Current Topics and Trends on Durability of Building Materials and Components

Carles Serrat, Joan Ramon Casas and Vicente Gibert (Eds.)

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Cover: Basilica of the Sagrada Família. Spiral staircase inside the Nativity towers.
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Impact of Climate Change in Building Envelope Design: The Performance to Withstand Mould Growth

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Abstract. *Mould growth is a biodeterioration phenomenon that jeopardizes the integrity, functionality and durability of building envelopes. The performance to withstand biodeterioration depends on the critical hygrothermal conditions inside the envelope. These conditions are subject to the configuration of building envelopes, and climate exposure, accounting for both the outdoor weather and indoor environments' conditions. These critical conditions are likely to intensify in response to the changing climate, and hence, modification and adaptation of the envelopes' configuration will be required. An understanding of the implications of envelope configurations' choices is required to set up guidelines for forthcoming building envelope design. Parametric analyses are a potent source of insight to investigate how the input parameters influence the desired outcome. In light of this, a parametric analysis is carried out to investigate the performance of three building envelopes to withstand mould growth. The impact of climate change in the performance evaluation is accounted for by employing both historic and future climate change scenarios in which the global climate temperature change is forecast to be 3.5°C. Input parameters related to the simulation of mould growth are also investigated. Recommendations to current building envelope design guidelines are drawn for the performance evaluation to withstand mould growth.*

Keywords: *Building Envelope, Climate Change, Mould Growth, Performance Evaluation.*

1 Introduction

1.1 Context

Mould growth is a biodeterioration phenomenon that jeopardizes the integrity, functionality and durability of building envelopes. The performance to withstand biodeterioration depends on the critical hygrothermal conditions, on the investigated material within or outside the building envelope, and also on the chosen approach to assess these conditions. The hygrothermal conditions are subject to the configuration of building envelopes on the one hand, and climate exposure, accounting for both the outdoor weather and indoor environments' conditions on the other hand. These critical conditions are likely to intensify in response to the changing climate, and hence, the exposure and strains will increase suggesting that the performance of building envelopes will have to accommodate new exposure. As a consequence, modification and adaptation of the envelopes' configuration will be required. Design approaches to performance evaluation to withstand mould growth available in current guidelines are more qualitative rather than quantitative. In most cases it is stated that mould growth should be avoided; a common criterion is based on a combination of threshold values of maximum relative humidity and a range of temperature values. However, mould growth is a complex biological phenomenon and studies show that its mathematical representation should simultaneously account for at least four factors: temperature, relative humidity, time, and substrate (Gradeci, Labonnote, Time, & Köhler, 2017). Many mould models, mathematical representations of the mould growth process, have been proposed during the past decades, but very few of them have been implemented in standards. ASHRAE 160 is indeed the only norm to base their guidelines on a mould model (VTT), and it suggests the growth not to exceed VTT index 3. Meanwhile, new guidelines which account for the performance to withstand mould growth are being developed

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for the design of building envelopes (Lacasse *et al.*, 2018). In light of this, two research question are raised: (i) What are the implications of climate change in the hygrothermal conditions within the building envelopes and how is this reflected in the performance evaluation to withstand mould growth?, and (ii) How can current building envelope design guidelines be improved when considering the performance evaluation to withstand mould growth?

1.2 Aim and Objectives of the Study

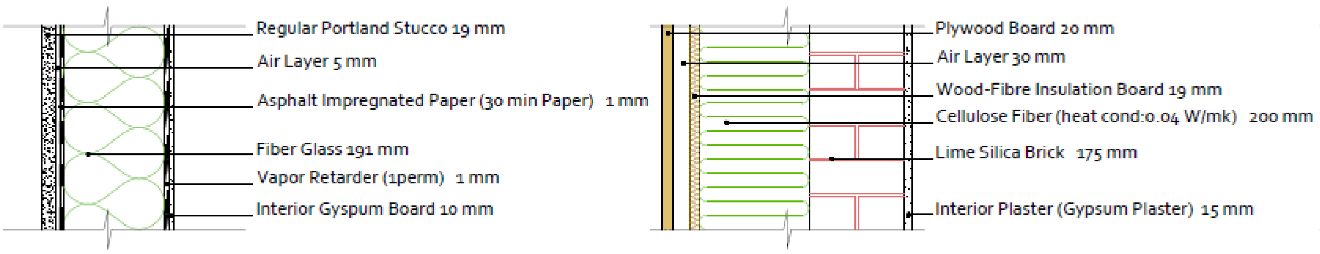
The aim of this study is twofold: (i) to understand the implications of climate change in the performance evaluation to withstand mould growth; (ii) to provide recommendation to current building envelope design guidelines regarding the performance evaluation to withstand mould growth. The objectives that address the aforementioned aims are:

