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Study on Improving the Surface Wet Condition of Subfloor by Hygroscopic material in Rural Residences of China

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Microporous surface materials are put forward to prevent condensation on subfloor in some building design standards and specifications in China. However, in the current study there are mostly applied cases, lacking of quantitative research. This paper simulated and compared the surface wet condition of three different surface materials by WUFI software: solid brick, hardwood and glazed tile brick. The results shows that the time on surface relative humidity that above 95%, hygroscopic subfloor reduces by more than 20% over non-hygroscopic subfloor, and the improvement is over 45% in relative humidity range of 99% to 100%. In high-humidity areas such as Chongqing, it is suitable to use the porous hygroscopic material which moisture absorption capacity rapidly increases when the environment humidity exceed 80%, and absorbs little moisture lower than 80%.

KEYWORDS

Hygroscopic material, Hot and humid area, Floor condensation, Heat and moisture transfer

INTRODUCTION

China is a big agriculture country and put forward New Rural Construction as a major strategy. After more than ten years of development, rural buildings have greatly improved in terms of functions, sanitation and indoor lighting, etc. The investigation and test of indoor thermal environment in rural buildings have been took widely to various climatic regions (Wang X.P et al., 2009; Zhu W. et al., 2009; Zhu Y. Y et al., 2010; Wang Z.J et al., 2014; Yang L. et al., 2014). Many optimization programs have been put forward and practical demonstration projects have been build (Zhu XR and Liu JP, 2009; Xie MD and Shi YL, 2011; Shao, NN. et al., 2017) However, most of the investigations, tests and improvement measures focus on temperature, but few consider humidity.

There is a large land of China in hot-humid area, the annual average humidity there is about 80% and even 90-100% in rainy season. Therefore, moisture proof and anti-condensation is an important factor in creating a good indoor environment in this area. Rural houses are low-rise building, and mainly surface materials of subfloor that adjacent to the ground is cement or glazed tiles or other little hygroscopic materials. Subfloor connects to the earth that has a large thermal inertia, so moist air is likely to condense on the floor in the humid season. Therefore, the issue of floor condensation brings inconvenience to the residents' lives, affects health (Lotz W A. 1989), and causes economic losses become more serious.

In current engineering practice, enhancing the insulation properties, suspended timber or concrete slab floor are usually used on anti-condensation of subfloor. However, the methods above are not conducive to the use of ground temperature in passive houses to improve indoor comfort in the summer and winter. Chinese traditional buildings commonly used breathable materials that have rich microcellular structure, such as earth, wood, brick, clay brick. They can absorb moisture in the humid weather, and then release it in the dry. Due to these materials, the surface of the traditional building rarely dews. Modern building technology can draw wisdom from traditional architecture and use its advantages to meet the development needs in the new age. At present, only proposal of the breathable material as subfloor surface materials was put forward (*Code for design of building ground*, 2013; *Design standard for energy efficiency of rural residential buildings,* 2013), and direct use without parameter selection and evaluation, lack of quantitatively studies on improvement. In order to provide reference for practical projects, this paper simulated and quantified the improvement effect of hygroscopic subfloors, and analyzes the characteristics of hygroscopic materials suitable for use in hot and humid areas.

METHODS

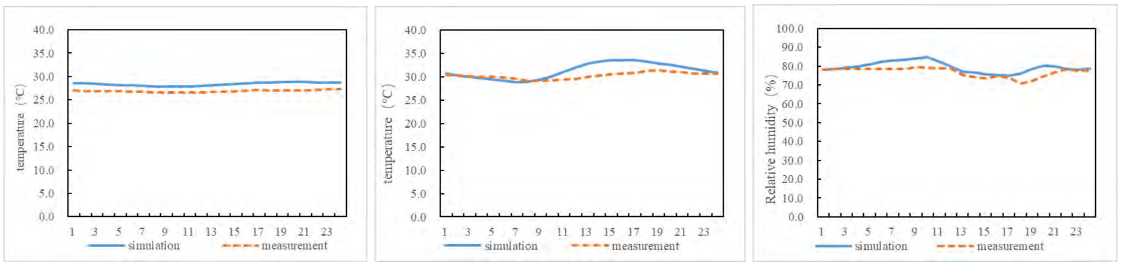
This paper established subfloor model by one-dimensional heat-moisture transfer simulation software WUFI, simulated and compared the heat and moisture performance by several different surface materials. The specific method is as follows.

