7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient

Buildings and Urban Environments

ibpc2018.org │ #ibpc2018

Performance evaluation of a highly insulated wall to withstand mould

Klodian Gradeci[1*] and Umberto Berardi[2]

[1]SINTEF Building and Infrastructure, Norway
[2]Ryerson University, Canada

[*]*Corresponding email: klodian.gradeci@sintef.no*

ABSTRACT
In this paper, the performance to withstand mould growth of a highly insulated wall is evaluated by applying a probabilistic-based methodology that accounts for the involved uncertainties and investigates their significance. A sensitivity analysis according to the Morris method is conducted to understand the influence of each parameter and simplify the system representation. Deficiencies in terms of moisture and air leakages are accounted for. The mould growth outcome is evaluated by integrating different mould models and assessment criteria. The study demonstrates that a probabilistic-based methodology enables a more systematic approach to evaluate wall constructions since it accounts for the involved uncertainties, provides a clear association of the microbial growth to its likelihood, and enables the identification and significance of the dominant parameters; hence, it delivers a more comprehensive assessment of a building envelope.

KEYWORDS
Uncertainty; Sensitivity analysis; Probability; Mould; Building envelope.

INTRODUCTION
Highly insulated walls, which are walls with a considerable insulation thickness, have found increasing acceptance over the last few years to reduce the heat flow across the construction by increasing its thermal resistance. However, by increasing the thickness of the insulation the likelihood of moisture-related damages may increase significantly on the layers on the colder side of the insulation (Gullbrekken et al., 2015; Lepage et al., 2013). Especially when wood-based materials are used, biodeterioration presents a serious concern due to the lower requirements for microbial growth (Gradeci et al., 2017).

The design of wall constructions is replete with uncertainties. These are related to the outdoor and indoor climate, physical parameters of the materials properties and geometries, and the transfer of physical phenomena into numerical equations and models. Probabilistic-based methodologies can account for these uncertainties, and thus have found increasing acceptance over the last few years in the field of building performance simulation. Similarly, sensitivity analysis techniques have found increasing application since they can facilitate a better understanding of the system representation and the relationship between inputs and outputs (Gradeci et al., 2018b). The objective of this study is to evaluate the performance to withstand mould growth of a highly insulated wall by applying a probabilistic-based methodology. A sensitivity analysis is performed to simplify the system representation and to identify the most influential parameters. Finally, potential deficiencies from moisture or air leakages are accounted for.

METHODS
Building envelope
The building envelope investigated in this study is a stacked wood outside wall (Waltjen et al., 2008) using an MDF-board as the wind barrier and a membrane as the vapour barrier (see Figure 1 and Table 1). A construction with a wood-based material is selected due to the higher susceptibility to biodeterioration. A ventilated construction is chosen since the simulated rain data in current software may need further improvement, and these constructions are the least affected by rain.

Spruce Cladding 22 mm
Air Cavity 50 mm
MDF as Wind Barrier 16 mm
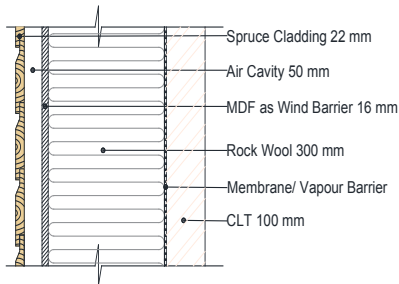Rock Wool 300 mm
Membrane/ Vapour Barrier
CLT 100 mm

Figure 1. Configuration of the building envelope analysed in this paper.

Table 1. Mean values of material properties of the wall construction analysed in this paper.

Material	Thermal conductivity [W/mK]	Water vapour diffusion factor [-]	Density [kg/m³]	Heat capacity [J/kgK]	Porosity [m³/m³]
Spruce Cladding	0.09	130	455	1500	0.73
MDF-board	0.12	15	508	1700	0.667
Insulation	0.033	1.3	91	840	0.95
Membrane			s_d=20 m		
CLT	0.13	156	462	1400	0.627

Probabilistic-based methodology
The probabilistic-based methodology (Figure 2) as presented in (Gradeci et al., 2018a) has been further advanced by considering potential deficiencies, as described in the subsequent sections. The Monte Carlo Latin Hypercube Sampling is used to propagate, in a stratified way, the input variables by the simulation model to output variables. A total of 80 simulations are performed with this technique and a Beta distribution is fitted to the results.