- to analyse the variations of the hygrothermal conditions within the building envelope by comparing historical and future climates,
- to investigate the changes of simulated mould growth within the building envelope by comparing historical and future climates.
- to investigate the impact of the selection of input in the simulated mould growth, including the choice of sensitivity and material class, simulation runtime, and performance criteria.

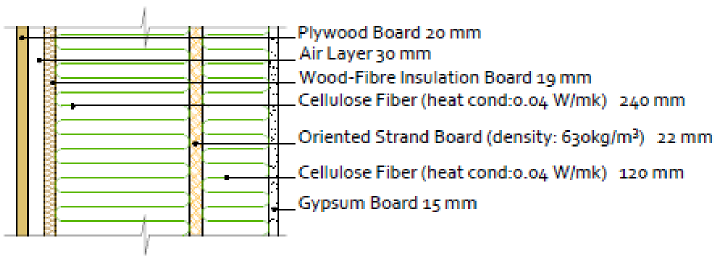
2 Material and Methods

2.1 Building Envelopes

Three North American wall assembly configurations are chosen and shown in Figure 1.



a) Wall Configuration 1(left) and 2 (right)



b) Wall Configuration 3

Figure 1. Three different wall assembly configurations.

2.2 Simulation and Evaluation of Mould Growth

2.1.1 Hygrothermal Simulations

The hygrothermal simulations are performed by WUFI 6.3 ® (Hartwig Michael Künzel, 1995), which has been validated by experimental studies for similar constructions (Mundt Petersen and Harderup, 2011). The initial conditions within the wall are set at RH = 80% and T = 20 ºC. Accounting for wind-driven rain falls out of scope of this study. The applicability of current available models for accounting for and determining the exposure for wind-driven rain may be questionable for ventilated structures (Tietze *et al.*, 2017). The hygrothermal conditions between the wind barrier layer and insulation layer are investigated since they offer most favourable conditions for microbial growth. A monitor is placed in the asphalt impregnated paper for first case study or wood-fibre insulation board for the second case study. A schematic overview of the simulation process is provided in Figure 2. The selected location is Calgary, Canada. Two sets of climate data are implemented. They were generated in (Gaur, Lacasse, and Armstrong, 2019) and include the following: a) 15 historical climate data set, and b)15 climate data set for a climate change scenario in which the global climate temperature change is forecast to be 3.5 ºC. The indoor climate is set up as Medium Moisture Load +5% according to EN 15026 (15026, 2007) for each of the case studies.

2.1.2 Performance Evaluation

The hygrothermal conditions are retrieved for each case study and then processed in WUFI Model Index VTT 2.1 (WUFI-VTT, 2018), which is an add-on developed within a collaboration between the Finnish research institute VTT and Fraunhofer IBP. This add-on allows for calculation according to the VTT model. Three parameters are investigated from the model: the material class and sensitivity class that account for different building materials and the decline rate when mould is exposed to unfavourable conditions (see Appendix).