Nowadays, the construction method to isolate the rising effect of groundwater has matured. Therefore, this paper only considered the underground temperature as the lower boundary of ground components by taking advantages of the fitted data provided by the Special Meteorological Data Set for Thermal Analysis of Indoor Buildings in China (Xiong A Y. et al., 2005). The upper boundary condition is the indoor thermal environment. This paper got the whole year indoor temperature and humidity through simulation, while the model has been verified by field measurement date. The simplified model (shown in the figure 1.a) was created using DesignBuilder which is a user interface for Energy+, with reference to the actual rural house according to its actual size and construction practices in Chongqing, who is typical hot and humid climate. The average error between simulations and measurements were shown in the figure2, while the average error of the indoor air temperature is 3.5%, 3.4% on relative humidity and 5.5% on surface temperature of the subfloor. So this model is reliable.

a) b)

Figure 1. Simulated model by software

a) Simulated building model by DesignBuilder b) Subfloor structure diagram by WUFI



a) b) c)

Figure 2. Comparison between simulated and measured.

a) Subfloor surface temperature b) Air temperature c) Relative humidity

A subfloor model consistent with DesignBuilder on structural hierarchy and material parameters was established in WUFI (shown in the figure 1.b). The average error of surface subfloor temperature between the two software was only 0.5%. The WUFI subfloor model can be used for the next comparative study.

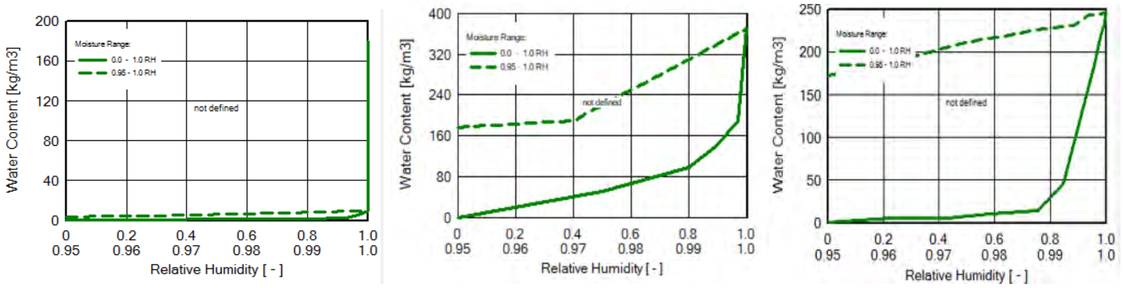
The simulation focused on the surface material, so the other factors that may affect the heat and moisture performance of the surface material were simplified. In order to make the contrast of the thermal characteristics of the surface layer more obvious, a waterproof layer was added between the cushion layer and the tamping layer based on the verified concrete floor above, while the material parameters of each structural were shown in table 1. Three different surface materials were selected, they are Brick ZI that is one kind of solid -bricks, hardwood and Brick H which is one kind of glazed tile brick. Solid Brick and Hardwood are hygroscopic, while glazed tile brick is little hygroscopic. The physical properties of the three in the dry state shows in Table 2, and the isothermal moisture sorption isotherm shows in Figure 3 from WUFI Material library.

Table 1. Material parameters of simulation subfloor structural.

Construction layer	Material	Thickness (*mm*)	Density (*kg/m*^{3})	Specific heat (*J/kg·K*)	Thermal conductivity(*W/m·K*)	Porosity (*m*^{3}*/m*^{3})
Combined course	Cement mortar	20	1900	850	0.8	0.24
Isolating course	Waterproof membrane	1	130	2300	2.3	0.001
Under layer	Concrete	100	2300	850	1.6	0.18
Isolating course	Waterproof membrane	1	130	2300	2.3	0.001
Foundation layer	Stone	370	2150	850	2.3	0.14

Table 2. Properties of simulated surface layer materials in dry state

NO.	Material	Thickness (*mm*)	Density (*kg/m*^{3})	Specific heat (*J/kg·K*)	Thermal conductivity(*W/m·K*)	Porosity (*m*^{3}*/m*^{3})
1	Brick H	10	1891	860	0.955	0.28
2	Brick ZI	10	1722	881	0.404	0.35
3	Hardwood	10	650	1500	0.1	0.47



a) b) c)

Figure 3. Isothermal moisture absorption curve. a) Brick H b) Hardwood c) Brick ZI