The Morris method (Saltelli et al., 2008) varies one parameter at a time and screens important parameters by calculating two sensitivity measures: a) the mean μ, indicating the overall effect of the parameter; and b) the standard deviation σ, indicating either interaction or non-linear behaviour. A total of 24 parameters are considered for this study (see following sections); thus, (24+1)x4=100 simulations are performed. Three case scenarios are considered: the standard case without any deficiency, the second case when an amount of wind-driven rain (WDR) is assumed to penetrate, and the last case when an air leakage is accounted for.

Hygrothermal simulations and deficiencies
The hygrothermal simulations are performed by WUFI® 6.1. WUFI does not entirely model the air layer; therefore, a simplification that the temperature and relative humidity in the air are similar to exterior conditions can be assumed (Tietze et al., 2017). The effect of the wind-driven rain ($WDR = 0.2 \times rain \times wind\ speed$) is considered by applying moisture sources, while short-wave radiation absorptivity is set to 0.4 for untreated wood cladding (Tietze et al., 2017).

The initial conditions are set at RH = 80 % and T = 20 ºC. The interface (wind barrier and insulation layer) is investigated due to the most favourable conditions for mould growth.
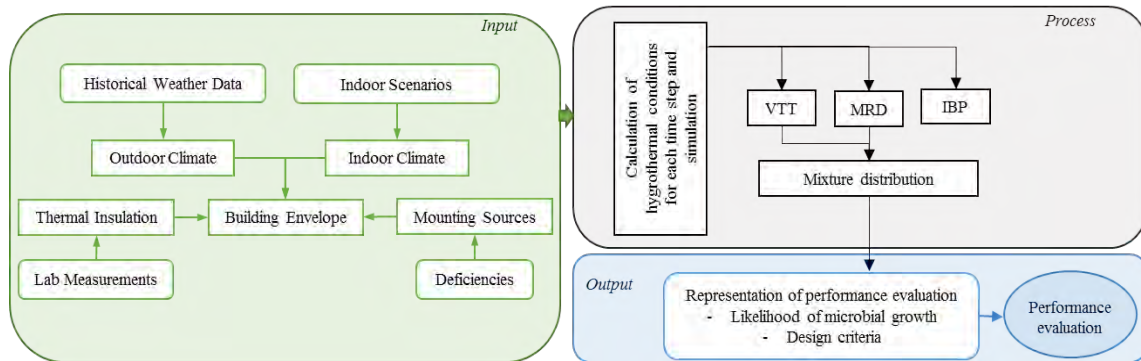

Figure 2. Schematic workflow of the probabilistic evaluation procedure.

In real life conditions, wall constructions are subject to moisture loads from a number of sources including wind-driven rain, bulk water (introduced by leakage), built-in moisture, water vapour (introduced by vapour diffusion or air leakage), and capillary transport through materials in contact with water or in contact with the ground (Lepage et al., 2013). Many of the latter may originate from human errors. They are difficult to identify and to represent quantitatively their distribution. Due to length requirements, this study considers only two scenarios, except for the base case, in a parametric way; 1 % moisture source representing moisture leaks from wind-driven rain according to ASHRAE recommendations and an interior air leak according to (Lepage et al., 2013). The moisture source is mounted between the MDF and insulation, while the air leak with airtightness class B is modelled according to recommendation in WUFI®️ (2017).