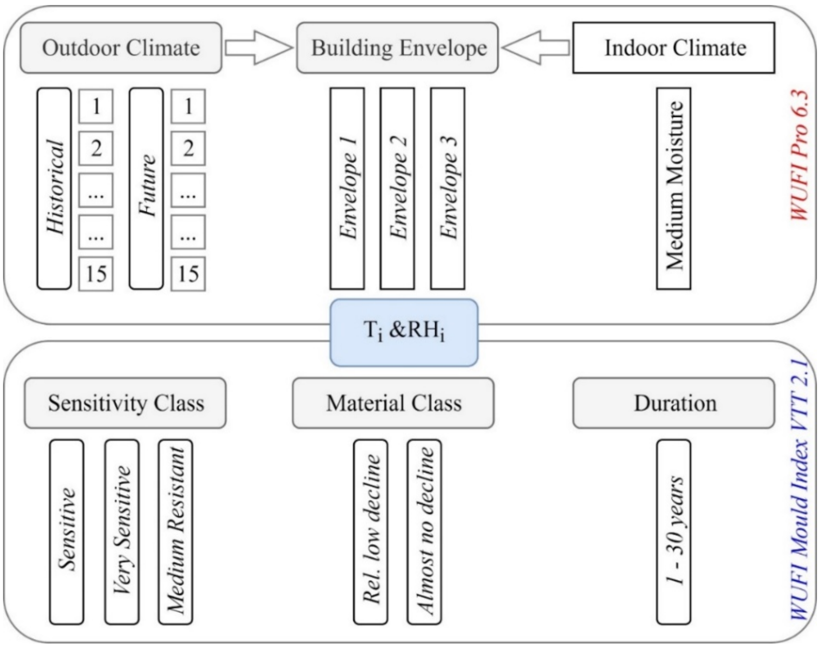


Figure 2. Schematic overview of the simulation process and its parameters.

3 Results

3.1 Implication of Climate Change in the Hygrothermal Performance of the Selected Building Envelopes

3.1.1 Implication in the hygrothermal conditions within the building envelopes

Table 1 shows the number of occurrences in hours of relative humidity and temperature that are usually favourable for the conditions of mould growth. The results are depicted for the three wall assembly configurations for the average of occurrences of the set of 15 historical and future climates. The results show that the effect of climate change is different for the three walls. For the first wall, it can be observed higher levels of temperature and relative humidity compared to the historic exposure in the investigated layer, asphalt impregnated paper. In the other two walls the difference of hygrothermal conditions between the historic and future climates appears insignificant in the investigated layer, wood fibre insulation board, which lies a bit further away from the outdoor climate exposure, and hence its hygrothermal conditions may be highly dependent on the indoor climate.

Table 1. Comparison of occurrences in hours of higher levels of temperature and relative humidity between historical and future climate files for 30 years simulations.

		Historical				Future			
		Temperature							
		15-20	20-25	25-30	30-35	15-20	20-25	25-30	30-35
Wall 1 (Relative Humidity [%])	80-85	1	5	8	3	46	223	308	260
	85-90	567	504	284	67	1022	1594	1278	685
	90-95	13316	5155	1282	88	17117	11985	5307	1314
	95-100	12825	3935	441	5	19840	11064	3336	309
Wall 2 (Relative Humidity [%])	80-85	539	183	22	1	359	187	28	1
	85-90	274	65	6	0	216	61	3	0
	90-95	106	25	2	0	94	14	0	0
	95-100	26	4	0	0	12	3	0	0
Wall 3 (Relative Humidity [%])	80-85	448	102	11	0	449	141	18	0
	85-90	124	23	1	0	110	13	1	0
	90-95	33	2	0	0	17	0	0	0
	95-100	0	0	0	0	0	0	0	0

3.1.2 Implications in the performance to withstand mould growth

The simulated mould growth results for the three wall assembly configurations exposed to 15 different outdoor climate files (both for historic and future) are plotted in Figure 3 and Table 4. The maximum simulated mould growth in a period of 30 years has been selected for each case study. For the first wall, the mould growth is simulated for the asphalt impregnated paper with the assumed sensitivity class '*medium resistant - relatively low decline*'. For the second and third wall, the mould growth is simulated for the wood-fibre insulation board with the assumed sensitivity class '*sensitive - low decline*'. As expected from the previous results, the difference between the simulated mould growth under future climate and historic climate is emphasised only for the first wall assembly configuration. Moreover, the results show that the simulated mould growth is sensitive to the uncertainties of outdoor climate for the first wall configuration assembly. Contrarily, the other two walls do not appear to be sensitive to the uncertainties of the outdoor climate, which may be justified from the fact that the hygrothermal conditions at the monitor position are highly dependent on the indoor climate.

