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OAK RIDGE NATIONAL LABORATORY
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# Hygrothermal Performance of West Coast Wood Deck Roofing System

## November 2013

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# HYGROTHERMAL PERFORMANCE OF WEST COAST WOOD DECK ROOFING SYSTEM

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## ABSTRACT

Simulations of roofing assemblies are necessary in order to understand and adequately predict the actual hygrothermal performance. At the request of GAF, simulations have been setup to verify the difference in performance between white and black roofing membrane colors in relation to critical moisture accumulation for traditional low slope wood deck roofing systems typically deployed in various western U.S. Climate Zones. The performance of these roof assemblies has been simulated using the hygrothermal calculation tool WUFI, from which the result was evaluated based on a defined criterion for moisture safety. The criterion was defined as the maximum acceptable water content for wood materials and the highest acceptable moisture accumulation rate in relation to the risk of rot. Based on the criterion, the roof assemblies were certified as being either safe, risky or assumed to fail. The roof assemblies were simulated in different western climates, with varying insulation thicknesses, two different types of wooden decking, applied with varying interior moisture load and with either a high or low solar absorptivity at the roof surface (black or white surface color). The results show that the hygrothermal performance of the studied roof assemblies differs with regard to all of the varying parameters, especially the climate and the indoor moisture load.

## 1. INTRODUCTION

New roofing technologies can provide better thermal performance and decrease the net energy demand. However, new technologies can result in unintended consequences related to moisture safety, such as rot of wood materials. These unwanted consequences are mainly a result of critical levels of moisture (water liquid and vapor) from moisture sources, both from the interior and the exterior environments. If the roof is not properly designed, these moisture sources may have too large an impact on the hygrothermal performance of the roof.

Cool roofs, or white roofs, are typically designed to decrease the thermal load from solar radiation. However, under certain conditions, these cool roofs can possess a higher risk of moisture failure in comparison with traditional dark colored roofs (Dregger 2012). Unfortunately, rot decreases the structural performance of wood materials, which eventually might lead to a structural failure of the roof.

The reason why a wood deck, with a cool colored exterior surface, has a higher risk of critical moisture accumulation is that the intended decrease in temperature can reach below the dew-point temperature (Pallin and Kehrer 2013). In such case, water vapor will condense or the relative humidity in the wood material will reach sufficiently high levels in terms of developing rot.

Based on the above discussed causes of critical levels of moisture in wood material, such as the wood deck of the studied roof assembly, an improved design of the roof has been evaluated. By the application of additional insulation on the exterior side of the wood deck, the temperature of the same will be less affected by the exterior surface temperature, thus a lower risk of rot since relative moisture levels increases with decreasing temperature. This study aims to investigate the required insulation thickness of the additional exterior insulation to ensure a good energy performance and moisture safety; in relation to different outdoor climate, indoor air humidity levels, surface absorptivity for solar radiation and type of wood deck material.

## 2. INVESTIGATION

In collaboration with GAF, different roof assemblies were established and their hygrothermal performances was simulated through transient hygrothermal calculations of WUFI1D (IBP 2012), which was developed to evaluate the long-time energy and moisture performances, and durability of building envelopes, such as exterior walls, roofs, and foundations (Künzel 1995). WUFI has been successfully validated repeatedly over the past two decades (Kehrer and Schmidt 2008) and has a large database of material properties and exterior climates from all U.S. Climate Zones.

Six different outdoor climates was studied; of which San Diego and Los Angeles represent U.S. Climate Zone 3 and San Francisco, Sacramento, Portland and Seattle represent Climate Zone 4. Different R-values of the fiberglass batt were applied to the simulated roof assemblies and varied according to Table 1. The roof assembly is illustrated in Fig. 1.

**Table 1. WUFI Simulation Conditions**

| Climate Zone | Nominal Rafter Size | Nominal Fiberglass Batt R-Value | Fiberglass Batt inches | Air Space | |
|---|---|---|---|---|---|
| | | | | inch | mm |
| 3 | 2x8 | R-11 | 3 ½ | 3.75 | 96 |
| | 2x10 | R-11 | 3 ½ | 5.75 | 146 |
| | 2x10 | R-19 | 6 | 3.25 | 83 |
| 4 | 2x8 | R-19 | 6 | 1.25 | 32 |
| | 2x10 | R-19 | 6 | 3.25 | 83 |
| | 2x10 | R-30 | 8 | 1.25 | 32 |

