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Assessing Different Insulation Strategies for Historic Wooden Facades Based on Modeled Mold Growth Risk

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Abstract. *Wood makes up a considerable proportion of applied construction materials in Chinese historic building envelopes. With increasing awareness of preserving historic heritage by promoting their further use and occupation, it becomes necessary to improve the current poor indoor thermal environment in abundantly existing historic buildings in southern China. One common approach for improvement is to install insulation materials on historic building envelopes, which can additionally improve their sustainability by reducing buildings' energy demand for heating and cooling. However, this measure of deep retrofits requires cautious design regarding the hygrothermal performance of insulated wooden facades, since an improper construction way would lead to mold growth in wooden materials, causing problems of durability and indoor hygiene. Therefore, this study investigates the mold growth risk of different insulation systems for historic wooden facades in the Chinese Hot-Summer-Cold-Winter zone based on a parameter study. The considered parameters are internal and external insulation systems, vapor-open (mineral wool) and vapor-tight (XPS) insulation materials, a U-value of 0.8 W/(m²K) as well as a lower U-value of 0.24 W/(m²K) for the insulated walls, different capabilities and positions of an additional vapor control layer, as well as different cooling/dehumidification conditions in the warm period of a year. The hygrothermal performance of insulated wooden facades is simulated with WUFI®Plus software, while the mold growth risk is assessed with mold index values of the Viitanen mold model. The results of this paper will provide a quantitative evaluation of different insulation strategies for historic buildings in southern China regarding the mold growth risk in wooden materials, which is of essential importance for the durability of construction materials. This study can also give instructions for deeply retrofitting wooden historic buildings in China.*

Keywords: *Historic Building Preservation, Thermal Insulation, Hygrothermal Simulation, Mold Growth Risk, Wooden Facades.*

1 Introduction

Wood makes up a considerable proportion of applied construction materials in Chinese historic building envelopes (Knapp, 2000). With increasing awareness of preserving historic heritage by promoting their further use and occupation, it becomes necessary to improve the current poor indoor thermal environment in abundantly existing historic buildings in southern China (Zhao et al., 2022). One common approach for improvement is to install insulation materials on historic building envelopes, which can additionally improve their sustainability by reducing buildings' energy demand for heating and cooling (Martínez-Molina et al., 2016; SHC Task 59/IEA EBC Annex76). However, this measure of deep retrofits requires cautious design regarding the hygrothermal performance of insulated wooden facades, since an improper construction way would not be able to fulfil the goal of performance improvement and may also lead to mold growth in wooden materials, causing problems of durability and indoor hygiene.

Historic wooden facades in southern China are normally constructed as wood panel walls with simple appearance. In an existing study (Zhao et al., 2023), a parametric investigation was conducted to evaluate the hygrothermal performance of two proposed insulation systems (external and internal) for Chinese historic wooden walls with variations in U-values, the type of insulation material, the position and vapor resistance value of a vapor control layer as well as the indoor cooling conditions in summer. This former study evaluated the hygrothermal performance based on the water content of wall assemblies and of the traditional wood layer. This current study is an extension of this conducted investigation and further evaluates the feasibility of different insulation systems regarding the VTT mold growth index in the wooden interfaces and on the wall internal surfaces. Some basic information such as the hourly climate data and wall configurations will only be briefly introduced in this paper. Detailed information regarding the boundary conditions of hygrothermal simulation can be found in (Zhao et al., 2023).

2 Methodology

Currently, two methods are commonly applied to assess the risk of mold growth in buildings (Viitanen et al., 2015). One is the VTT model (Viitanen & Ritschkoff, 1991) which developed an experimentally validated empirical model based on visual findings of mold growth. The other one is the biohygrothermal IBP model (Sedlbauer, 2001) quantifying the growth of a mold hyphen in mm as a function of the transient ambient conditions. The VTT model has been adopted in the ASHRAE 160 – 2016/2021 (ANSI/ASHRAE Standard 160-2016; ANSI/ASHRAE Standard 160-2021) as a moisture performance evaluation criterion.

This study applies the 6-level VTT mold index value to assess the risk of mold growth according to ASHRAE 160 – 2021, while the required input data such as hourly temperature and relative humidity on the investigated surfaces are simulated by WUFI®Plus (WUFI Plus V 3.2.0.1).

2.1 Geographic Location and Weather Conditions

The investigated wooden walls are of historic buildings located in the Tongren City, which is in the south-west part of China. The climate of the Tongren City is characterized by cold winters and hot summers. The monthly temperature and relative humidity are shown in Table 1. Since traditional wooden walls in southern China are commonly shaded by wide roof eaves for rain protection, external wooden walls receive very limited solar radiation and wind-driven rain. Therefore, the effect of solar radiation and wind-driven rain is not considered in this study.

