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Citation for the original published paper (version of record):
Svensson Tengberg, C., Blomsvik, Å. (2021). Impact on a CLT structure concerning moisture and mould growth using weather protection. Journal of Physics: Conference Series, 2069(1). http://dx.doi.org/10.1088/1742-6596/2069/1/012017

Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: C Svensson Tengberg and Å Bolmsvik 2021 *J. Phys.: Conf. Ser.* **2069** 012017

Impact on a CLT structure concerning moisture and mould growth using weather protection

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Abstract. Timber buildings, including cross laminated timber (CLT), are gaining market shares globally, mainly due to anticipated environmental benefits, but a new technical solution also raises new questions. Durability is critical to obtain real sustainable constructions built for the future. There are field studies concerning hygrothermal conditions of timber structures, however, there is a lack of documented experiences combining hygrothermal conditions, mould growth potential and weather protection during construction using CLT. The use of full weather protection is being debated in the building industry as well as in the research community, due to lack of knowledge of the combined effects. How does weather protection during the construction affect hygrothermal conditions and risk of mould growth in a CLT structure? A case study using a weather protected six-storey CLT building was performed. The hygrothermal conditions – indoors and outdoors – were monitored during construction and samples from CLT were analysed with respect to mould. The results were analysed together with simulations of mould growth using actual hygrothermal conditions. Theoretical conclusions show the weather protection gives significantly improved conditions resulting in lower potential of mould growth compared to outdoor conditions. The results also show lessons to be learned concerning planning of the construction site.

Key words. Weather protection, CLT, moisture safety, mould growth

1. Background

Issues of moisture conditions during construction of cross laminated timber buildings are being debated in the building industry and research community, e.g., [1]. The instructions for handling of the products with respect to moisture given by the suppliers of CLT are not specific in this question as shown in [2]. Instead, they are typically qualitatively expressed as variants of: *"protect from weather conditions"* and: *"take note of weather conditions while unloading"*. One of the suppliers state the product: *"...can come briefly into contact with water."* without quantification of e.g., exposure time or amount of water. The CLT-handbook, US-edition [3] states "*CLT panels, similar to other wood products, should always be protected from exposure to rain, snow, and wet ground during transport, jobsite storage, and construction process ...*". This is suggested to be achieved with e.g., minimizing exposure time, temporary protection of panels and swift installing of exterior protection (i.e., WRB). The Swedish CLT handbook [4] refer to general requirements in the building regulations, and refer to a maximum of 18% MC before built-in. There is also a note to "*protect the CLT*", however without specification. The Swedish building regulations [5] states the critical moisture level of a material should not be exceeded. The critical moisture level with respect to mould growth should take into consideration when the growth of mould begins, without respect to visibility. One way to mitigate the consequences of precipitation on a building site is to use a full-size weather protection. During the last two years, two of Sweden's top three contractors have established internal guidelines [6] prescribing the use of a full weather protection when building with this type of CLT structures. However, there is no consensus in the industry and there are several other contractors that do not use weather protection for these structures arguing high costs, although there are reports from the industry stating significant productivity benefits using weather protection [7]. There are also few documented data on expected hygrothermal conditions in a weather protection during construction of a CLT structure, and even fewer on the possible positive effects, such as lowering risk of mould growth, on the structure. To investigate the issue, a case study was performed with the scope of answering the question: How does a weather protection affect the hygrothermal conditions and the risk of mould growth in a CLT structure.

2. The case study

A six-storey building located in the south of Sweden was constructed using CLT in intermediate floors and in some of the external walls. A full weather protection [8] was used, it consisted of a metal pillars and beams with tarpaulin material as rain protection. The tarpaulin material is fastened in the metal frame and is expected to be airtight as well as watertight. The construction is expected to have neglibible thermal insulation, except for heat transition coefficients. They started raising the weather protection 15 days before the construction of the CLT-structure begun and it remained for almost a year until roof and facades of the building were fully operational. The weather protection was essentially larger than the building, with approximately 10 m around the building on each side. Furthermore, there were ventilation possibilities at roof height as well as at ground level where the tarpaulin started above ground floor. All of this created a large volume of air, good ventilation and possibilities for weather protected delivery and storage of goods. No specific heating devices or mechanical ventilation equipment were installed. The temperature and RH inside the weather protection were expected to be similar to the external conditions, except for the protection from precipitation. In November 2019, heating was initiated in parts of the building. The weather protection was used April 2019 to March 2020.