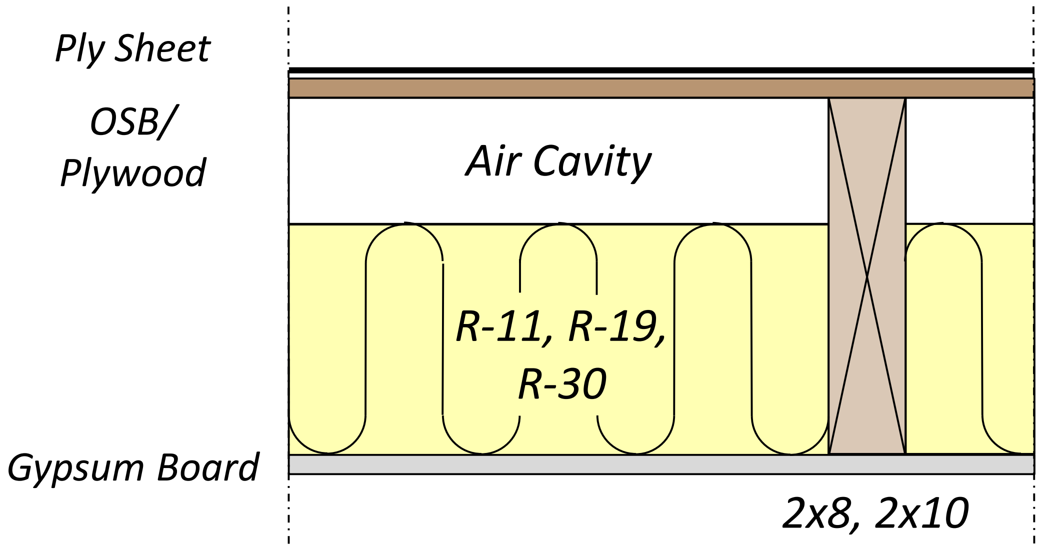


**Fig. 1. The design of the investigated roof assembly.** Both 2x8 and 2x10 rafters where simulated, depending on the required R-value of the fiberglass batts. The deck was either OSB or Plywood.

Three combinations of rafter dimension and cavity insulation were used for each simulated outdoor climate. A 2x8 rafter with R-11 cavity insulation, a 2x10 rafter with R-11 insulation, and a 2x10 rafter with R-19 insulation were used in the simulated cities of Climate Zone 3. Due to building code; San Francisco, Sacramento, Portland and Seattle were instead simulated with a 2x8 rafter with R-19 cavity insulation, 2x10 rafter with R-19 insulation, and finally a 2x10 rafter with R-30 insulation.

Two different types of deck were used in the model; Plywood and Oriented Strand Board (OSB) with a ½ inch thickness. The roof assemblies were designed with an exterior TPO membrane with varying solar radiation absorptivity in accordance with either a “cool” white color or a traditional dark surface. The solar absorptivity for the white and the dark surface was set to 0.35 and 0.90 respectively.

The indoor air humidity was simulated under four different scenarios; with a low, medium and high moisture load (WTA 2004) and as an excess of moisture in compliance with a 2-bedroom residential building (ASHRAE 160 2011).

In all assemblies, an appropriate air space was applied to fulfill the thermal insulation requirements. On the interior side of the roof, a ½ inch gypsum board with a 10 perm latex paint was applied. The roof assemblies were assumed to be overall air tight and constructed with satisfactory workmanship.

The evaluation of the simulated roof assemblies was based on a criterion, which is given in Table 2. The simulated assemblies was considered to either pass, be associated with risks or considered to fail.

According to the 2013 ASHRAE Handbook Fundamentals (ASHRAE 2013), decay in wood materials usually requires 30% saturation. However, to maintain a safety margin, levels below 20% should be maintained.

The criterion applied to this study is based on this guideline, which is presented in Table 2. The different roof assemblies were simulated for three consecutive years, though the result from the first year was excluded from the evaluation due to possibly being too affected by the initial boundary conditions (i.e. the assumed moisture content of the building materials). Consequently, the roof assemblies were evaluated based on the results from the second and third year.

**Table 2. Evaluation Criterion for the Simulation Results**

| Maximum Water Content in Second and Third Year of Simulation | Evaluation Result |
|---|---|
| Value ≤ 20% | “Pass” |
| 20% < Value ≤ 30% | “Risk” |
| Value > 30% | “Failure” |

In total, the number of simulation scenarios, thus different roof assemblies, was 48 for each of the six climates. Consequently, the total number of simulation runs was 288 from which the hygrothermal performance was evaluated based on previously discussed criterion.

In addition, those simulated scenarios which were considered as a failure, or risky, was simulated with an improved design according to Fig. 2. The intention of the design is to decrease the influence of the exterior climate on the wood deck by adding additional insulation on the exterior side of the sheathing. The outcome of re-simulating the failed roof assemblies was a required insulation thickness of the supplement exterior insulation which will increase the temperature of the OSB or Plywood and thus lowering the risk of critical moisture levels. This approach provides a safe hygrothermal design of the investigated roof construction, independent of exterior or interior climates; or other varying material, surface or structural properties.

