Microclimates at the Sixth Facade

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Abstract

Elevating buildings above grade is an increasingly-common design approach to address risks of costal and riverine flooding. While elevating buildings improves resistance to flood waters and potentially debris damage, other implications are less well-understood, including the influence of unique thermal and moisture conditions in the space between the ground and the underside of the elevated building—the so-called sixth facade. Unlike conventional basements, crawlspaces, or slabs-on-grade that respond to soil moisture through the installation of a vapor barrier, exposed, elevated floors contend with unique hygrothermal conditions, linked-to but distinct-from both the soil and the ambient air.

Uncontrolled moisture has significant energy consequences, can foster mold and fungi growth, and contributes to deterioration of building materials through rot and corrosion. To better understand conditions at the sixth facade, this study compares the conditions of the sixth facade to those of the interior and exterior ambient air of the same elevated building during the condensation-risk period of a year. Temperature and relative humidity were recorded inside, under, and adjacent-to the building at sub-hourly intervals for eleven months, to enable calculations of condensation risk. While extensive prior literature considers condensation in wall and roof assemblies and vented versus unvented crawlspaces; little data or guidance is available about the frequency of condensation risk on the underside of elevated buildings. The growing awareness and effort to improve building resilience at the residential scale demands a greater understanding of conditions at the sixth façade to guide design.

Background

Risks of water in Buildings

Water has long been understood as the enemy of building durability. Since wood is hygroscopic, the moisture content of the wood increases with relative humidity; even when not directly exposed to precipitation or ground water. Wood moisture content must remain below 19% to prevent rot, and below 16% to prevent mold.[1] The fiber saturation point of wood is between 27% and 30% for most species, and if wood remains above this threshold for a prolonged period decay occurs.[2] Excessive moisture can also affect the structural integrity of wood-framed buildings.[3] Moisture, oxygen and temperature, along with an adequate food source, are the main factors for mold and fungi growth in buildings, and since the presence of spores can never be adequately controlled, the moisture conditions in which they thrive must be managed. Water condensing on surfaces creates conditions conducive to mold growth, and if water diffuses into the grain of cellular materials like wood it can support fungal growth.[4] Molds and fungi can have consequences on the health and well-being of building inhabitants, and the integrity of building materials. Practically speaking, the occurrence of these biological activities and material decay are best controlled by controlling moisture and temperature through building systems to avoid moisture accumulation.

Vapor Drive and Condensation

Water vapor generally moves from the warmer to the colder side of building assemblies, from the wetter to drier; and from higher air pressure to low; as a result, vapor diffusion depends on the combined differences in temperature, humidity, and pressure usually described as vapor pressure. Moisture can condense within assemblies if the hygrothermal conditions reach saturation and dew-point temperature, so vapor diffusion is a greater problem in colder climates, where significant vapor drives can be coupled with large temperature gradients. The design of vapor retarders to restrict the diffusion of water vapor in assemblies depend on seasonal temperature shifts and the heating and cooling of a building. Thus climate, plus the location and type of vapor retarder affects the amount of moisture accumulation and mold growth.

Vertical Wall Assemblies

There has been significant research in recent years focusing on the effect of moisture on the building envelope of wood framed buildings, particularly on the effect of moisture within vertical walls. Many empirical studies compare humidity, temperature and moisture transfer measured in various wall assemblies under real world conditions.[5] For greater control of variance, some experiments test the hygro-thermal performance of wall assemblies in controlled laboratory environments,[6] while others seek a compromise by designing and constructing test-bed buildings with specific component and assembly performance that operate under ambient conditions.[7] These studies describe the effects of materials and assemblies on heat and vapor transfer, with data including temperature and relative humidity at different points in the wall, under various indoor and outdoor conditions.[8] While this prior work describes the effect of moisture on the building envelope and defines research methods, vertical walls and horizontal floors are subject to significantly different exterior conditions and internal flows.