Table 1. Monthly air temperature and relative humidity of the Tongren City

Climate factor	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Air temperature	4.8	7.5	12	17	21	24.2	26.8	25.8	22.8	17.5	12.1	6.8
Relative humidity	73	73	72	73	73	76	71	72	70	76	73	72

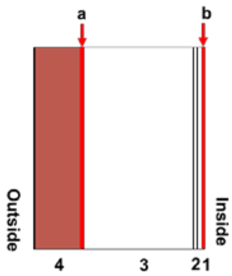
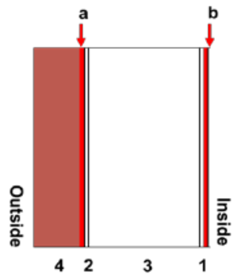
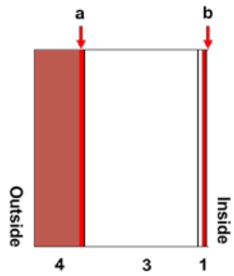
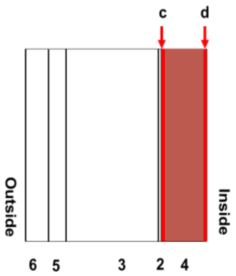
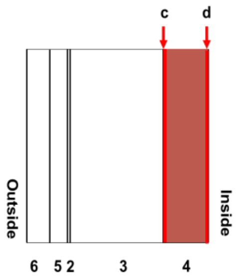
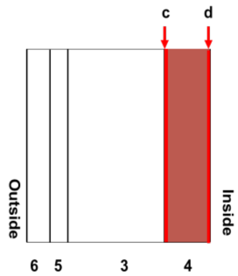
2.3 Simulation Variants

As described in (Zhao et al., 2023), 168 simulations cases were investigated using WUFI®Plus with variations in the U-values, the type of insulation material, the position and vapor resistance value of a vapor control layer as well as the indoor cooling conditions in the warm time of a year.

Regarding the wall configurations, there are six types with different arrangement of material layers, each three for internal and external insulation systems with a vapor control layer either on the external side, on the internal side of the insulation layer or not existent. Besides, three kinds of vapor control layers are considered with an equivalent air thickness s_d of 1500 m, 2 m and moisture dependent property. Furthermore, the insulation material differs between vapor-tight extruded polystyrene XPS and vapor-open mineral wool, while the thickness of insulation materials is also different, resulting in two U-values of each wall configuration: 0.8 W/(m^{2}K) and 0.24 W/(m^{2}K). The investigated wood interfaces a and c, internal surfaces b and d, as well as different arrangement of material layers are presented in Table 2.

Besides, three indoor conditions were considered: free-running in warm time and a design temperature of 20 °C for heating, design temperatures ranging from 20 – 25°C with the upper design relative humidity of 70%, and design temperatures varying between 20 - 22 °C with the upper design relative humidity of 60%. The defined indoor moisture load equals to a moisture production of two adults sitting (1.2 met) in a room with a floor area of about 12 m^2.

Table 2. Arrangement of material layers

Insulation systems	Vapor control layer on the internal side	Vapor control layer on the External side	No vapor control layer
Internal Insulation system			
External Insulation system			

1 - Gypsum board 13 mm; 2 – Vapor control layer 1 mm; 3 – Insulation material XPS (13 mm/85 mm)/mineral wool (30 mm/13.7 mm); 4 – Traditional wood layer 40 mm; 5 – Air layer 20 mm; 6 – Wood cladding 15 mm

Other boundary conditions for the hygrothermal simulation will not be further introduced in this paper.

2.4 Boundary Conditions for the VTT Model

In order to calculate the mold index according to VTT model, the coefficients k_1 for the mold grow intensity, k_3 as the mold index decline coefficient, as well as parameters A, B, and C need to be defined based on the sensitivity class of the investigated material according to Table 6-2 in (ANSI/ASHRAE Standard 160-2021). In this study, the material traditional wood has a class of "Very sensitive" with a k_3 value of 0.1, while the material gypsum board has a class of "Sensitive" with a k_3 value of 0.1 for the safe side.

Table 3. Arrangement of material layers

Material	Sensitivity class	k_1 (if M < 1)	k_1 (if M > 1)	k_3	W	A	B	C
Traditional wood	Very sensitive	1	2	0.1	0	1	7	2
Gypsum board	Sensitive	0.578	0.386	0.1	1	0.3	6	1

2.5 Material Properties

The material properties are shown in Table 4.

Table 4. Material properties.

