The Hygrothermal Behavior of a Flat Roof Insulated with Wood Fiber

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In the Bauhaus era, the flat roof was introduced to modern design. Its simplicity was attractive. However, such a structure had various problems, stemming from water vapor condensation. We analyzed the hygrothermal behavior of a flat roof insulated with wood fiber. To analyze such water condensation, the software tool “WUFI” was used. As a result, we found that wood fiber insulation could be installed without damage from water vapor in three different climate regions (Sapporo, Tokyo and Kagoshima) in Japan.

Introduction

The Staatliches Bauhaus, commonly known as the Bauhaus , was a German art school from 1919 to 1933, famous for its approach that combined crafts and the fine arts.

The Bauhaus was founded by Walter Gropius in Weimar. The Bauhaus style later became one of the most influential currents in modern design, modernist architecture and art, design, and architectural education.

Bauhaus architecture respected simple design. In the Bauhaus era, the flat roof was introduced. Up to that time, the gable roof was common in Germany. Architect Bruno Taut, who built many collective houses in Berlin during the Bauhaus era, regarded the roof as an umbrella. The space under this umbrella could also be used for drying laundry. The floor under the space played the role of thermal insulation. However, this took up too much space, so a flat roof that simultaneously fulfills both the role of waterproofing and that of thermal insulation was developed.

However, the new design introduced the problems of rainwater leakage and water vapor condensation.

In Tokyo, every day in the summer of 2018 was very hot , with maximum outside temperatures often over 35 ℃. Many elderly people living on the top floor of a house died because there was no air conditioner. The insulation of the roof of the house was clearly insufficient.

Wood Fiber

Wood fiber insulation is an environmentally friendly material. During production, most building materials, such as plastics, steel, aluminum, glass, and cement discharge a great amount of CO_2. However, wood absorbs CO_2 while growing in a forest.

Wood materials, such as wood fiber board, return to the earth when the house is no longer used. Therefore, the application of wood material is environmentally friendly. In the future, the authors believe wood materials must become more common in the construction of houses.

From the point of view of building physics, wood fiber thermal insulation has the following advantages. Thermal insulation performance is equivalent to glass fiber and EPS. Wood fiber insulation can be dense or porous, and both have high sound insulation. Wood fiber insulation has a high thermal storage capacity. Therefore, an unpleasant rise in room temperature can be prevented in summer. Wood fiber insulation has moisture transmission ability. Currently, wood fiber insulation is not common in new construction in Japan. However, its use there is expected to spread in the future. It is necessary to specify a construction method that uses wood fiber insulation and will resist water vapor for a long time. Therefore, our analysis showed that heat and moisture move simultaneously to a flat roof that uses wood fiber insulation. For analysis, we used the software package, WUFI Pro 6.3.

WUFI Software

WUFI (Wärme und Feuchte Instationär) is a software package for unsteady-state hygrothermic analysis. It was developed by the Department of Hygrothermics at Fraunhofer IBP. WUFI performs dynamic simulations of coupled heat and moisture transfer. The methods have been validated worldwide and provide realistic simulation of hygrothermal conditions in buildings and building components under actual climate conditions.

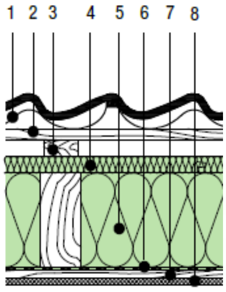
WUFI is based on the latest knowledge of vapor diffusion and liquid transport in building materials. The WUFI software requires only standard material properties and easy-to-determine moisture storage and liquid transport functions. For boundary conditions, measured outdoor climates – including driving rain and solar radiation – are used. Various types of models thus allow the analysis of multi-layer materials, component connections, and even multi-zone buildings under actual exposure to actual weather conditions.

WUFI software uses meteorological data from the Automated Meteorological Data Acquisition System (AMeDAS).

The AMeDAS data are collected from the Automatic Weather Stations (AWSs) run by Japan Meteorological Agency (JMA). Precipitation, wind direction and speed, temperature, humidity, and sunshine duration data support real-time monitoring of weather conditions with high temporal and spatial resolution. AMeDAS data play an important role in developing measures to mitigate the effects of severe weather conditions on human activity.