Representation of climate exposure and material parameters
The performance of the building envelope is evaluated when exposed to Oslo climate, which is a humid continental climate (ranked Dfb) with hot summers and very cold winters. The hourly-based historical data, from 01.01.1997 to 31.12.2016, are used to represent the outdoor climate. Each year among the 20-year long measurements is randomly distributed for each simulation as applied in (Hagentoft et al., 2015). In the current study, the initiation date of the simulation is also randomly sampled since it is another stochastic variable. Especially when the simulation period is one year long, the results of mould growth are very sensitive to the initiation (Gradeci et al., 2018a). The indoor climate is represented by a stochastic model based on a random distribution of the moisture categories and model uncertainties, as developed in previous study (Gradeci et al., 2018a).
A stochastic representation of the thermal conductivity of insulation material by conducting experiments is presented in (Gradeci et al., 2018b) and used in this study. Ideally, all parameters involved in the performance evaluation should be represented by their probabilistic models. However, due to limitations of the necessary data that are retrieved from experimental analyses, simplified assumptions are considered. A normal distribution (Salonvaara et al., 2001) is assumed for the parameters presented in Table 1, while the rest of the parameters were assumed as deterministic. The coefficient of variation is assumed 15 % for the vapour diffusion resistance, 8 % for the thermal conductivity of material other than insulation, 5 % for the density, 10 % for the heat capacity and 10 % for the porosity. The initial conditions for the relative humidity and temperature are also randomly distributed with mean values as presented in previous section and a coefficient of variation equal to 10%.

Representation of the failure event and performance evaluation

Different models have been developed to represent the mould growth and are characterised by specific strengths and limitations (Gradeci et al., 2017). Consequently, in the current study, the mould growth is calculated according to the integration of three most established mould models: VTT model (Viitanen et al., 2007), MRD model (Thelandersson et al., 2013) and IBP-biohygrothermal model (Sedlbauer, 2002), as previously presented in (Gradeci et al., 2018a). The *substrate class 1* is used for the biohygrothermal model, the standard case (*spruce, planed*) for the MRD, and the *very sensitive class* for the VTT model. Due to the lack of established design criteria related to building envelopes and biodeterioration, results are expressed as a density function associating potential levels of microbial growth to their respective likelihood.

RESULTS AND DISCUSSION

The sensitivity analysis results are presented in Figure 3 and Figure 4. The screening between influential and non-influential parameters, among the variables set up previously, is performed according to Morris method criteria (Saltelli et al., 2008). Only the influential parameters are depicted in the figures. They differ based on which mould model is applied. Similarly, the parameters' importance in the sensitivity analysis, as presented by the mean value, and its non-linearity or interaction, as presented by the standard deviation, differ based on which mould model is selected. The Mixture model and MRD model conclude that more parameters are important. The outdoor weather is screened as the most important parameter with non-linearity or interaction with other parameters. The indoor temperature in screened as important only from MRD model and the Mixture model. This parameter is judged as important considering engineering experience. The initial relative humidity is screened as an important parameter, which makes sense considering the short time of simulations. For the standard case and when an air leakage is accounted for, only the outdoor temperature and initial relative humidity are screened as important parameters. The reason might be the fact that this construction provides satisfactory performance, with low mould growth and/or due to one-dimensional simulations. The important screened parameters are increased when the wind-driven rain penetration is accounted for. The calculated mould growth is highly increased for this case.
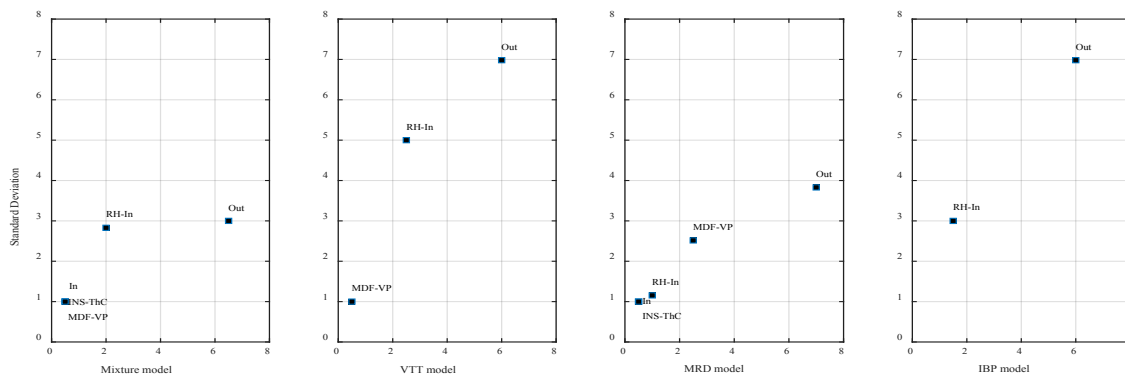