Material	Density [kg/m^3]	Specific thermal capacity[J/(kgK)]	Thermal conductivity [W/(mK)]	Water vapor diffusion resistance factor [–]
Wood	650	1400	0.13	200
XPS	28.6	1470	0.025	170.56
Mineral wool	60	850	0.04	1.3
Gypsum board	625	850	0.2	8.33
Air layer 2 cm	1.3	1000	0.13	0.56
Vapor control layer	130	2300	2.3	1500000, 2000, variable

3 Results and Discussions

The hourly mold indices of all simulation variants at the position a, b, c, and d are calculated and their yearly maximums are illustrated in Figure 1. As shown by the figure, the interstitial surfaces of traditional wood with internal insulation in some cases show considerably high yearly maximum values, exceeding the recommended limit value of 3 according to (ANSI/ASHRAE Standard 160-2021). In contrast, simulation cases with external insulation all have decreasing or stabilized yearly maximum values smaller than 3. There is little mold growth risk on internal surfaces of the two simulated insulation systems.

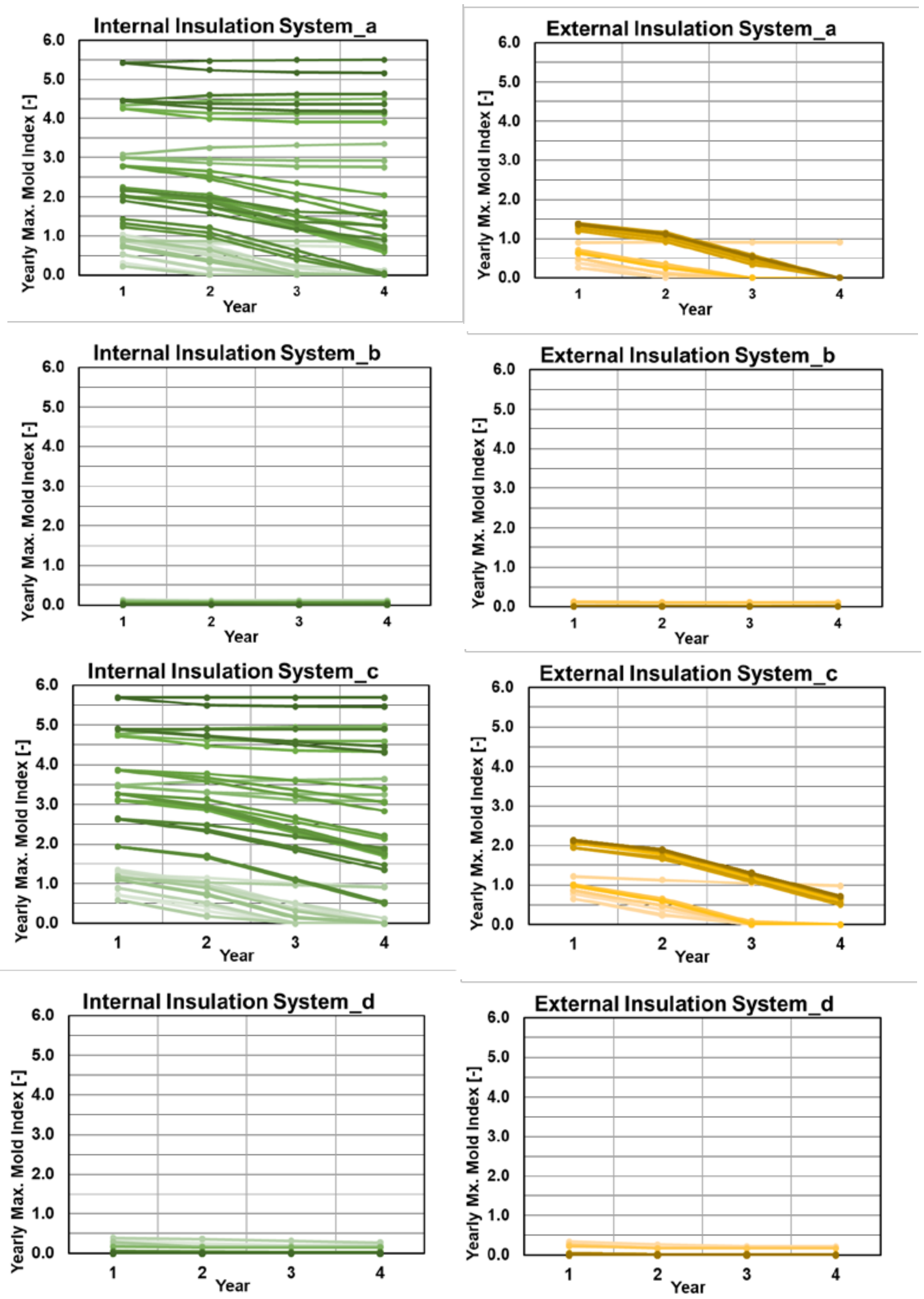


Figure 1. Yearly maximum mold index at the invesitgated positions a, b, c, and d in the simulated wall configurations under diferent indoor conditions