JMA began operating the AMeDAS system, in 1974. The system includes upwards of 1,300 rain gauges at an average interval of 17 km nationwide, and around 840 stations to observe wind direction/speed and sunshine duration. In addition, snow precipitation and depth are observed at about 320 manned and unmanned stations in snow country.

Simulation



1. Tile Roofing
2. Base Plate
3. Air Layer 50mm
4. Wood Fiber(180kg/m^3)
5. Soft Wood Fiber(50kg/m^3)
6. Moisture Barrier Layer sd=3.5m
7. Air Layer 20mm
8. Gypsum Board

Fig. 1 Roof Structure

For this analysis, the flat roof structure that actually exists in Europe was adopted. The structure of the roof was taken from the Pavatex company catalog. (Fig.1) Because tile is not appropriate for the flat roof, asphalt roofing material was used.

The analysis was conducted at three locations: Sapporo, Tokyo, and Kagoshima.

Since the air layer in a flat roof cannot be expected to be ventilated, it was used as a still air layer. Table 1 shows the simulated layer from the outside air to the inside and its physical properties.

・ Weather data: Standard year for Sapporo, Tokyo, and Kagoshima

・Indoor climate: The room temperatures were sinusoidal, with extremes of 27 °C on July 31 and 20 °C on January 31.

・The room relative humidity readings were likewise sinusoidal with extremes of 60% on August 16 and 40 % on February 16.

・Surface Condition: Surface heat transfer coefficient of roof outside surface:19 W/m^{2}K

Surface heat transfer coefficient of indoor surface: 8 W/m^{2}K

Long wavelength emissivity: 0.9 (Roofing)

Solar absorption rate: 0.8

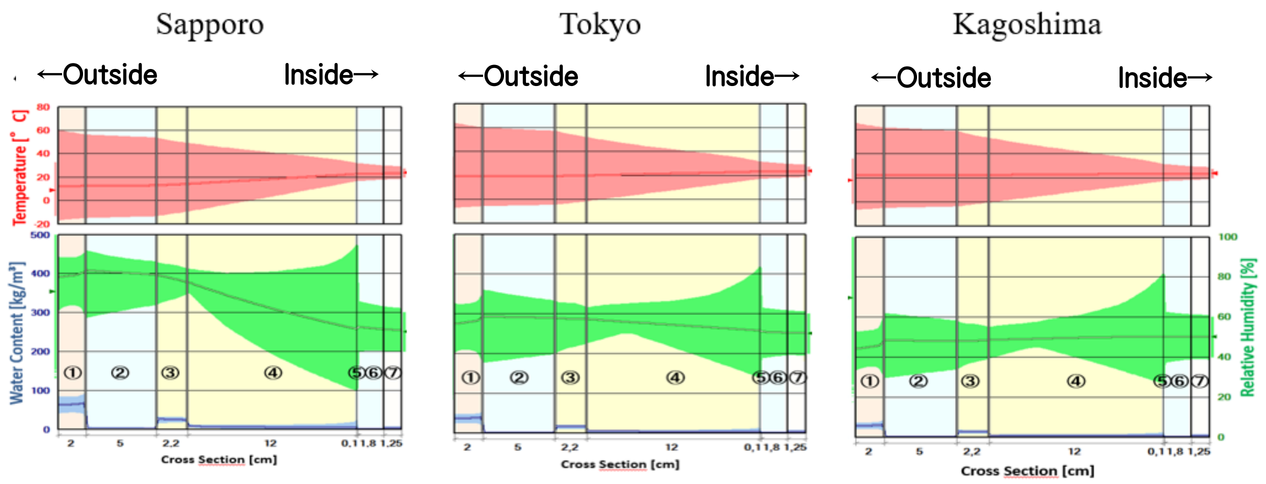
・Calculation period: 3 years beginning October 1.

