Condensation and mold growth risks on interior surface of a corner wall in an apartment

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ABSTRACT

The paper presents the results of mold growth risks in a corner wall near an entrance door in an apartment house. The corner wall is recognized as a trouble spot for condensation and mold risk in apartment buildings. This study analyses mold risks based on a mixed simulation approach. This approach requires a reliable aggregation method to arrive at quantified mold growth risk and extension of standard simulation capacity to account for additional mechanisms of the mold phenomenon. The application of the developed mold risk indicator (MRI) is reported in apartment building case studies located in KOREA. This study reveals that 0.9 of temperature factor is required to avoid condensation and mold risks in the corner wall near an entrance door.

1. INTRODUCTION

Condensation and microbial growth in indoor spaces have been identified as the main moisture- related causes in Indoor Air Quality (IAQ) problems. Recently, mold and condensation problems in apartment houses have been increased due to the significant use of environment-friendly materials, more air-tightness, and energy-saving design.

Moisture problems in buildings can cause building deterioration and adverse health effects, and lead to high maintenance cost, low occupant productivity and high profile litigations. Although condensation problems are directly related to microbial growth, visible condensation is not an indispensable condition for mold growth. Indoor mold growth is likely to occur when a combination of relatively high humidity and temperature on building material surfaces constitutes favorable conditions for mold germination.

In this study, mold growth risks on interior surface of a corner wall are analyzed using a mixed simulation approach.

2. SIMULATION APPROACH

This study analyses mold risks based on a mixed simulation approach with additional mechanisms of the mold phenomenon and an aggregation method to arrive at quantified mold growth risk. This mold risk indicator (MRI) approach is applied to the selected trouble spot for quantitative condensation and mold growth risks.

In the mixed simulation approach, the simulation inputs are initially prepared by hand. The transfer of output from one simulation to the boundary condition of the next model is hardwired into the simulation input. Figure 1 shows the modeling procedures and simulation tools that are used in this study. Each box represents a step in the simulation, i.e., deployment of particular simulation tool (Moon 2005).

To analyze mold growth risks, the analysis starts with a standard building energy simulation model that is capable to give zone level information with respect to temperature and relative humidity over time in each zone. EnergyPlus and COMIS were chosen in this study for the heat transfer and airflow model respectively, since both software tools can easily be combined.

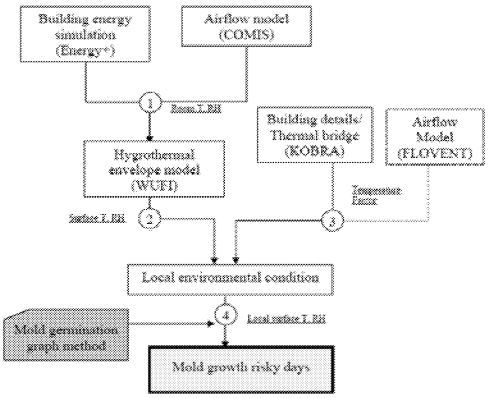

Figure 1. Flowchart of mixed simulation approach

In this study, National Renewable Energy Laboratory data is used for the schedule of the number of residents in each room (Hendron 2005). The selected apartment unit is assumed to be heated at 21.5°C in winter, no cooling system in summer. Yearly simulations were conducted with weather data of Seoul, Korea.

To predict detailed moisture behavior on specific locations on interior surfaces of the building envelopes, hygrothermal envelope models such as WUFI, MOIST are good candidates. In this study, we chose WUFI for our purpose as it is ideally suited to simulate moisture transport in multi-layered envelope and surrounding environment. It provides temperature and relative humidity on surfaces of the building envelopes. The mixed EnergyPlus/COMIS calculation results in zone air temperature and relative humidity, which are used as an interior boundary condition for WUFI hygrothermal envelope model.

Thermal bridge can affect temperature and relative humidity change on interior surfaces at the corner wall. To analyze moisture transportation more accurately, we perform simulation using KOBRA that offers flexible configuration of thermal bridge types. It qualifies the severity of a thermal bridge by a "temperature factor" which is defined as the inside surface temperature that results from an indoor-outdoor temperature difference of 1°C.

$$f = \frac{Ts - To}{Ti - To} \qquad (1)$$

Where,
Ts : internal surface temperature
Ti : internal air temperature
To : external air temperature

The above paragraphs introduce hygrothermal models that calculate temperature and relative humidity at a trouble spot. The calculated result now can be compared to the germination graph to quantify mold risk. Figure 2 presents one of the germination graphs showing the relationship between temperature, relative humidity, and exposure time. This graph was established based on the isopleths of Aspergillus, which were derived from the experiments reported by Smith(1982) and Ayerst (1969). In this graph, the surface condition in the group 1 should be maintained at least one day for initiation of mold germination to occur. With the germination graph, we can count the number of days that the environmental conditions are maintained longer than the required exposure time. The final result is presented as a yearly average number of "risky days for mold growth" (a value between 0 and 365).