For a closer insight, Table 5 shows the maximum mold indices of the position a (with internal insulation) and position c (with internal insulation) during the simulated period of 4 years. Following results can be observed from the table for the investigated region with hot summers and cold winters:

- A smaller U-value would result in a higher mold index when deeply renovating wooden walls with internal insulation systems.
- The investigated internal insulation systems with vapor-tight insulation material have overall good performance with the maximum mold index smaller than 3 at the interstitial wood interfaces. A vapor control layer is not necessary when retrofitting wooden facades with vapor-tight insulation material regarding the mold growth risk.
- Internal insulation systems with vapor-open insulation material such as mineral wool should always have a vapor control layer, either on the internal or external side of the insulation material. However, with decreasing U-values, external insulation systems should have a vapor control layer on the external side of the insulation material to prevent the outdoor moisture from entering the wall assembly during the moist and warm period.
- A vapor control layer with moisture dependent vapor diffusion resistance factor does not show noticeable advantage over a vapor retarder or barrier.

Table 5. Maximum mold index in the simulated four years for the positions a and c

Vapor control layer	Position a												Position c											
	Mineral Wool						XPS						Mineral Wool						XPS					
	0.8 W/m2K			0.24 W/m2K			0.8 W/m2K			0.24 W/m2K			0.8 W/m2K			0.24 W/m2K			0.8 W/m2K			0.24 W/m2K		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Internal side: s_d1500m	0.3	0.3	0.9	2.0	2.0	2.0	0.3	0.3	0.9	1.3	1.3	1.4	0.7	0.7	1.2	3.1	3.1	3.1	0.7	0.7	1.2	2.1	2.1	2.1
Internal side: s_d 2m	1.0	0.9	0.9	2.8	2.8	2.8	0.5	0.5	0.5	1.4	1.4	1.4	1.4	1.3	1.3	3.1	3.1	3.1	0.9	0.9	0.9	2.1	2.1	2.1
Internal side: s_d variable	0.9	0.5	0.5	2.2	2.2	2.2	0.4	0.4	0.4	1.3	1.3	1.4	1.2	0.9	0.9	3.3	3.3	3.3	0.8	0.8	0.8	2.1	2.1	2.1
External side: s_d 1500 m	0.2	0.2	0.9	1.2	1.3	1.4	0.3	0.3	0.9	1.2	1.3	1.4	0.6	0.6	1.1	1.9	1.9	1.9	0.6	0.6	1.2	1.9	1.9	1.9
External side: s_d 2 m	0.9	0.8	0.7	2.2	2.0	1.9	0.5	0.5	0.5	1.4	1.3	1.4	1.2	1.1	1.1	2.6	2.6	2.6	0.9	0.9	0.9	2.1	2.1	2.1
External side: s_d variable	3.4	3.0	3.0	4.6	4.5	4.5	0.7	0.6	0.6	1.4	1.4	1.4	3.6	3.5	3.5	4.9	4.9	4.9	1.0	1.0	1.0	2.1	2.1	2.1
None	4.5	4.3	4.3	5.5	5.4	5.4	0.7	0.6	0.6	1.4	1.4	1.4	5.0	4.7	4.7	5.7	5.7	5.7	1.0	1.0	1.0	2.1	2.1	2.1

Indoor design conditions: A: 20 °C for heating and free-running in summer; B: 20 – 25 °C, design relative humidity of 70% when cooling; C: 20 – 22°C, design relative humidity of 60% when cooling

It is worth noting that this study did not consider the effect of possible air leakages in insulated wooden walls due to i.e., wall penetrations, poor workmanship, or construction quality. This would, however, pose considerable influence on the hygrothermal performance of insulated wall assemblies. However, this should be investigated in follow-up studies.

4 Conclusion

This study evaluates numerically the mold growth risk of different insulation strategies for traditional wooden panel walls in the Chinese Hot Summer Cold Winter zone. The mold growth risk is evaluated with the VTT mold index for the interstitial wood interfaces and wall internal surfaces. The results show that in both internal and external insulation systems, there is no noticeable mold growth risk on the wall internal surfaces. However, attention should be paid to the choice of vapor-open insulation material in internal insulation systems and the position of the vapor control layer, since there could be a high mold index exceeding the recommended limit value of 3 at the interstitial wood interface. Due to the high moisture level in summer, a vapor control layer should be placed on the external side of vapor open insulation material in an internally highly insulated system, rather than on the internal side as in some cold regions.

Besides, although vapor tight insulation materials show generally lower mold indices, most sustainable insulation materials made of renewable resources are vapor open, such as wood fibre insulation material. For a sustainable preservation and restoration of wooden heritage buildings in southern China, the construction layers of insulation systems should be carefully designed to promote the use of renewable materials in the restoration practice.

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