and Experience. 10th Nordic Symposium on Building Physics 2014, Lund.