3. Method

Hygrothermal conditions were monitored throughout the construction process as the conditions are relevant to the development of microbial growth. Microbial sampling was made at the end of the construction period as microbial growth is potentially developing during the whole period. The hygrothermal measurements were assessed in comparison to outdoor climate and to microbial growth.

3.1. Hygrothermal measurements

An external weather station was placed above the roof of the weather protection. The five internal sensors were attached to the CLT structure and installed along with the structure. The placement of the equipment is listed in Table 1. The sensors occasionally lost signal for different reasons (e.g., interference with frequency of overhead crane or battery issues) and thus the monitoring lacks some values. The data from the external weather station have also been compared to data from a nearby SMHI meteorological station [9] where the measurements from the external weather station showed good compliance. As the external sensor for precipitation was out of order until June 3, precipitation from SMHI was used during this initial period.

Table 1. Data on equipment.

Sensor	Interval	Accuracy	Accuracy	Position
External	60 min	±0.5°C	±2.5 % RH	Roof level
0120	15 min	±0.5 (0-60°C)	±3 (20-80% RH)[a]	Floor 4
0140	15 min	±0.5 (0-60°C)	±3 (20-80% RH)[a]	Floor 4
0123	15 min	±0.5 (0-60°C)	±3 (20-80% RH)[a]	Floor 5
0011	15 min	±0.5 (0-60°C)	±3 (20-80% RH)[a]	Floor 6
0122	15 min	±0.5 (0-60°C)	±3 (20-80% RH)[a]	Floor 7
SMHI	60 min	Not specified	Not specified	Approx. 4 km

[a] According to the supplier, Nordtech, accuracy is applicable > 80%RH by when using calibration procedure.

3.2. Measurements of microbial growth

Microbiological sampling and analysis are performed. The Swedish building regulations [5] set requirements based on microbial presence. Both moulds and bacteria are important in assessment of microbial presence and therefore Eurofins Pegasuslab's [10] analysis, the Damage Control, is used. It is a quantitative assessment using a microscopy method based on fluorescence technology. In this technique, the total number of mould (fungi) and bacteria is analysed separately along with an assessment of the state of condition of the sample based on the present levels of microorganisms.

The on-site test is conducted by taking specimens samples. Prior to sampling three points on the CLT-floor per floor with good spread are marked. Clean tools, a round drill and a knife, are used in the sampling. Each specimen is then placed in individual numbered plastic bags which are sealed. In total 15 samples are analysed.

The delivery plan for all CLT-elements is observed, the dates each lorry delivered elements are noted together with the mounting dates for each element. This makes it possible to backtrack the number of days each element was kept at the building site until assembly. It is shown that most of the elements were mounted within a week after delivery to the building site. While kept at the building site the elements were kept under the weather protection. For each section of the building, it took almost 10 weeks from delivery to the building site until all floors and the roof were mounted.

3.3. Simulations of microbial growth

It is a challenging task to predict mould growth as it is connected to a wide range of uncertainties, both in predicting the hygrothermal conditions and in modelling the actual biological process. In a literature review on mould growth modelling [11], its governing factors: surface humidity and temperature, exposure time (including fluctuating conditions) and substrate are studied, indicating a very complex biological phenomenon. Often there are uncertainties regarding the substrate, e.g. heartwood/sapwood, surface quality, drying schedule. Nevertheless, there are several mathematical models for predicting mould growth, whereof a few have been applied in industry e.g. the VTT-model [12], the WUFI Bio module [13], the m-model [14] and the MRD-model [15]. For the evaluation of the hygrothermal conditions in this study, the m-model is used. The assessment of the results is based on the VTT mould index with six levels of growth on surface 0-6 [16]. The Swedish building regulations [5] states the critical moisture level of a material should take into consideration when the growth of mould begins, without respect to visibility. Mould growth index 1 according to VTT is described as *Initial stages of growth* with "Small amounts of mould on surface (microscope)". Thus, the mould index exceeding 1 is chosen as the limit for the studied surfaces with a possible impact on the indoor environment [17].