Figure 3. Sensitivity analysis results for the case when the wind-driven rain is accounted for. Difference between mould models. (In: indoor climate, Out: outdoor climate, RH-In: initial relative humidity, MDF-VP: water vapour diffusion factors of MDF, INS-ThC: thermal conductivity of insulation material.)

The results from sensitivity analysis enables a simplification of the system representation by reducing the number of variables, and thus the number of simulations. For the following calculation, only the influential parameters are accounted for as uncertain. The mould growth

results are shown in Figure 5 as the cumulative density function assessed against different available criteria. In addition, the results from applying the deterministic approach are shown as vertical lines when applying the MDRY (Moisture Design Reference Year), which is a conventional engineering approach, and the maximum mould growth during one year for the past 20 historical years in Oslo. The likelihood of obtaining the mould growth based on the historical data is high, while for MDRY is relatively lower implying that the probabilistic approach prevails the conventional one when representing the past twenty years.
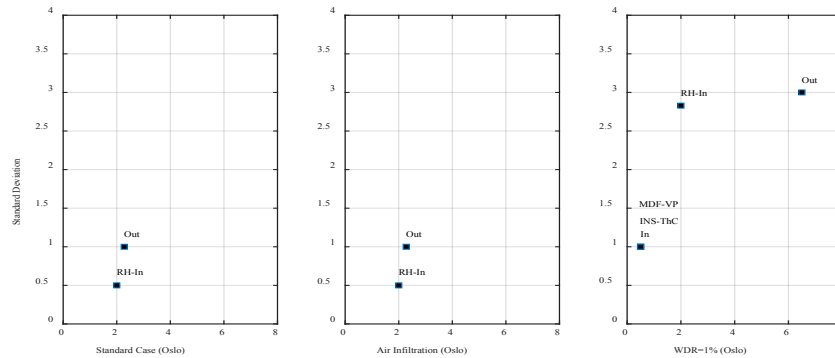

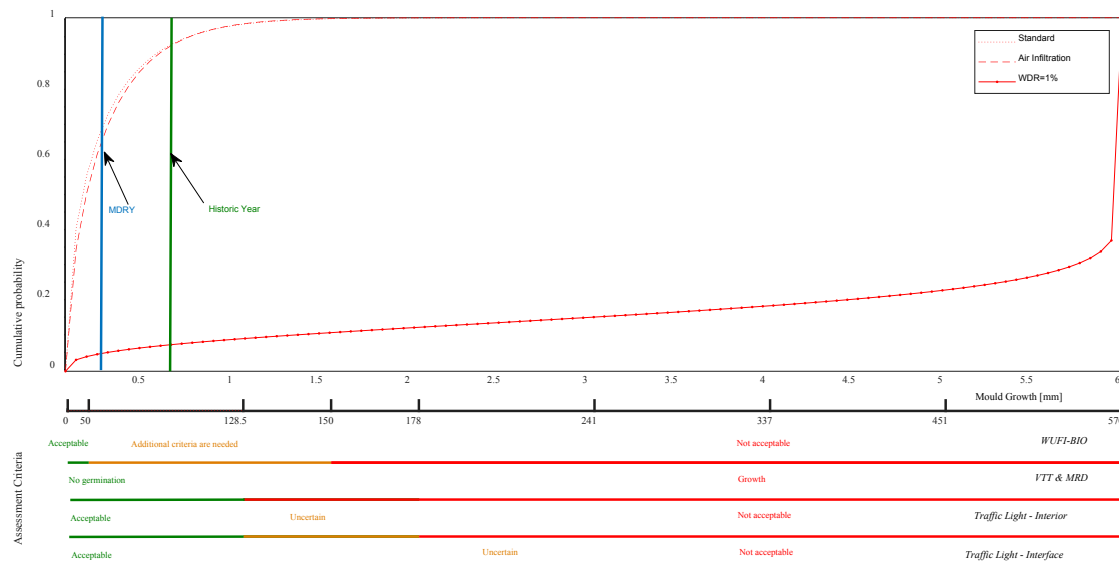Figure 4. Sensitivity analysis results. The effect of deficiencies.