RESULTS

The annual average relative humidity of indoor environment is 78%, and the room maintained at a high damp level from April to June. The hours on different surface relative humidity of the three were categorized into statistics throughout the year shown in Figure 4. The time of the three on surfaces relative humidity that less than 80% are almost equal. The difference increases in the high humidity range. The accumulated time when the surface humidity above 95% of Brick H is 1512 hours, while Hardwood and Brick ZI decreases by 504 hours and 319 hours respectively, and the improvement ratios are 33.3% and 21.1% respectively. Among them, in range of 99%-100% on the humidity, the time value of Hardwood and Brick ZI are significantly smaller than that of Brick H, while the accumulated time of Brick H is 944 hours, and the improvement ratios of Hardwood and Brick ZI are 50.3% and 46.8% respectively. At the same time, the comparison shows that solid brick (Brick ZI) is better than Hardwood in the high humid condition, cause the hours for the Brick ZI approaching 100% (99.99% bound) is 0, Hardwood is 118 hours, while Brick H is 829 hours.

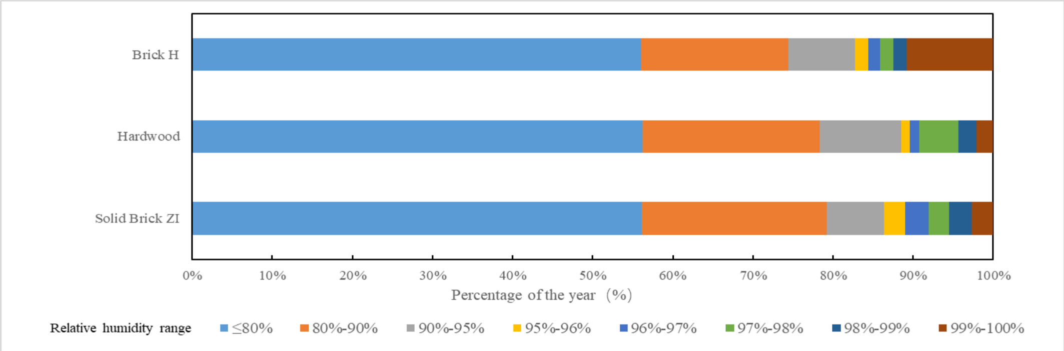
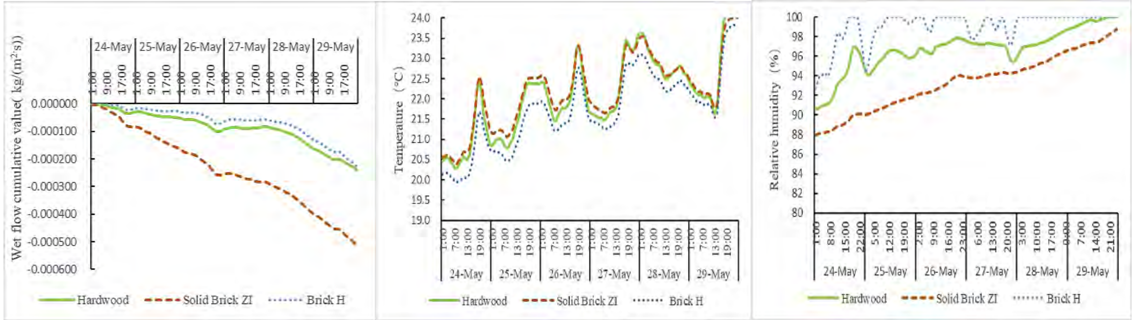


Figure 4. Surface Relative Humidity Hours Statistics Comparison Chart

This paper selected May 24 to May 29 for a typical humid period time on heat and moisture analysis. Figure.5a shows the surface wet-flow accumulation. The wet flow is overall negative means the moisture absorption, and the cumulative moisture absorption of solid brick(Brick ZI) is greater than that of hardwood, while glazed tile brick (Brick H) is the smallest. Since the material releases energy when it absorbs moisture, the surface temperature increases to reduce the possibility of condensation. As shown in Figure.5b, the surface temperature of Brick H is the lowest, followed by Hardwood, and the surface temperature of Brick ZI is the highest, which with the largest wet flow. Figure.5c showed the surface relative humidity of Brick ZI the lowest. With humid weather continues, surface humidity of Brick ZI continues to increase, with an average value of 93%, Hardwood following by an average humidity of 97%. The surface humidity of Brick H is the highest with an average value of 98.5%. What more, from May 28 to May 29, the value of Brick H reaches 100%, resulting in condensation. In general, the wet conditions of the hygroscopic subfloor are clearly better than non-hygroscopic subfloor, and the Brick ZI used in the simulation is better than Hardwood.



a) b) c)

Figure 5.Heat and moisture performance contrast a) Surface wet flow cumulative b) Surface temperature c) surface relative humidity

Figure 6 shows the change in moisture content throughout the year. The fluctuations occurred during the humid months from April to July, indicating that moisture absorption and release are seasonal. The moisture content of Brick H varies little and it is almost 0 in autumn and winter. The moisture content of Brick ZI varies the largest, the minimum value is 9.48 kg/m^3, the maximum of 245.45 kg/m^3, and the elasticity is 235.81 kg/m^3. The maximum moisture content of Hardwood is similar to Brick ZI, but higher in autumn and winter, the minimum value is 71.46 kg/m^3, the maximum of 238.51 kg/m^3, and the elasticity is 167.04 kg/m^3.