Crawlspace Conditions

Fewer studies have considered conditions in elevated crawl spaces, focusing on the management of moisture, ventilation requirements, ground moisture evaporation, and the use of ground cover in crawlspaces.[9] One study compared conditions (air change, relative humidity, temperature, pressure variation) of a mechanically ventilated to a naturally ventilated crawl space in Finland.[10] A subsequent experiment focused on the effect of ground moisture evaporation on the moisture of a crawlspace 0.9 meter in height and 1 meter below ground level.[11] In this experiment, Kurnitski found that a crawlspace with relative humidity levels over 80-85% for “several weeks or months” can result in mold growth.[12] Similar periods of elevated moisture have been found to occur in crawl spaces when ground moisture evaporation raises the relative humidity of the space.[13]

Adding ground cover in the crawlspace, coupled with a low air change rate or natural ventilation, has proven effective in controlling the moisture of crawlspaces. Ground covers prevent evaporation from the ground, as the studies show a clear correlation between relative humidity of ground surface and moisture evaporation rate. Higher ventilation rates may lower relative humidity which can in turn prompt greater evaporation rates. Ventilation may also reduce air temperature and thus potentially increase relative humidity. Seasonal and daily weather changes significantly affect the moisture conditions of crawlspaces. Dry, winter air removes absolute moisture from the crawlspace; however, colder ventilation air decreases the temperature of the crawlspace and increases the relative humidity. Summer air is warmer and more humid than the crawlspace air, so ventilation increases temperature and decreases the relative humidity of the crawlspace. The studies did not find high relative humidity levels in summer, and only short condensation peaks were detected.[14] Together these results emphasize the need to characterize conditions under elevated buildings seasonally.

Elevated Floor Assemblies

Given that it is not exposed to precipitation, condensation is an important source of moisture at the sixth facade. In older buildings without floor insulation, the floor framing generally remains above the dew point temperature of the crawl space, preventing condensation.[15] Adding insulation can reduce surface temperatures below dew point, resulting in condensation on the insulation and exposed floor framing. Cantilever floors with a similar exposure to exterior conditions address the problem by sealing exposed joists with a foam barrier.[16]

As ground moisture evaporation is a primary moisture source under the building, many authors recommend the use of polyethylene sheeting as a vapor barrier between the ground and crawlspace.[17] Additional steps for reducing moisture in crawlspaces include effective site drainage and providing a minimum of 8-inches vertical clearance.[18] These recommendations have been proven for crawlspaces, but not for an open, sixth-façade condition.

Building regulations in flood zones require elevating buildings above average flood levels. The FEMA Advisory Base Flood Elevation guidelines require new homes built in post-Katrina New Orleans to be elevated a minimum of five feet above grade on raised pier or raft slab foundations but note that flood waters may reach higher levels. FEMA further requires the use of moisture resistant materials such as fiber cement protection board over insulation, and a 2-inch foil-faced polyisocyanurate to act as vapor control layer. To address concerns of moisture accumulation in floors with these new insulation requirements, the guidelines require insulation to be on the exterior and be removable to assist in drying if vapor/water enters cavity.[19]

The organization Project Home Again (PHA), replaces homes that were badly damaged or destroyed from Katrina and developed a system of building assemblies to prevent flooding and moisture damage. PHA Phase 1 houses are elevated at 3-feet above grade on a block foundation. The 3-foot space is vented and surrounded by latticework to allow flood waters to pass underneath. Floor framing is insulated with 2-inches of high-density spray foam underneath CDX subflooring. Spray foam has a low vapor permeability, keeps the subfloor warm to minimize condensation, it can also dry quickly in the event of moisture intrusion.[20] In some cases, as with the PHA homes, enclosed or partially-enclosed crawlspaces are permitted in flood zones, if they include flood openings not more than one foot above grade to allow water ingress. Ventilation openings do not generally satisfy these flood requirements.[21] Because the FEMA regulations focus on the threat of flooding, they do not address the less-dramatic effects of ongoing moisture damage, although they may create these conditions.

Method

The test building for this study is a wood-framed residential building on the Tug Hill Plateau in north-western New York, climate Region 5A. The building measures approximately 24’ x 36’. The structure is elevated on wood piers above the ground, which slopes slightly such that grade level is approximately two feet below the finished floor at the south end, and approximately three feet at the north end. The walls and floor are insulated with friction-fit fiberglass batts between studs and joists. The first floor is finished with vinyl tile adhered to an OSB base on a plywood subfloor. The floor insulation is protected with an asphalt impregnated particle board attached between (not below) the joists, which does not provide a continuous air- or vapor seal. The soil under the building is uncovered, the spaces between the piers are open to the air, and surrounding site is a grass lawn.