Figure 5 Cumulative density function of the mould growth according to three case scenarios assessed against different available criteria.

Moreover, a clear association can be retrieved between the different mould growth levels and their likelihoods. The performance of the investigated wall is satisfactory unless wind-driven rain penetration is simulated. However, it should be noted that there are no available criteria in codes/standards following simulations results with a duration of one year. Therefore, different assessment criteria can be considered, as shown in Figure 5, providing the flexibility to adapt the requirements and criterion based on the case study at hand. Otherwise, it is advised a longer time for the simulations to resemble the expected service life of the construction.

CONCLUSIONS

The probabilistic-based methodology enables a more systematic approach to performance evaluation of highly insulated walls since it accounts for uncertainties and delivers a clearer association of the mould growth to its likelihood. Furthermore, the application of sensitivity analysis is very beneficial in the design of wall constructions since it identifies and ranks the most dominant parameters influencing the outcome. The application of this methodology could be extended to different wall constructions, failure modes, climate exposures, and other deficiencies.

REFERENCES

Gradeci, K., Berardi, U., Time, B., & Köhler, J. (2018b). Evaluating highly insulated walls to withstand biodeterioration: A probabilistic-based methodology *(under review)*.

Gradeci, K., Labonnote, N., Time, B., & Köhler, J. (2017). Mould growth criteria and design avoidance approaches in wood-based materials – A systematic review. *Construction and Building Materials, 150*, 77-88.

Gradeci, K., Labonnote, N., Time, B., & Köhler, J. (2018a). A probabilistic-based methodology for predicting mould growth in façade constructions. *Building and Environment, 128*, 33-45.

Gullbrekken, L., Geving, S., Time, B., Andresen, I., & Holme, J. (2015). Moisture conditions in well-insulated wood-frame walls. Simulations, laboratory measurements and field measurements. *Wood Material Science & Engineering, 10*(3), 232-244.

Hagentoft, C. E., Kalagasidis, A. S., & Rode, C. (2015). *55, Reliability of Energy Efficient Building Retrofitting-Probability Assessment of Performance & Cost (RAP-RETRO)*.

Lepage, R., Schumacher, C., & Lukachko, A. (2013). *Moisture management for high R-value walls*.

Salonvaara, M., Karagiozis, A., & Holm, A. (2001). Stochastic building envelope modeling—the influence of material properties. *Thermal Performance of Exterior Envelopes of Whole Buildings VIII*, 2-8.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., . . . Tarantola, S. (2008). *Global sensitivity analysis: the primer*: John Wiley & Sons.

Sedlbauer, K. (2002). Prediction of Mould Growth by Hygrothermal Calculation. *Journal of Building Physics, 25*(4), 321-336.

Thelandersson, S., & Isaksson, T. (2013). Mould resistance design (MRD) model for evaluation of risk for microbial growth under varying climate conditions. *Building and Environment, 65*, 18-25.

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*.

Viitanen, H., & Ojanen, T. (2007). *Improved model to predict mold growth in building materials*. Proceedings of the X International Conference on the Performance of the Exterior Envelopes of Whole Buildings, Clearwater, FL.

Waltjen, T., Pokorny, W., Zelger, T., Torghele, K., Mötzl, H., Bauer, B., . . . Unzeitig, U. (2008). Details for passive houses. A catalogue of ecologically rated constructions: Springer, Wien.

WUFI[®]. (2017). *Guideline for Using the Air Infiltration Source in WUFI[®]*.