4. Results

Two issues are studied, the performance of the weather protection with respect to hygrothermal conditions, and the effect of hygrothermal conditions on CLT elements with respect to mould growth.

4.1. Hygrothermal conditions outdoors

The average outdoor temperature was 8.7°C while the average relative humidity was 83.2%RH, see Figure 1. There were long periods of high RH. By using the m-model to assess the outdoor hygrothermal conditions, a high potential of mould growth initiation is indicated, see Figure 2. The inclination of the curve is especially high during October to January. Compared to historical data [18], the temperature was significantly higher than average (6.5°C), while the precipitation was close to average (645 mm). Especially the winter was warmer than the historical data indicated.

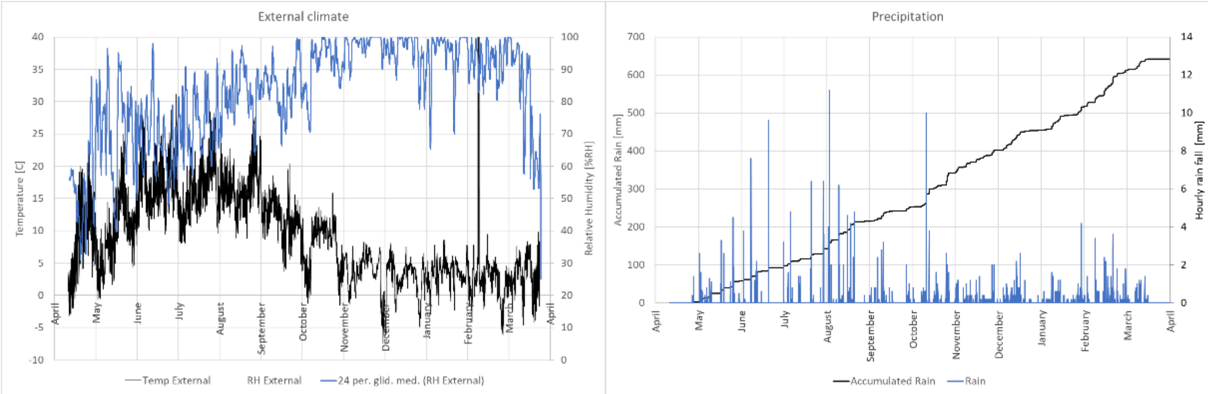

Figure 1. Outdoor conditions during the construction period. April to March. Left: Temperature and RH outside the weather protection. RH is shown as a sliding 24-h value. Right: Precipitation outside the weather protection, hourly values and accumulated value.

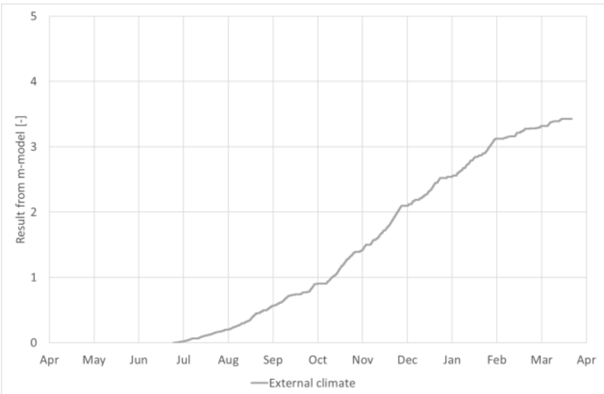

Figure 2. Mould growth initiation potential according to the m-model using the outdoor hygrothermal conditions. April to March.

4.2. Hygrothermal performance of weather protection

Measurements of hygrothermal conditions were performed from April to March for the outdoor conditions and from June to March for indoor conditions, Figure 3. However, for the effect of the weather protection on the hygrothermal conditions, a period of six months, June to November was chosen as the relevant period as values after November are affected by heating of the building. During this period, the temperature was in average 1°C warmer, with a variation of -3.6°C to 8°C and the moisture content was in average 0.1 g/m^3 dryer with a variation of -2.1 g/m^3, to 3.1 g/m^3. Observing the daily variations during the same period, Figure 4, left, show a sinusoidal variation with an approximately three-hour delay in the temperature peak inside the weather protection compared to outdoors. One concern about using weather protection was elevated temperatures during summer periods. The warmest summer week was studied, see Figure 4, right. The temperature in the weather protection followed the outdoor temperature quite well in the morning, however, there was a slight delay in high temperatures and for some days up to 2°C warmer within the weather protection. No clear difference at the different heights of the sensors could be seen. Typical variation in the weather protection can be illustrated by a week in September, where the deviation from the outdoor conditions is shown in Figure 5. The variations of temperature and moisture content during the day are significant, while the daily averages are quite stable. During a period of rain, the moisture content in the weather protection is lower than outside, indicating a positive effect on moisture content of the indoor air.