・ Initial Condition: 80 % relative humidity and 20 °C temperature throughout the roof structure

Table 1 Building Materials Used for Simulation

Building Material	Thickness (mm)	Density (kg/m^3)	λ＊ (W/m・K)	μ＊＊ (-)
Asphalt Roofing	1	1000	0.16	150000
Base Plate	20	400	0.09	200
Air Layer	50	1.3	0.18	0.46
Wood Fiber	22	1.80	0.043	3
Soft Wood Fiber	160	50	0.035	2
Moisture Barrier Layer	1	130	2.3	3500
Air Layer	20	1.3	0.112	0.59
Plaster Board	12.5	11.53	0.32	16

λ＊ : Thermal Conductivity　μ＊＊: Water Vapor Diffusion Resistance Factor



Layer: ①Base Plate ②Air Layer ③Wood Fiber (180 kg/m³) ④Soft Wood Fiber (50 kg/m³) ⑤Moisture Barrier Layer (sd=3.5 m) ⑥Air Layer ⑦Gypsum Board

Fig 2. Distribution of Temperature, Relative Humidity, and Water Content in the simulated Flat Roof Structure

Result of simulation:

The distribution of temperature, relative humidity, and water content in the flat roof structure simulated at three locations (Sapporo, Tokyo, and Kagoshima) are shown in Figure 2. Temperature is shown in red, relative humidity in green, and water content in blue. Calculations were performed for three years. In this figure, the left side is the top of the outside of the roof, and the right side is the inside.

We see that the relative humidity level inside the flat roof was highest in Sapporo, followed by Tokyo and Kagoshima, respectively. Among the wood fiber insulation materials, the relative humidity is the highest at the three points where it contacts the vapor barrier on the inside. The temporal change of relative humidity at this place is shown in Figure 3, below:

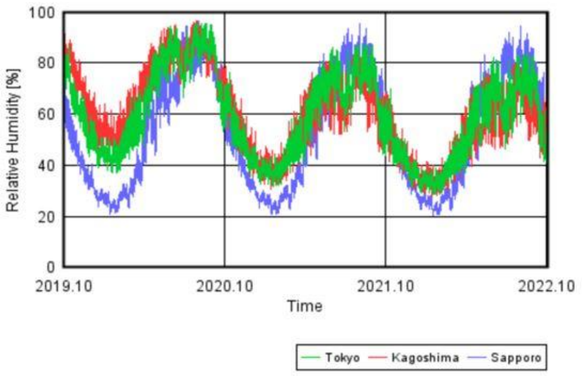


Fig. 3 Relative humidity over time at the innermost position in the wood
fiber thermal insulation material on the moisture barrier layer (sd: 3.5 m)

Calculations for 3 years of data were done. Sd value of moisture barrier layer is 3.5 m. The relative humidity rises to 95 % in summer at all three locations (Sapporo, Tokyo, and Kagoshima) in the first year. However, no condensation has occurred. This is because water vapor flows from the upper surface of the roof, which has a higher temperature, and thus, a higher water vapor pressure, toward the room side, which has a lower temperature, and therefore, a lower water vapor pressure. However, this water vapor is blocked by the moisture barrier, so the relative humidity rises.

In Sapporo, relative humidity rises to the same level in the second and third years, but in Tokyo and Kagoshima the maximum value falls in both those years. From this, it can be seen that the internal water vapor is gradually discharged at these points.

When the condition of high temperature and high humidity continue, mold growth occurs. In addition, decay of wood-based materials is likely to occur. In order to prevent these from happening, it is necessary to lower the relative humidity at this location. Therefore, the simulation was performed by using a vapor control layer instead of vapor barrier layer. Sd value of the vapor control layer changes from 4 m to 0.14 m, according to the relative humidity. The Sd value is expressed by the thickness of the static air that provides the same moisture permeation resistance. It can be determined by multiplying the μ value (water vapor diffusion resistance factor) by the thickness.

The vapor control layer has high moisture permeation resistance in winter, making it difficult for water vapor in room air to enter the roof structure. In summer, permeability increases, and the water vapor accumulated in the roof structure is discharged to the inside. As a result, as shown in Fig. 4, the maximum relative humidity in summer for all three locations decreases over time. Relative humidity only temporarily exceeds 80 % in Sapporo after the second year.