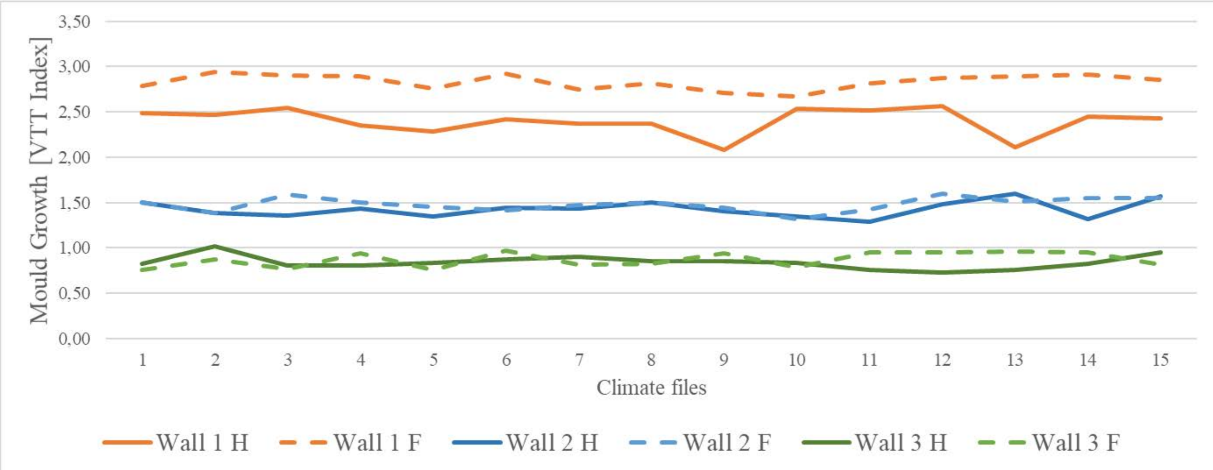


Figure 3. Results of mould growth for three wall assembly configurations simulated under historical and future climate files.

Table 2. Results of mould growth for three wall assembly configurations simulated under historical and future climate files.

Climate File	Wall 1		Wall 2		Wall 3	
	Historic	Future	Historic	Future	Historic	Future
Mean	2,4	2,83	1,43	1,48	0,84	0,87
Standard Deviation	0,15	0,18	0,09	0,08	0,08	0,08

3.2 Implications of Input Parameters in the Mould Growth Calculation

The results of mould growth for wall assembly one and two are shown in the tables below[1] for different selection of the sensitivity classes. For both cases it is also provided the amount of time in years until the peak simulated mould growth is reached. The results show that in both cases, the simulated mould growth and subsequently, the performance to withstand mould growth, are very sensitive to the selection of the material class and the sensitivity class. For example, in the first wall, the mould growth was simulated for the layer asphalt impregnated paper. According to the recommendation in the help guide (WUFI-VTT, 2018), this layer may fall under both sensitivity classes, *medium resistant* or *sensitive* with *relatively low decline* or *almost no decline*. This choice would shift the performance evaluating from acceptable (Mould Index lower than 3) to unacceptable (Mould Index greater than 3). This sensitivity is even more apparent for the second and third wall. Moreover, this sensitivity of the input parameters in the mould model is also reflected in the amount of time the simulated mould growth peak is reached. However, the latter is not the case for the other two walls where the maximum mould growth is reached within the first months, as expected considering the materials that were used in this simulation and that the initial conditions within these materials were assumed RH=80%.