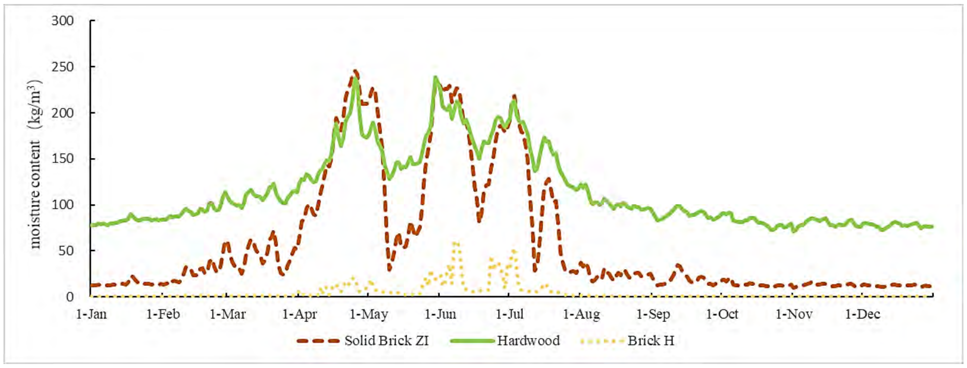


Figure 6.Daily average moisture content comparison chart

During the humid season, the material is in a period of moisture absorption and desorption. As the hygroscopic equilibrium curves showed, Brick ZI has a faster moisture absorption capacity with humidity changing when relative humidity above 80%. The moisture absorption elasticity is about 200 kg/m^3, and the moisture content growth rate is 5.56, so there is no condensation on the surface. Hardwood has the moisture content of 98 kg/m^3 at relative humidity of 80% and 92 kg/m^3 of elasticity at 80% to 97%, with the growth rate of 0.93 that lower than Brick ZI. The moisture content of Hardwood increases from 190 kg/m^3 to 370 kg/m^3 in the humidity range of 97% to 100% which is Hardwood's hygroscopic and supersaturation range that prone to condensation, so there are 118 hours when the relative humidity is greater than 99.99%. From the isothermal moisture absorption curve of Brick H, the moisture content is 1.2 kg/m^3 when the ambient humidity under 80%. Only when ambient humidity closes to 100%, the moisture content increases fast to 180 kg/m^3. In the humidity range from 80% to 100%, the increase in moisture content is less than 5 kg/m^3. Therefore, there are 829 hours of Brick H when surface humidity greater than 99.99% with condensation for a long time.

In summary, in order to reduce the wetness of the subfloor in humid season, the hot and humid areas, represented by Chongqing, is suitable to use porous hygroscopic materials that have hygroscopic behavior that absorption capacity rapidly increases when the environment humidity exceeds 80%, and absorbs little moisture when the environment humidity is lower than 80%.

DISCUSSIONS

The materials in this paper were taken from the WUFI material library which may has some differences between hygroscopic materials in China. Since the standard database of wet physical properties of construction materials in China has not been established yet, the paper uses existing databases to simulate the effects of differences in material properties, and to find the characteristics of hygroscopic materials suitable for high humidity areas from the analysis and comparison. Evaluating building materials or recommendation material selection through experimental measurement or after the establishment of a domestic wet material property standard for building materials may can be the follow-up work.

CONCLUSIONS

This article draws on the fact that most of China's traditional building materials have rich pore structure, which reduces subfloor condensation through the ability to absorb moisture, and also conducive to the use of ground temperature. Through simulations, the improvement effect of wet condition on hygroscopicity was quantified. By comparing the surface wetness and moisture content of different materials, the characteristics of hygroscopic subfloor surface materials in hot and humid areas was summarized. Take Chongqing as a case, it is suitable to have hygroscopic behavior that absorption capacity rapidly increases when the environment humidity exceeds 80%, and absorbs little moisture when the environment humidity is lower than 80%.

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