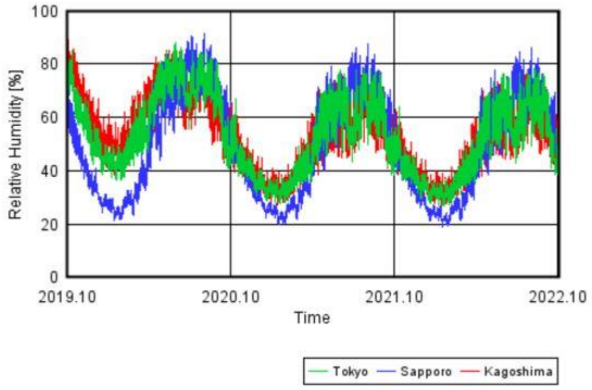


Fig. 4 Relative humidity over time, at the innermost position in the wood fiber thermal insulation material on the vapor control layer (sd: 4 m～0.14 m)

As the next step, the load resistance of the base plate was examined for the cases with a vapor control layer.Fig.5 shows the change over time of the moisture content of the base plate. The German Industrial Standard specifies that 20 M.-% (mass %) is the standard value for reducing the load-bearing capacity of solid wood. In all three regions, moisture content decreased year by year. In the first year, in Sapporo , it peaked at 24 M.-%, but in Tokyo and Kagoshima the peaks never exceeded the standard value.

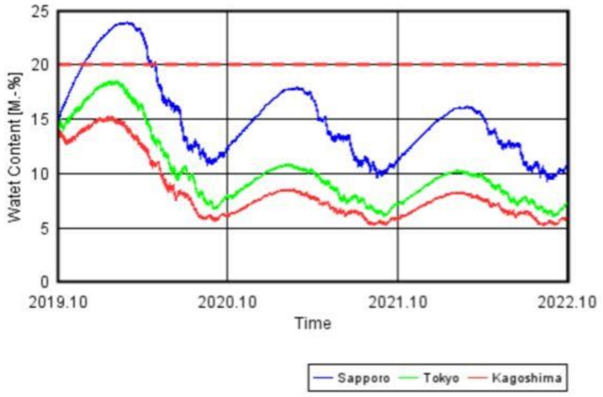


Fig. 5 Water content of base plate over time
Red dotted line: Baseline for timber strength reduction
(DIN 68800-2)

As a method to prevent the high water content of the base plate in Sapporo, the stationary air layer above the base plate was replaced with flowing air. Simulations were performed with air change rates of 5 and 10. The results are shown in Fig. 6. The moisture content of the base plate no longer exceeds the standard value of the 20 M.-%.. In addition, no significant difference was observed in the air change rate of either 5 or 10.

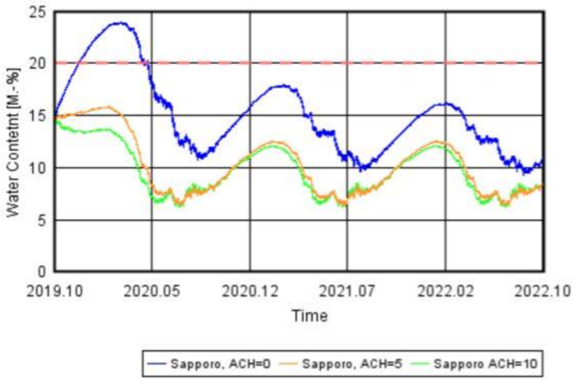


Fig. 6 Water content of base plate over time,for 3 air change rates of air layer, in Sapporo
Red dotted line: Baseline for timber strength reduction
(DIN 68800-2)

Conclusion

It has been found that wood fiber insulation can be installed without damage from water vapor under three different climate zones (Sapporo, Tokyo and Kagoshima) in Japan.
However, the selection of the vapor barrier layer on the inside is an important consideration. Especially in cold areas, ventilation in the roof is important. Although not considered in this paper, the behavior of water vapor in the roof structure also depends on the color of the roof and the change in solar radiation absorptivity, e.g. ,after setting of a solar panel. The way of living indoors, like heating and air conditioning, can also affect water vapor behavior. It is thus important to carry out a hygrothermal simulation to plan a building free of moisture problems.

References

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