Data were collected using Onset Hobo datalogging sensors. Type MX2301 temperature and relative humidity sensors were placed centrally in the first and second floors. Type MX2302 sensors (which have the sensors in an external probe to facilitate placement in awkward locations) were installed in the attic and at the sixth façade, in both cases in the center of the building and the vertical midpoint of the space. Both the MX2302 and MX 2301 have an accuracy of +/- 0.2ºC and +/- 2.5% relative humidity and can download data via Bluetooth once installed. To measure ambient exterior conditions, an Onset U23-002 housed in a light-colored solar radiation shield was mounted five feet above the ground on a pole north of the house above low grass. This sensor has an accuracy of +/- 0.21ºC. Additionally, Onset UA-002-64 pendant dataloggers with an accuracy of +/- 0.53ºC, were placed under the eaves on the north, south, east and west facades of the house to record radiation and air temperature for each orientation. Figure 1 diagrams the locations and placement of the sensors.

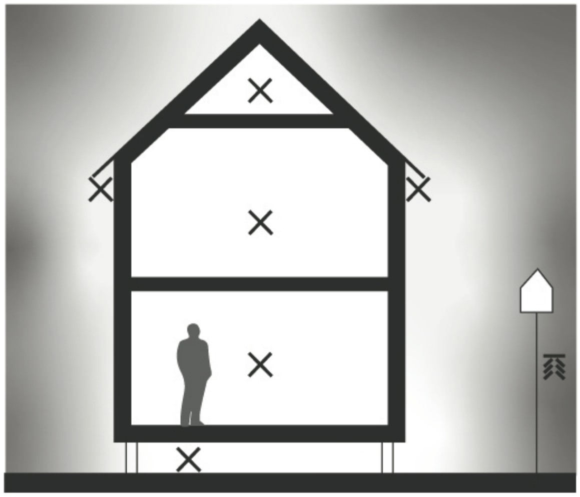

Fig. 1. Sensor placement diagram, section cut east/west.

The study was conducted over winter, the period with highest condensation risk, recording data from August 5, 2017 through June 27, 2018. The sensors logged temperature and relative humidity at 15-minute intervals. At the end of the study period, data values were read out and the sensors left in place for further study.

Results

Industry standards suggest risk of condensation on surfaces whenever relative humidity of the air exceeds 80%.[22] Of course, whether or not condensation will occur on any *particular* surface depends on the temperatures of the surface, and the presence of water vapor (by infiltration or diffusion), all tied to specific assemblies as well as environmental conditions. However, the 80% RH benchmark was used as the threshold for this analysis, because it is based on measurements of surrounding air temperature and humidity, rather than the temperatures and moisture content of possible condensing surfaces in the floor assembly.

Over the study period, ambient relative humidity consistently enters and remains in the condensation risk zone, as shown in Figure 2. However, the trend line for the outdoor data stays within the risk zone for almost the entire year, with less variance in the hourly data between the months of December and February corresponding with the lowest air temperatures.

At the sixth façade, there is a clear trend of an increasing relative humidity for the below-building air during the winter months; between December and March the conditions at the sixth façade remain in the risk zone and then decrease in the warmer months. When compared to the sixth façade, the first-floor interior conditions maintain a low relative humidity. The temperature mirrors the sixth façade and outdoor temperatures as the house remains unconditioned throughout the year, aside from several weekends when it is inhabited, these weekends can be seen in the spikes in November.

Discussion

A risk index was developed to identify times when the relative humidity of the sixth facade was greater than 80% and the relative humidity of the outdoors was less than 80%, indicating times of unusually high moisture below the building while excluding times that might have overall high RH, for example when it rains. Parameters were set by the accuracy of the sensors (+/- 2.5% RH) with a conditional statement: if the difference of the sixth facade and 80% was greater than the absolute value of 2.5, and the difference of the outdoors and 80% was less than the absolute value of 2.5. Data that fit between these parameters was compared with the difference of the relative humidity of the sixth façade and 80% relative humidity divided by the difference of 80% relative humidity and the relative humidity of the outdoors, as shown in the Risk Index Equation. During 520 out of 7,824 hours (6.6% or 22 out of 326 days) the relative humidity of the sixth façade was higher than that of the outdoors. The risk index ratio described below quantifies these hours of condensation risk.

Figure 3 depicts the trend lines in comparison to the risk index and condensation risk zone. The index peaks at the times when the trend of the sixth façade is greater than that of the outdoor relative humidity.