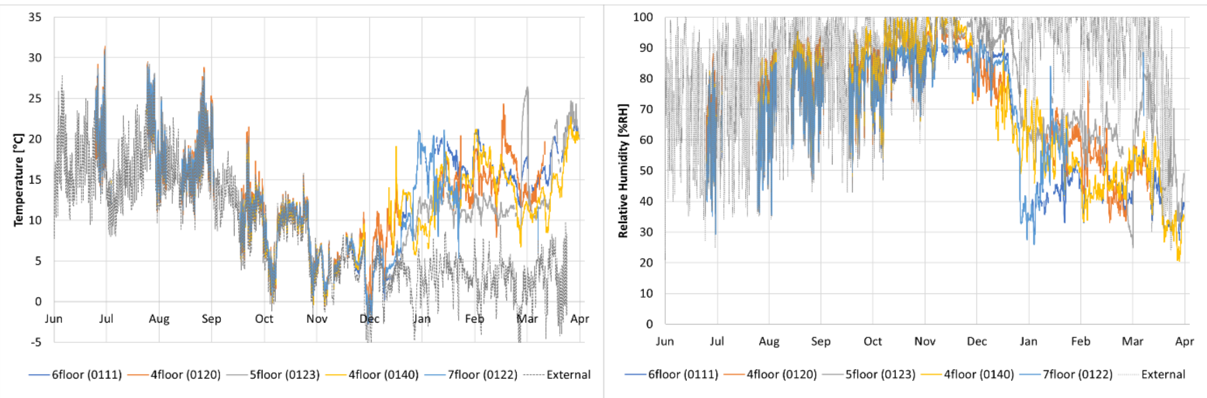

Figure 3. Hygrothermal conditions during construction of air within the weather protection and outdoors. June to March. Left: Temperature. Right: Relative humidity.

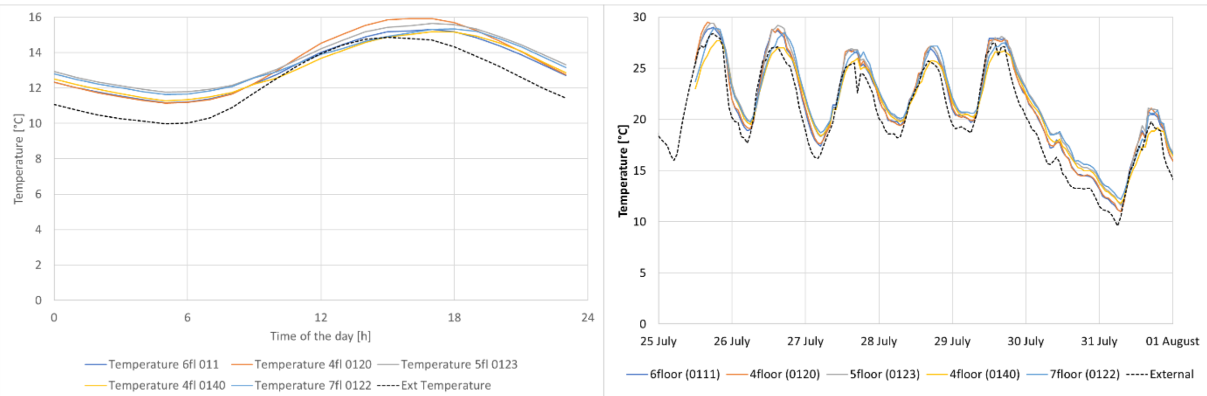

Figure 4. Left: Average daily variation of the temperature conditions June to November. Right: Temperature within weather protection during a week with a (Swedish) heat wave.