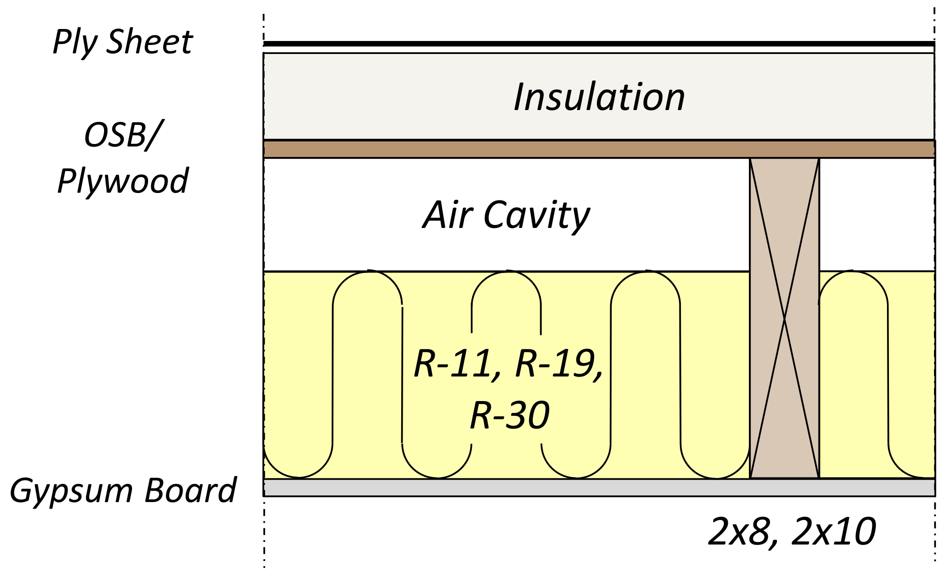


**Fig. 2. An alternative design of the investigated roof assembly, which is applicable under otherwise expected failing or risky conditions.** A supplement of insulation is added to the exterior side of the wood deck, with the intention of decreasing the effect of the outdoor climate in the wood deck. The re-cover insulation material is polyisocyanurate and the thickness depends on whether the performance criterion is fulfilled.

## 3. RESULTS

The results from the simulations are presented for each climate i.e. each of the six simulated cities. In general, the more northern located cities are expected to be more sensitive to the varying parameters; especially the surface solar absorptivity and the excess of indoor moisture.

### 3.1 SAN DIEGO

San Diego is located in Climate Zone 3. The climate file representing San Diego is measured near the coast which apparently results in small annual variations of the exterior temperature (Künzel 1995). On average, the temperature ranges from 55 and 70 °F. All of the 48 simulated scenarios of the roof assembly passed the criterion, which is illustrated in both Fig. 3 and

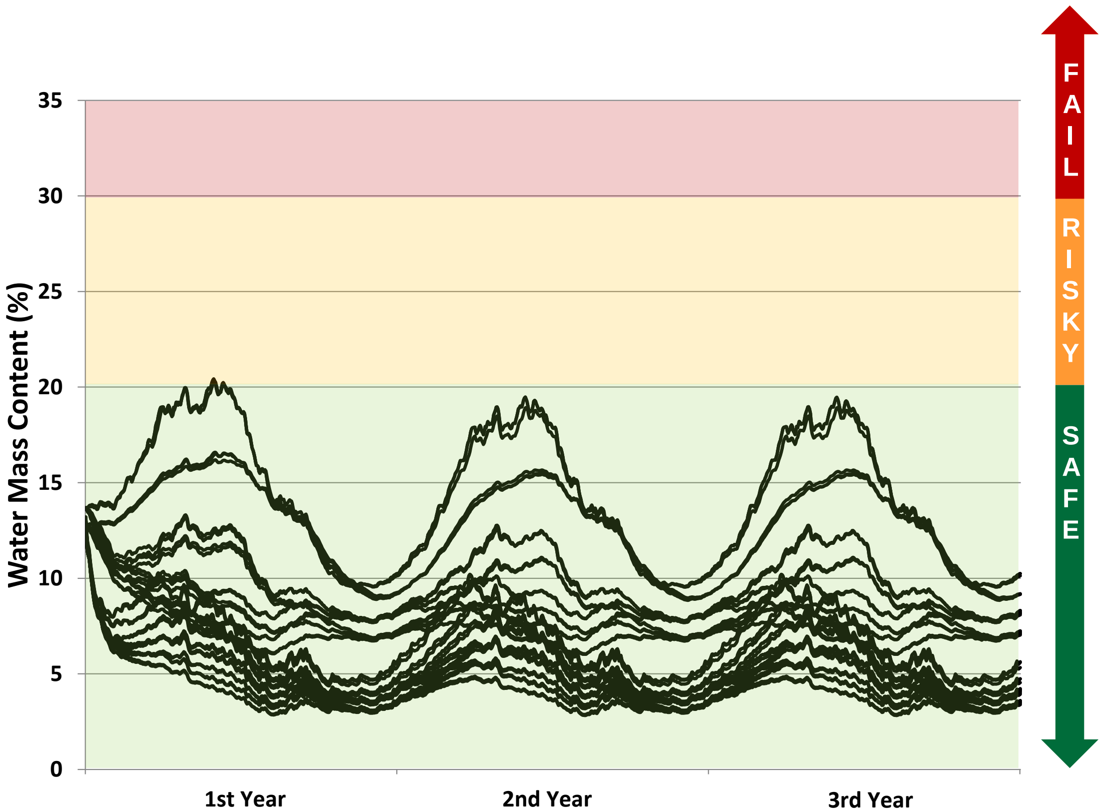


**Fig. 3. Simulated annual variations of the moisture content in both the OSB and the Plywood deck in the climate of San Diego.** The result is based on three years of consecutive simulations.