Risk Index Equation

$$r_s = Sixth\ Facade\ Relative\ Humidity$$

$$r_o = Outdoor\ Relative\ Humidity$$

$$If\ r_s > 80\ and\ r_o < 80,$$

$$and\ if\ r_s - 80 > |2.5|\ and\ 80 - r_o > |2.5|\ ,$$

$$then\ Risk_{\ condensation} = \frac{(r_s - 80)}{(80 - r_o)}$$

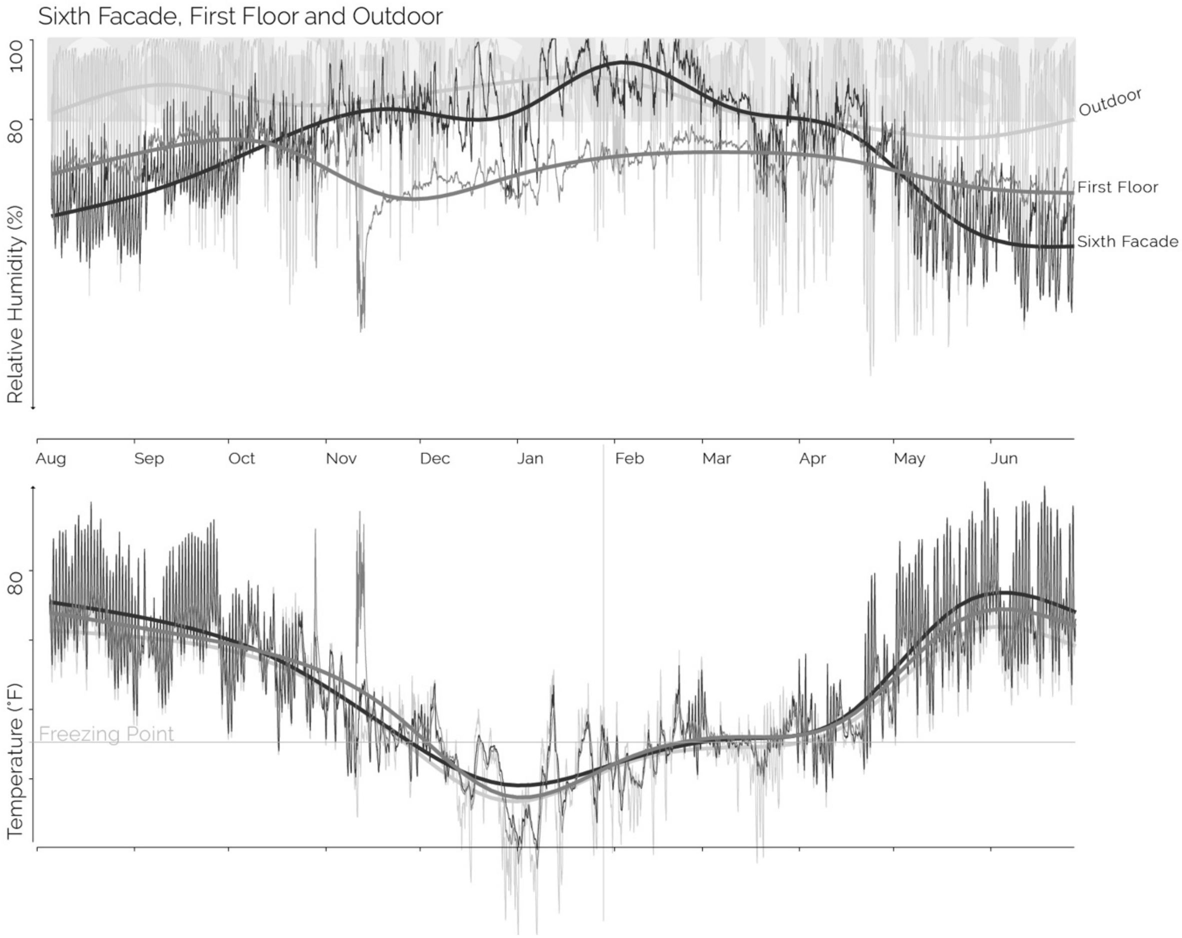

Fig. 2. Annual hourly of Relative Humidity and Temperature

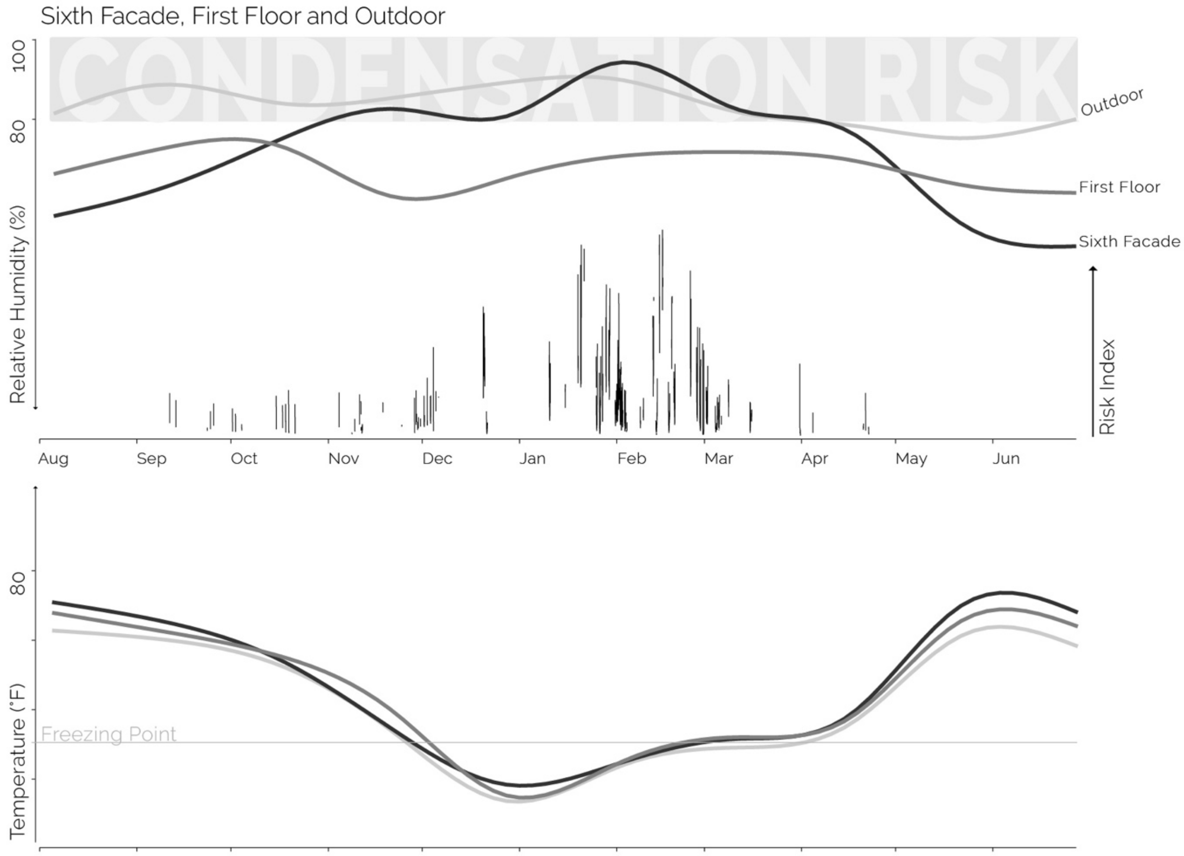

Fig. 3. Annual trends versus calculated risk index.

Conclusions

While limited to measurements of temperature and humidity of air, this data helps provide a better understanding of the microclimates that occur at the sixth façade. Understanding that buildings experience (and indeed create) multiple surrounding conditions, rather than a singular "exterior" supports further study of the response of various building assemblies to their specific environments. The condensation risk index clearly illustrates winter as the risk season even though RH is low. This risk is particularly evident when the house is heated (although this may also reverse the vapor drive) and on the edges of winter, when the temperature is near but not quite below freezing. This can be seen in the spikes between the end of January and early March.

Since the test building was unoccupied for most of the year, future work includes an analysis of occupied buildings to determine the condensation risk and moisture accumulation in various locations of floor assemblies separating occupied (heated) space with the environments below the sixth façade measured here. This would necessarily incorporate measurements of the specific assemblies, and their materials' conductivity, permeability, and airtightness relative to the vapor drive and exterior conditions.

Although well-documented for walls, the effects of building-ground radiant exchange and solar radiation on vapor drive at the sixth façade are not well studied. Similarly, the influence of the dimension between grade to the underside of the floor and the effect on ground moisture evaporation represent areas for additional work. Finally, while not the focus of this study, the experimental design included collecting data in the attic, which exhibited even greater extremes of relative humidity than those on the sixth façade. Comparing this data to the second floor and outdoor condition may lead to similar conclusions.

Notes:

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