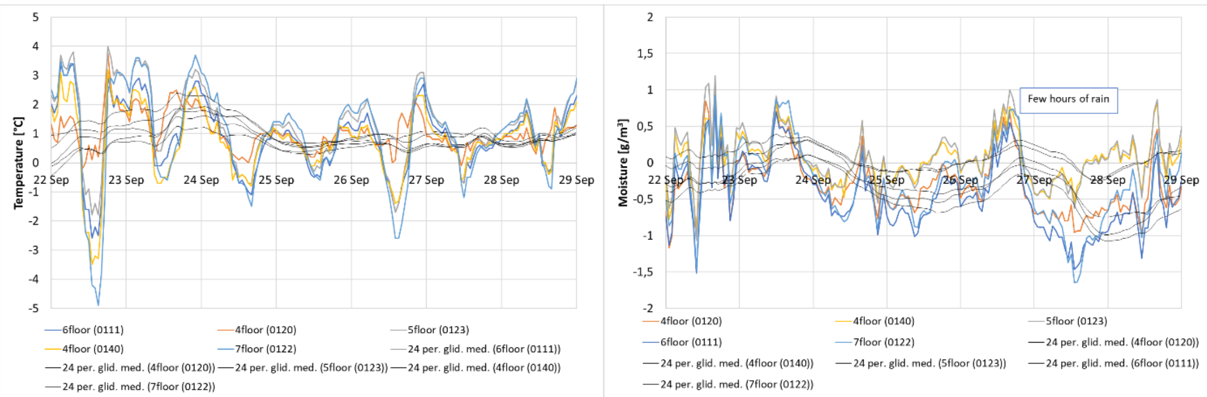

Figure 5. Hygrothermal conditions inside the weather protection compared to outdoor conditions during an autumn week with a few hours of rain. Left: Temperature difference. Right: Moisture content difference.

4.3. *Microbial growth on CLT elements*

The CLT panels were visually inspected before mounting and as there were no visible indications of mould growth at the time, a decision was made to not perform any sampling at this stage. However, later the project management wanted to show the good performance of the weather protection and decided on taking mould sampling in the last phase of the building before built-in. Three well spread sampling positions on each CLT floor from floor 3 to floor 7 were analysed, were floor 3 is the lowest intermediate floor. The lab assessments state none of the samples contained unacceptable levels of microorganisms, nor any microbial damage.

4.4. Modelling mould growth

The hygrothermal measurements were disturbed by heating in parts of the building, and the hygrothermal conditions for the CLT elements during the later period has instead been approximated by using the outdoor hygrothermal condition and adjusting them with the average differences in temperature and moisture supply as shown in section 4.2. At the end of the construction period, the interior is gradually heated as the building is being completed. The mould growth potential for the studied CLT-elements is estimated using the m-model, see Figure 6. The results indicate a moderate risk for mould growth at the end of the studied period for the CLT components within the weather protection. The results are shown for the elements with the longest documented period between mounting and heating of the building. The values can be compared to the substantially higher risk for mould growth using the outdoor conditions, even without influence of precipitation. The results also show the importance of keeping the duration of the exposure, i.e., time before the space is heated, low.