4 Discussion and Recommendations

4.1 Implications of Climate change in Building Envelope Design

The results show that the implication of climate change, as accounted for by the generated climate files, can vary depending on the configuration of the wall assembly and numerical simulations. While the difference in the outdoor historic and future climate files is significant,

[1] The results of the third wall were similar to the second wall and were not shown to save space. In addition, the results are provided only for the first 5 historic climate.

its implications in the simulated mould growth were not. It was observed that mould growth results were intensified for only one among the three selected walls. This implies a potential future case scenario for building materials present in wall assemblies that is different from the current state, and hence underlies the need for a more detailed investigation of the hygrothermal conditions of different wall configurations. The latter can be exploited by carrying out multiple parametric analysis of simulated walls exposed to generated future climate. The results can be useful for direction and ideas of the properties that future building materials should have.

Table 3. Results of mould growth depening on different selection of input parameters of VTT model for wall configuration 1.

Climate	**Max Mould Growth [*VTT Index*] in 30 years**			**Years until peak**	
	S-ND	*S-LD*	*MR-LD*	*S*	*MR*
1	4,65	4,55	2,49	4	20
2	4,70	4,65	2,47	7	21
3	4,70	4,70	2,55	5	20
4	4,70	4,60	2,35	5	22
5	4,60	4,60	2,28	4	26

S- Sensitive, MR – Medium Resistant, ND – Almost no decline, LD- Relatively low decline

Table 4. Results of mould growth depening on different selection of input parameters of VTT model for wall configuration 2.

Climate	Max Mould Growth [*VTT Index*] in 30 years				Years until peak
	S-ND	*S-LD*	*VS-ND*	*VS-LD*	
1	1,5	1,480	4,250	4,150	1
2	1,380	1,290	4,100	3,900	1
3	1,360	1,280	4,100	4,000	1
4	1,430	1,350	4,300	4,180	1
5	1,350	1,300	3,800	3,750	1

S- Sensitive, VS – Very Resistant, ND – Almost no decline, LD- Relatively low decline

4.2 Recommendations about Building Design Guidelines

Choice of sensitivity class and material class: The study demonstrated that the simulated mould growth is very dependent on the selection of the sensitivity class and material. Shifting from one class to another can change the (un)acceptable performance of the building envelope. Current materials classes and sensitivity classes may not provide the required detailing that can accommodate current materials used in building envelopes. Therefore, the study underlies the need for the provision of a more detailed guideline recommending the categorization of common building materials into the respective sensitivity class of the mould model.

Simulation runtime: This study demonstrated that peak of mould growth can vary depending on wall configuration. In many mould models, the growth is represented as cumulative, with few ones considering optionable decline when unfavorable conditions are met. This underlies the need for connecting the performance criteria to runtime simulation. In other words, if the simulation runtime is short, then the performance criteria should be relative and conservative enough to accommodate the designated service life, otherwise, if the simulation runtime is as long as the designated service life, then the performance criteria should reflect the maximum absolute amount of tolerable mould growth.

Performance criteria: Currently, the only available performance criteria specifying the maximum acceptable level of mould growth is provided in ASHRAE 160, suggesting an amount of mould growth not to exceed VTT Index 3. The World Health Organization (2007) claims that there exists an association between health consequences and occurrence of mould growth; even though, there is no clear evidence that relates the microbial growth and mortality. This would imply that the threshold value should be depending on the case being investigated. For example, the same threshold may not be acceptable as in a hospital or other environments with higher exposure. Hence, the development of performance criteria to withstand mould growth can be approached by merging the following categories:

1. *Mould Index levels.* The mould index can have values from 0 to 6, as in the VTT model.
2. *Direct consequences*. The direct consequences of the mould growth are related to Indoor Air Quality (IAQ) and aesthetics.
3. *Exposure and extension*. Different levels of microbial growth can be associated with different levels of indirect consequences depending on several extents and exposure. They can be categorised based on: the depth of the wall (outer part of the wall, within the wall and inner part or contact with the indoor environment); the height of the building (i.e. underground, first floor, upper floors); part of the building (close to risk spots, the front part of the building); and typology of the building (i.e. hospital, museum, residential, office).
4. *Simulation runtime*. The design criteria should also consider the reference period as argued before.