**Table 3. Evaluation of the results from simulating the hygrothermal performance of the wood deck roofing system in the climate of San Diego** According to the Table, none of the simulated scenarios exceeds the performance criterion of more than 20% in moisture content in the wood deck.

| San Diego | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture Supply | OSB | | | | | | Plywood | | | | | |
| | 2x8 R-11 | | 2x10 R-11 | | 2x10 R-19 | | 2x8 R-11 | | 2x10 R-11 | | 2x10 R-19 | |
| | Black | White | Black | White | Black | White | Black | White | Black | White | Black | White |
| Low Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| Medium Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| High Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| ASHRAE 160 | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |

## 3.2 LOS ANGELES

The climate of Los Angeles, used in the simulations of the hygrothermal performance of the roof deck, is similar to the climate of San Diego. Consequently, the simulated scenarios of Los Angeles all pass the criterion of never exceeding a moisture content of 20% in the OSB or the Plywood, see Table 4 and Fig. 4 for details.

**Table 4. Evaluation of the results from simulating the hygrothermal performance of the wood deck roofing system in the climate of Los Angeles** According to the Table, none of the simulated scenarios exceeds the performance criterion of more than 20% in moisture content in the wood deck.

| Los Angeles | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture Supply | OSB | | | | | | Plywood | | | | | |
| | 2x8 R-11 | | 2x10 R-11 | | 2x10 R-19 | | 2x8 R-11 | | 2x10 R-11 | | 2x10 R-19 | |
| | Black | White | Black | White | Black | White | Black | White | Black | White | Black | White |
| Low Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| Medium Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| High Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| ASHRAE 160 | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |

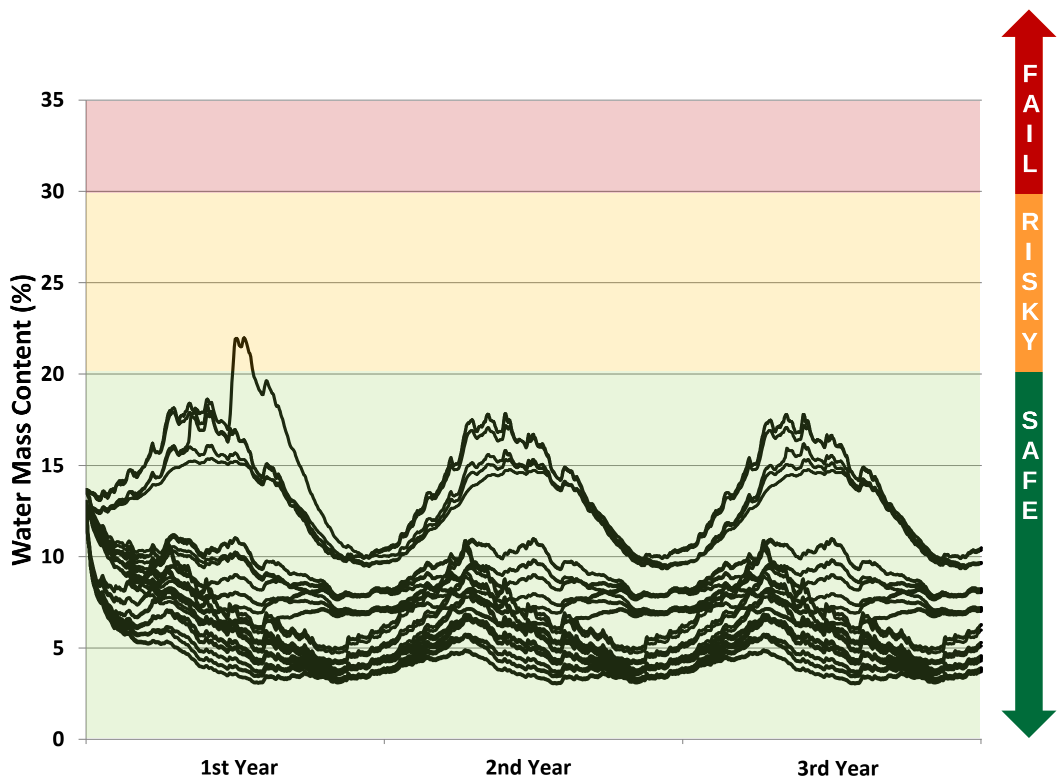


**Fig. 4. Simulated annual variations of the moisture content in both the OSB and the Plywood deck in the climate of Los Angeles.** The result is based on three years of consecutive simulations.

### 3.3 SAN FRANCISCO

According to the simulated performance of the roofing system, there are several scenarios that are expected to fail in terms of the criterion. The annual progressions of moisture content in these scenarios are illustrated in Fig. 5 which depicts failure in six out of 48 roof assemblies. Their compositions of the varying parameters are given in Table 5.