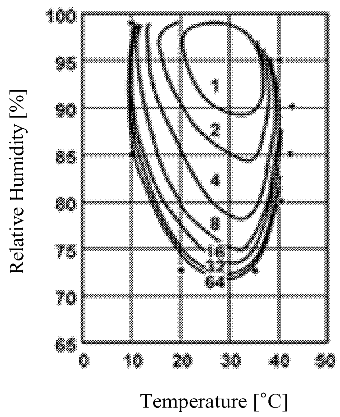

Figure 2. Mold germination graph for the initiation of mold germination (from Smith 1982)

3. ANALYSIS OF MOLD GROWTH RISKS

The selected apartment unit (size of 76 m²) is located in the city center of Seoul with severe winter and humid summer. The entrance door is exposed to outdoor directly. Figure 3 shows the plan of the selected apartment unit and a trouble spot is highlighted for this particular study.

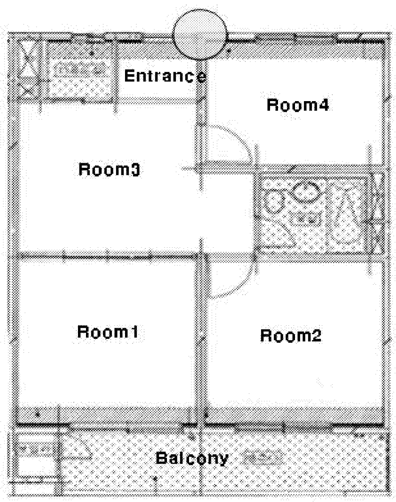

Figure 3. Plan of the selected apartment unit and trouble spot

3.1 Result of zone temperature and relative humidity simulation

First, zone air temperature and relative humidity in each room are calculated using EnergyPlus/COMIS. Figure 4 shows zone air temperature and relative humidity in room3. Figure 4 also shows outdoor temperature and relative humidity in Seoul.

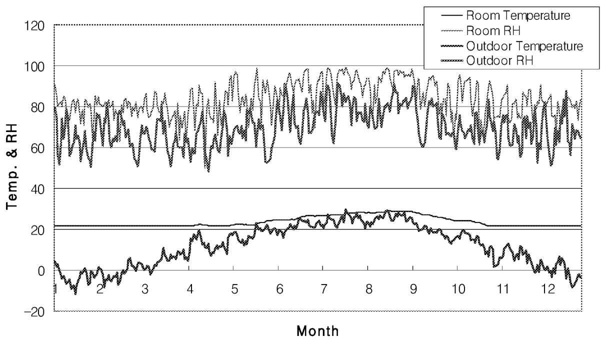

Figure 4. Zone air temperature and relative humidity in Room3 with outdoor conditions

Relatively high mold growth risks are observed in room3 and room4 based on zone air temperature and relative humidity. Thus, more detailed analysis with respect to moisture transportation is required for the wall between the two rooms.

3.2 Result of heat and moisture simulation

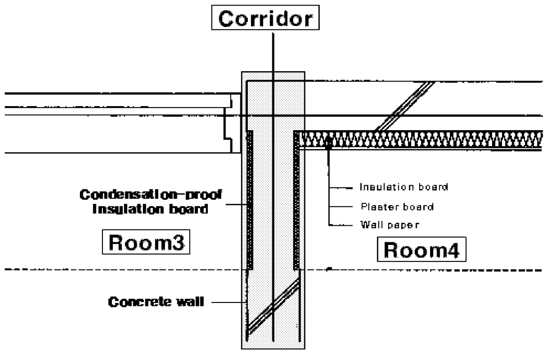

Figure 5. Detail drawing showing the corner wall near an entrance door and simulation region

Table 1. Hygrothermal properties used in WUFI-2D and KOBRA simulation

	Concrete	Condensation-proof insulation board	Insulation board
Thickness(mm)	96	12	50
Bulk density (kg/m³)	2200	115	115
Porosity (m³/m³)	0.18	0.95	·
Heat capacity (J/kgK)	850	1340	1300
Heat conductivity dry (W/mK)	1.6	0.043	0.1
Diffusion resistance factor dry (-)	92	3.4	·