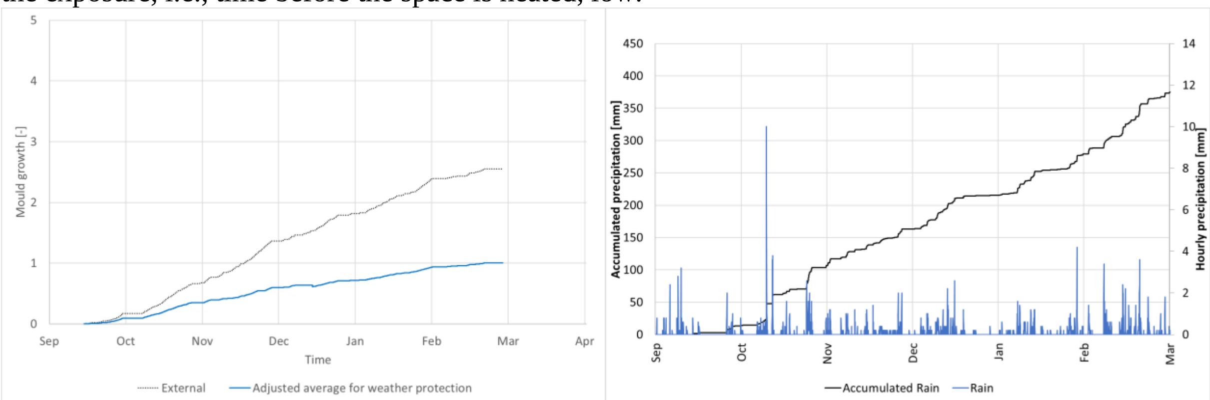

Figure 6. Left: Mould growth potential (m-model) during construction using weather protection compared to outdoor conditions (no precipitation). September to March. Right: Hourly and accumulated precipitation during the same time.

5. Discussion

The CLT construction in the studied case was not exposed to critical moisture levels during the construction phase which also was confirmed by the mould growth sampling. Even though the hygrothermal conditions inside the weather protection have similarities to outdoors, the potential of mould growth is significantly lower than outside, even without consideration to precipitation. The time aspect is shown to be important, by shortening the exposure the potential of mould growth is significantly reduced. The seasonal differences are also significant, the increase of the mould growth index during summer is substantially lower than during autumn.

In literature, there are several examples of monitoring CLT buildings without weather protection during the construction phase, e.g. [1] [19] [20] [21] [22] [23]. These studies indicate a significant rise in moisture content in wood due to precipitation. These studies are mainly concerned by the drying potential of CLT material that has been exposed to precipitation, not to protect the material and few studies provide documentation on mould growth. Compared to these studies, the use of a full weather protection in the present study indicates a substantial amount of water, over 600 mm on a yearly basis, is redirected from the structure. As a wide perimeter around the building was protected, water intrusion could be successfully avoided even though the lower parts of the weather protection were open enabling easy entries and increasing ventilation. During rainfall there are indications of lower moisture supply in the air inside the weather protection compared to outside.

Overall, the moisture supply can be anticipated to be slightly reduced due to moisture uptake in dry CLT material.

In [1], a CLT building without weather protection was studied with respect to mould growth. In the study, half of 200 samples were assessed as “some mould growth” and one third had “moderate or extensive mould growth”. In that study, mould growth was found on essentially all investigated floor structures. It should be noted mould growth samples were taken on several occasions during the construction period potentially missing to register mould growth that might occur later during the construction period. This was also indicated by samples taken at later stages in the process showed a higher percentage of “extensive growth”. The report [1] stated precipitation as the cause of the mould growth as an assessment using the MRD model of the outdoor climate showed negligible risk of mould growth. However, the MRD model define the onset of mould as “Sparse but clearly established growth, often conidiophores are beginning to develop”, stage 2 on a 5-point scale whereas the m-model uses the limit of mould growth set to “small amounts of mould on surface (microscope), initial stages of local growth” based on spruce sapwood and thus not comparable. Our assessment is however assumed to be conservative. Furthermore, the outdoor hygrothermal conditions of the former study were also significantly less beneficial to mould growth, dependant on season and the significantly warmer conditions compared to an average year.

A concern expressed by practitioners was anticipated high temperatures particularly in the upper parts of the weather protection. The measurements showed slightly elevated temperatures in the weather protection, up to 2 degrees, during heat waves, and warmer temperatures during evenings. Even though the absolute temperature difference is moderate, the impact on work safety should be considered. The large volume of the weather protection is probably beneficial in this concern.

6. Conclusions

In the study, the weather protection was clearly beneficial and significantly lowered the risk of mould growth on the CLT elements. Choosing a production method should take into consideration the season of construction as well as having a safety margin allowing for “bad luck” with the weather. The conditions within the weather protection was slightly warmer and slightly drier than outdoors during the studied period of May to November. The temperature increase was in the range of one degree and there was no or slightly negative moisture supply within the weather protection during that period. Even though the difference on temperature and RH were moderate, the effect on mould growth potential was substantial, indicating a 50-percent reduction of mould growth index for the case with weather protection. At the same time, a large amount of water is redirected from the building and its perimeter, reducing risk of wetting CLT elements. However, the study also indicated that even with a weather protection, constructing with CLT elements require focus on moisture issues and the planning of the project. Anticipated climate change with higher volumes of precipitation and slightly warmer and wetter climate it is increasingly important to lower risk moisture problems.

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