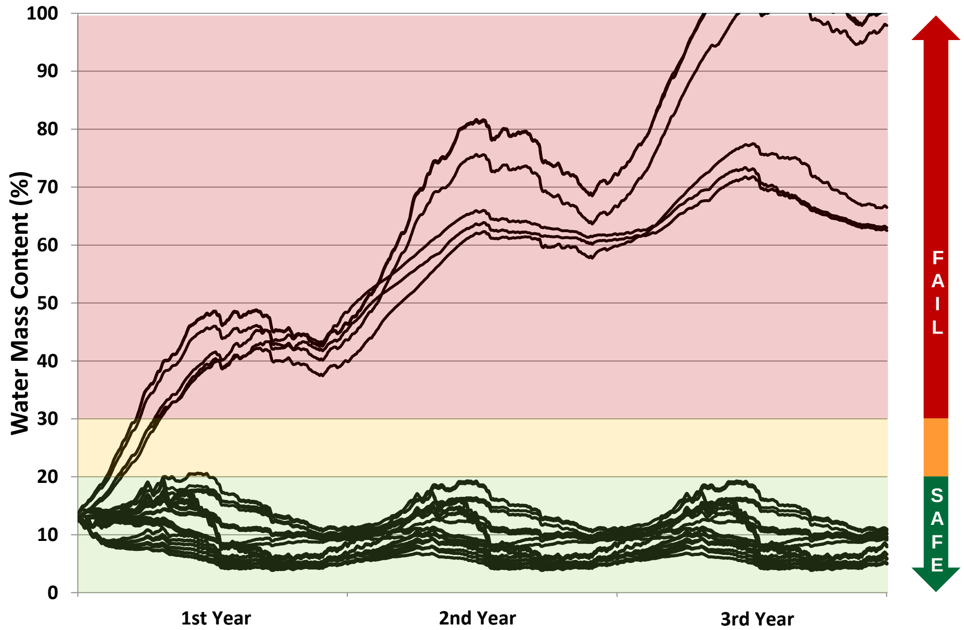


**Fig. 5. Simulated annual variations of the moisture content in both types of wood deck in the climate of San Francisco.** The result is based on three years of consecutive simulations.

**Table 5. Evaluation of the results from simulating the hygrothermal performance of the wood deck roofing system in the climate of San Francisco** Six out of 48 simulated scenarios are expected to fail. These roof assemblies are all applied with a white surface and with an indoor humidity according to ASHRAE standard (ASHRAE 160 2011).

| San Francisco | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture Supply | OSB | | | | | | Plywood | | | | | |
| | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | |
| | Black | White | Black | White | Black | White | Black | White | Black | White | Black | White |
| Low Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| Medium Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| High Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| ASHRAE 160 | OK | FAIL | OK | FAIL | OK | FAIL | OK | FAIL | OK | FAIL | OK | FAIL |

## 3.4 SACRAMENTO

The expected performance of the roofing system in the climate of Sacramento behaves similar to San Francisco. In addition to six expected failures, there are also four scenarios in which the performance must be assumed to be risky. The results from the simulations are presented in Table 6 and Fig. 6.

**Table 6. Evaluation of the results from simulating the hygrothermal performance of the wood deck roofing system in the climate of Sacramento.** Eleven out of 48 simulated scenarios are expected to fail from which only one is applied with a dark roof surface.

| Sacramento | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture Supply | OSB | | | | | | Plywood | | | | | |
| | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | |
| | Black | White | Black | White | Black | White | Black | White | Black | White | Black | White |
| Low Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| Medium Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| High Moisture | OK | OK | OK | OK | OK | OK | OK | RISK | OK | RISK | OK | RISK |
| ASHRAE 160 | OK | FAIL | OK | FAIL | OK | FAIL | RISK | FAIL | OK | FAIL | OK | FAIL |

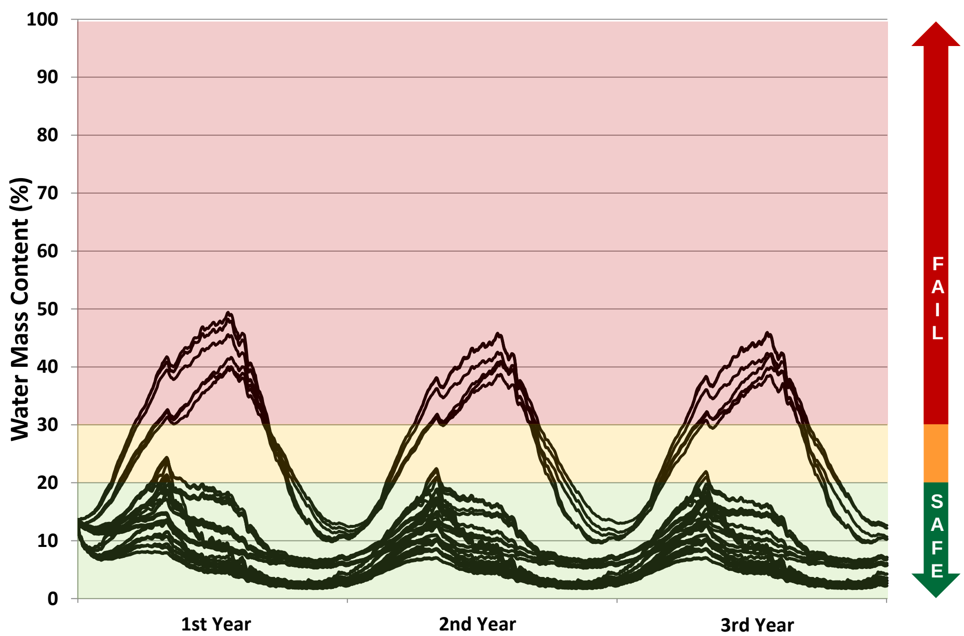


**Fig. 6. Simulated annual variations of the moisture content in both types of wood deck in the climate of Sacramento.** The variations of moisture content illustrate several compositions of the roof assembly with expected unsatisfying hygrothermal performances.