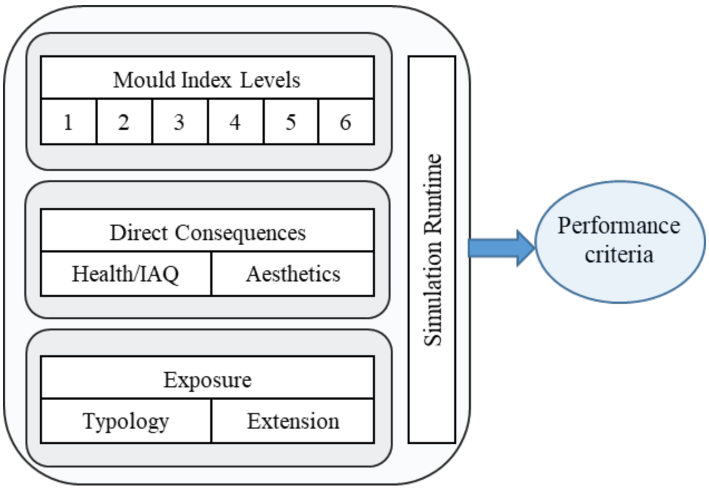


Figure 4. Schematic overview of developing performance criteria for the evaluation to withstand mould growth.

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References

15026, E. (2007). Hygrothermal performance of building components and building elements–assessment of moisture transfer by numerical simulation. In: International Organization for Standardization Geneva.

Gaur, A., Lacasse, M., and Armstrong, M. (2019). Climate Data to Undertake Hygrothermal and Whole Building Simulations Under Projected Climate Change Influences for 11 Canadian Cities. *Data, 4*(2), 72.

Gradeci, K., Labonnote, N., Time, B., and Köhler, J. (2017). Mould growth criteria and design avoidance approaches in wood-based materials – A systematic review. *Construction and Building Materials, 150*(Supplement C), 77-88. doi:https://doi.org/10.1016/j.conbuildmat.2017.05.204
Hartwig Michael Künzel. (1995). Simultaneous heat and moisture transport in building components, One-and two-dimensional calculation using simple parameters. IRB-Verlag Stuttgart
Lacasse, M., Ge, H., Hegel, M., Jutras, R., Laouadi, A., Sturgeon, G., and Wells, J. (2018). Guideline on Design of Durability of Building Envelopes. *National Research Council of Canada, March*.
Mundt Petersen, S., and Harderup, L.-E. (2011). *Control of moisture safety design by comparison between calculations and measurements in passive house walls made of wood.* Paper presented at the XII DBMC-XII International Conference on Durability of Building Materials and Components.
Organization, W. H. (2007). Development of WHO guidelines for indoor air quality: Dampness and mould. *Germany: WHO*.
Tietze, A., Ott, S., Boulet, S., Gradeci, K., Labonnote, N., Grynning, S., . . . Pousette, A. (2017). *Tall Timber Facades – Identification of Cost-effective and Resilient Envelopes for Wood Constructions*. Retrieved from Munich:
WUFI-VTT. (2018). *WUFI® Mould Index VTT Help*. Retrieved from

Appendix: Details of input for VTT mould model

Table 5. Mould sensitivity classess and their respective materials according to the VTT mould model.

Mould sensitivity class	**Materials**
Very sensitive	Untreated wood, includes lots of nutrients for biological growth
Sensitive	Planed wood, paper coated products, wood based boards
Medium resistant	Cement or plastic based materials, mineral fibres
Resistant	Glass and metal products, materials with efficient protective compound treatments

Table 6. VTT index and performance criteria according to ASHRAE 160.

VTT Index	**Description of the growth rate**	**Interior**	**Interfaces**
0	No growth	Acceptable/ Green light	Acceptable/ Green light
1	Small amounts of mould surface (microscope), initial stages of local growth		
2	Several local mould growth colonies on surface (microscope)	Yellow traffic light	
	Visual findings of mould on surface, <10% coverage, or <50% coverage of mould (microscope)	Unacceptable/ Red light	Yellow traffic light
4	Visual findings of mould on surface, 10 - 50 % coverage, or >50% coverage of mould (microscope)		Unacceptable/ Red light
5	Plenty of growth on surface, > 50% coverage (visual)		
6	Heavy and tight growth, coverage about 100%		