### 3.5 PORTLAND

The result from simulating the moisture content of the wood deck in the climate of Portland indicates that the climate, as a varying parameter, plays a significant role on the expected hygrothermal performance; thus whether the different simulated roof assemblies fail the criterion or not. There are represented risky or failed roof assemblies for all values of the varying parameters except for the scenarios with a simulated low moisture supply. The less satisfying compositions of the roofing system are simulated with an indoor moisture supply according to standard (ASHRAE 160 2011), as seen in Table 7.

**Table 7. Evaluation of the results from simulating the hygrothermal performance of the wood deck roofing system in the climate of Portland** Several of the 48 simulated scenarios are either expected to fail or must be classified as risky. The most severe scenarios are simulated with an indoor moisture supply according to standard (ASHRAE 160 2011).

| Portland | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture Supply | OSB | | | | | | Plywood | | | | | |
| | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | |
| | Black | White | Black | White | Black | White | Black | White | Black | White | Black | White |
| Low Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| Medium Moisture | OK | OK | OK | OK | OK | OK | OK | RISK | OK | RISK | OK | OK |
| High Moisture | RISK | RISK | OK | RISK | OK | RISK | OK | RISK | OK | RISK | OK | RISK |
| ASHRAE 160 | RISK | FAIL | RISK | FAIL | RISK | FAIL | RISK | FAIL | RISK | FAIL | RISK | FAIL |

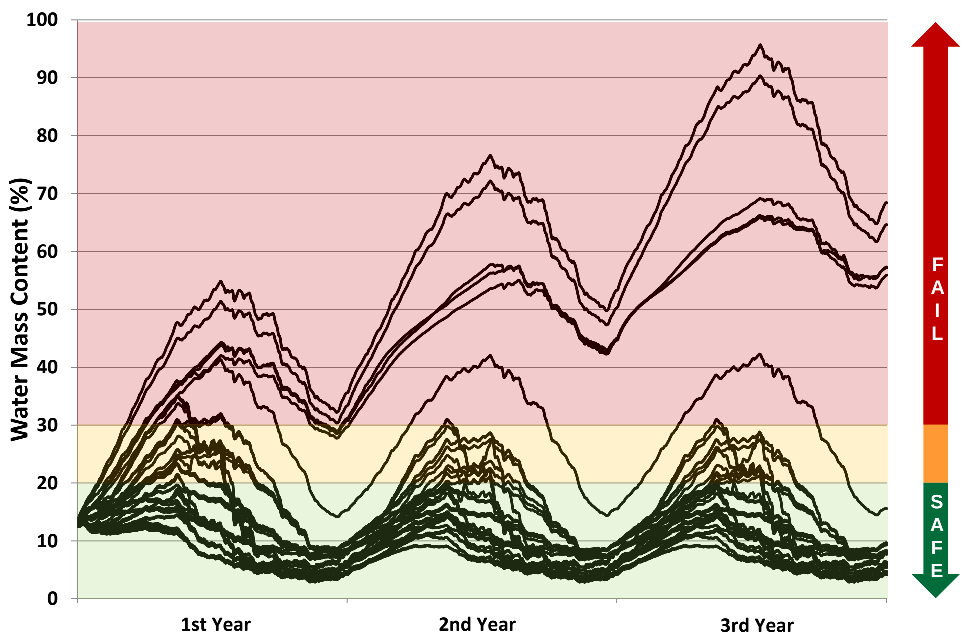


**Fig. 7. Simulated annual variations of the moisture content in both types of wood deck in the climate of Portland.**

## 3.6 SEATTLE

The climate of Seattle resulted in many unsatisfying performances of the simulated roofing system. Failures, or assumed risky, performances existed in all values of the varying parameters. However, a low level of indoor moisture only resulted in one case of an expected risky performance. As previously seen, the level of indoor moisture production seems to have a great impact on the performance which will also be discussed and further investigated in Section 3.7. The results from simulating the roofing system in the climate of Seattle are presented in Table 8 and Fig. 8.

**Table 8. Evaluation of the results from simulating the hygrothermal performance of the wood deck roofing system in the climate of Portland** The level of indoor moisture supply seems to have a great impact on moisture content of the wooden sheathing,

| Seattle | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture Supply | OSB | | | | | | Plywood | | | | | |
| | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | | 2x8 R-19 | | 2x10 R-19 | | 2x10 R-30 | |
| | Black | White | Black | White | Black | White | Black | White | Black | White | Black | White |
| Low Moisture | OK | OK | OK | OK | OK | OK | OK | OK | OK | RISK | OK | OK |
| Medium Moisture | OK | RISK | OK | RISK | OK | RISK | OK | RISK | RISK | RISK | OK | RISK |
| High Moisture | RISK | FAIL | RISK | FAIL | RISK | RISK | RISK | RISK | FAIL | FAIL | RISK | RISK |
| ASHRAE 160 | RISK | FAIL | FAIL | FAIL | FAIL | FAIL | RISK | FAIL | FAIL | FAIL | FAIL | FAIL |

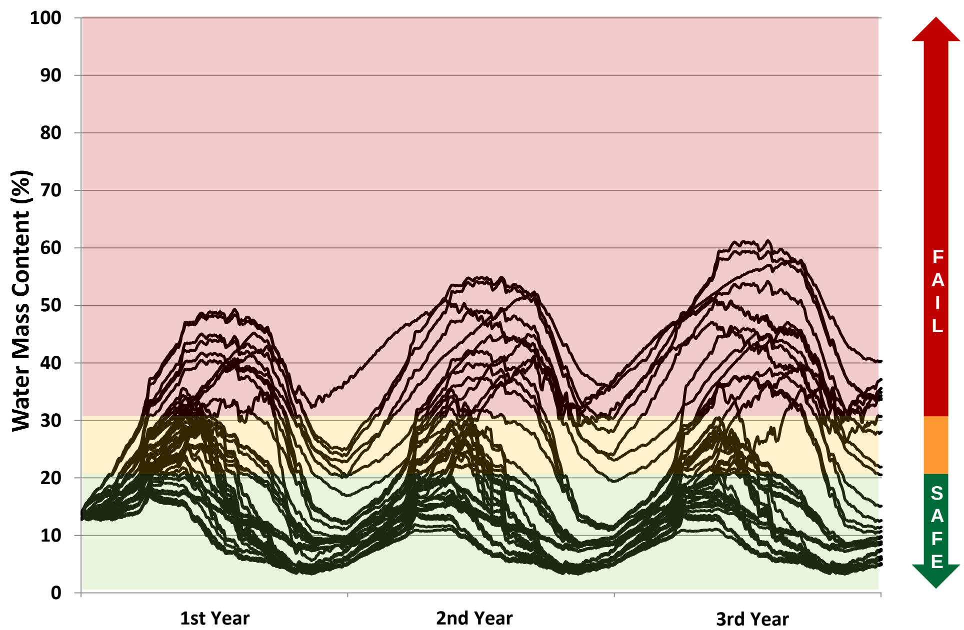


**Fig. 8. Simulated annual variations of the moisture content in both types of wood deck in the climate of Seattle.** The annual average in moisture content increases in several of the simulated roof assemblies.

### 3.7 ADDITIONAL SIMULATIONS

According to the result presented in Section 3.1 to 3.6, the level of indoor moisture supply plays a significant role on whether the simulated roof assemblies are considered as safe, risky or a failure. Table 9 summarizes the evaluation of the simulated roof assemblies with an indoor moisture supply according to provided guidelines (ASHRAE 160 2011). These unsatisfying roof assemblies have been re-simulated with an alternative design, as seen in Fig. 2. The intention of the design is to increase the thermal resistance on the exterior side of the wood deck and therefore make it less influenced by the exterior boundary conditions. This increase in thermal resistance is achieved by adding board(s) of polyisocyanurate between the wood deck and the surface membrane.

**Table 9. Summary of the evaluation of all the roof assemblies simulated with an excess of indoor moisture according to standard (ASHRAE 160 2011)** Neither San Diego nor Los Angeles has any roof assembly which is considered unsatisfying.

| Indoor Humidity - ASHRAE 160 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Climate | OSB | | | | | | Plywood | | | | | |
| | 2x8 | | 2x10 | | 2x10 | | 2x8 | | 2x10 | | 2x10 | |
| | R-19 (R-11)[a] | | R-19 (R-11)[a] | | R-30 (R-19)[a] | | R-19 (R-11)[a] | | R-19 (R-11)[a] | | R-30 (R-19)[a] | |
| | Black | White | Black | White | Black | White | Black | White | Black | White | Black | White |
| San Diego | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| Los Angeles | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK | OK |
| San Francisco | OK | FAIL | OK | FAIL | OK | FAIL | OK | FAIL | OK | FAIL | OK | FAIL |
| Sacramento | OK | FAIL | OK | FAIL | OK | FAIL | RISK | FAIL | OK | FAIL | OK | FAIL |
| Portland | RISK | FAIL | RISK | FAIL | RISK | FAIL | RISK | FAIL | RISK | FAIL | RISK | FAIL |
| Seattle | RISK | FAIL | FAIL | FAIL | FAIL | FAIL | RISK | FAIL | FAIL | FAIL | FAIL | FAIL |

a. *R* -values of San Diego and Los Angeles.

The outcome of re-simulating the roof assemblies with an unsatisfying performance is a required insulation R-value of the polyisocyanurate boards in order to fulfill the performance criterion. All the different scenarios of a roof assembly with an assumed risky or failing hygrothermal performance, presented in Table 9, are re-simulated with the alternative roofing system design. The required insulation R-value to fulfill the performance criterion for each simulated assembly is presented in Table 10.

**Table 10. Required insulation R-value of the polyisocyanurate insulation boards situated between the wood deck and surface membrane in order to achieve satisfactory hygrothermal performance** Apparently, the stated performance criterion can be fulfilled, no matter the composition of the influential parameters.

| Required insulation *R*-value at indoor humidity according to ASHRAE 160 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Climate** | **OSB** | | | | | | **Plywood** | | | | | |
| | 2x8 | | 2x10 | | 2x10 | | 2x8 | | 2x10 | | 2x10 | |
| | R-19 (R-11)[a] | | R-19 (R-11)[a] | | R-30 (R-19)[a] | | R-19 (R-11)[a] | | R-19 (R-11)[a] | | R-30 (R-19)[a] | |
| | **Black** | **White** | **Black** | **White** | **Black** | **White** | **Black** | **White** | **Black** | **White** | **Black** | **White** |
| **San Diego** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Los Angeles** | - | - | - | - | - | - | - | - | - | - | - | - |
| **San Francisco** | - | R-9 | - | R-9 | - | R-12 | - | R-9 | - | R-9 | - | R-15 |
| **Sacramento** | - | R-6 | - | R-6 | - | R-6 | R-3 | R-9 | - | R-9 | - | R-12 |
| **Portland** | R-3 | R-9 | R-3 | R-9 | R-3 | R-12 | R-6 | R-9 | R-6 | R-9 | R-6 | R-15 |
| **Seattle** | R-3 | R-9 | R-3 | R-9 | R-3 | R-9 | R-6 | R-9 | R-6 | R-9 | R-9 | R-15 |

a. *R*-values of San Diego and Los Angeles.

In addition, the unreliable roof assemblies representing Portland and Seattle and with medium moisture supply, as seen in Table 7 and Table 8, was re-simulated with the atlernative design. The required additional insulation thicknesses to fulfill the criterion for these initally unsatisfying roof assemblies are presented in Table 11.

**Table 11. Required insulation R-values for the re-simulated assemblies with medium moisture supply**

| Required exterior insulation *R* -value | | | | | | |
|---|---|---|---|---|---|---|
| **OSB** | 2x8 | | 2x10 | | 2x10 | |
| *Medium Moisture* | R-19 | | R-19 | | R-30 | |
| | **Black** | **White** | **Black** | **White** | **Black** | **White** |
| Portland | - | - | - | - | - | - |
| Seattle | - | R-3 | - | R-3 | - | R-3 |
| **Plywood** | 2x8 | | 2x10 | | 2x10 | |
| *Medium Moisture* | R-19 | | R-19 | | R-30 | |
| | **Black** | **White** | **Black** | **White** | **Black** | **White** |
| Portland | - | R-3 | - | R-3 | - | - |
| Seattle | - | R-3 | R-3 | R-3 | - | R-6 |

## 4. DISCUSSION

The result from making a performance study of a typical west coast roofing systems indicate that the hygrothermal performance must be expected to vary greatly, depending on reigning conditions. This study included the variation of several influential parameters; the exterior climate, the indoor moisture production rate, the surface solar absorptivity, R-values of the insulation and type of wood deck materials. All of these variables were proven important on the hygrothermal performance; however, the exterior climate and indoor moisture supply seem to have the largest impact. In total 288 different roof assemblies were simulated using the hygrothermal calculation tool of WUFI1D.

The performance of the roof was evaluated based on not exceeding critical levels of moisture in the wood deck in terms of the risk of accelerated biological decay; in compliance with ASHRAE guidelines. All of the simulated roof assemblies in the climate of San Diego and Los Angeles fulfilled the criterion, while San Francisco and Sacramento had a number of simulated scenarios which were either considered as risky or as a failure. Most of the expected unreliable compositions had a high indoor moisture production rate, which indicates that this parameter is very influential on the hygrothermal performance; the simulated roof assemblies of Portland and Seattle also supply proof of the influence of the indoor moisture supply. In general, the number of risky or failing roof assemblies increased with a simulated colder climate. Therefore, the exterior climate is expected to be very influential as well, since the largest number of failing roof assemblies was found in Seattle. In addition, the solar surface absorptivity also has a large impact on whether the simulated roofs passed the criterion or not. This can clearly be seen in the simulation result of San Francisco and up to Seattle where the roofs with a white surface, thus a lower solar absorptivity, are more prone to fail or to be risky.

However, all of the roof assemblies, even those with an initial unreliable hygrothermal performance, can still pass the criterion by instead applying an alternative design. By adding exterior insulation of polyisocyanurate, the hygrothermal conditions of the wood deck become less influenced by the exterior climate. Whether the roof assemblies fail or pass the criterion only depends on the R-value of the polyisocyanurate boards located between the wood deck and the surface membrane. The result from this study shows that the improved roof design works for all of the initially failing roof assemblies.

The reason why several of the simulated roofs fail the criterion of not exceeding critical levels of moisture in the wood deck is a result of the following. There is usually an excess of moisture from the inside, since the interior water vapor content is the sum of the exterior water vapor content and the supply from moisture generative indoor activities or appliances. However, the interior air humidity can be lowered by a desiccant cooling HVAC system, if running. Consequently, this effect must be taken into account during the cooling season and will naturally have the largest impact in climates where the cooling is needed more frequently. Further, the interior air humidity will affect the vapor and water content of the wood deck, which is also a moisture sensitive material. The moisture content in the wood together with the temperature will affect the drying potential. In general, it is plausible to assume that moisture moves from the interior to the wood material during the night and dries inwards during the day. If the temperature of the wood is large enough, the drying potential is favorable and acceptable levels of moisture will exist. However, if the temperature in the wood is too low, the water vapor storage capacity is lower and the therefore the relative air humidity in this material is larger. In addition, if this material is not reaching sufficiently high temperatures during the day, the drying potential is too low and accumulation of moisture will exist. This is the main reason why roof assemblies of this type are more prone to fail in colder climates and when the net solar intensity is lower. As seen in this study, the hygrothermal performance can be improved by adding insulation on the exterior side of the wood deck. By this measure, the temperature of the wood deck rises during the night time, and therefore the roof deck becomes less affected by the outwards moisture flux.

## 5. REFERENCES


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