As a next step, surface temperature and relative humidity of the corner wall near an entrance door are analyzed with indoor air temperature and relative humidity from EnergyPlus/COMIS as boundary conditions. WUFI-2D is used for this hygrothermal simulation in the concrete wall between room 3 and room4. Figure 5 shows the detail drawing of the corner wall near an entrance door and simulation region. Table 1 presents the hygrothermal properties used in this simulation. Condensation-proof insulation boards are intentionally installed both sides of the wall according to the design guideline in this particular construction company. Surface temperature and relative humidity are calculated using WUFI at the surface of the concrete wall and condensation-proof insulation board adjacent to the entrance door.

From the WUFI simulation, it is found that surface temperature on the condensation-proof insulation board is similar to the indoor heating set temperature in winter. However, surface temperature on the concrete wall adjacent to the entrance door shows lower temperature than the set temperature in winter time. Figure 6 shows surface temperature and relative humidity on condensation-proof insulation board.

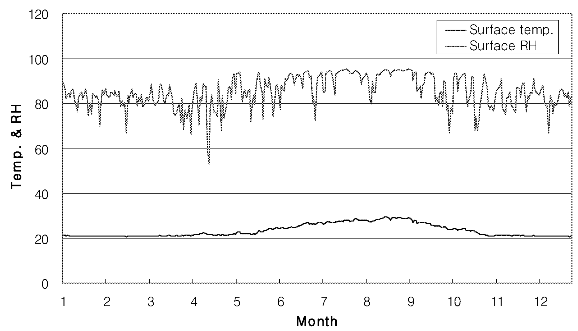

Figure 6. Surface temperature and relative humidity on the condensation-proof insulation board

Table 2 and table 3 show that mold risky days on the concrete wall and condensation-proof insulation board adjacent to entrance door, respectively. We analyzed mold growth risks based on the result of the surface temperature and relative humidity using the germination graph.

Mold risky days on the concrete wall adjacent to the entrance door showed 358 risky days. Mold risky days on the condensation-proof insulation board showed relatively lower risk (199 days) due to higher surface temperature using germination graph. Although the calculated mold risky days do not represent an absolute risk, we can compare these relative results. From the above results, it can be said that mold risk is reduced by installing the condensation-proof insulation board on the wall. However, this result did not consider thermal bridge effects that may occur in the case. For more accurate analysis, thermal bridge effect should be included in the simulation.

Table 2. The result of mold growth risk analysis on the concrete wall adjacent to entrance door (days)

WUFI Result	Total	Winter	Summer
Risk Days (Germination Graph)	358	180	178

Table 3. The result of mold growth risk analysis on the condensation-proof insulation board around entrance door(days)

WUFI Result	Total	Winter	Summer
Risk Days (Germination Graph)	199	63	136

3.3 Result of heat and moisture simulation with thermal bridge effect

Surface temperature and relative humidity may be changed due to thermal bridge effect around the entrance door and frame. To account thermal bridge effect KOBRA simulation is conducted at the trouble spot. Figure 7 shows KOBRA model for the selected trouble spot.

Point A indicates the intersection between the door frame and condensation-proof insulation board. Point B indicates the location of 10cm distance from the door frame, and Point C indicates the center point of the condensation-proof insulation board.

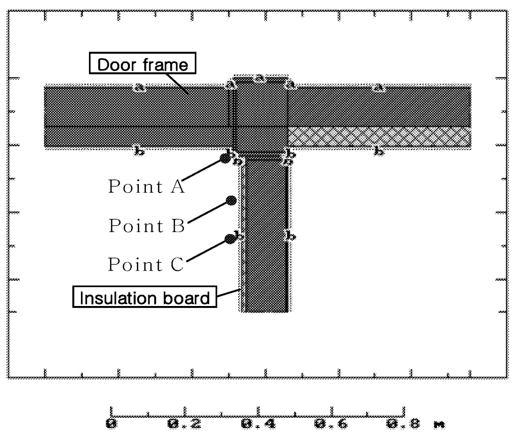

Figure 7. KOBRA model for the selected trouble spot

In each point, surface temperature and relative humidity are recalculated based on the temperature factor obtained by KOBRA analysis. Figure 8 shows Recalculated surface temperature and relative humidity in the thermal bridge location at point A.

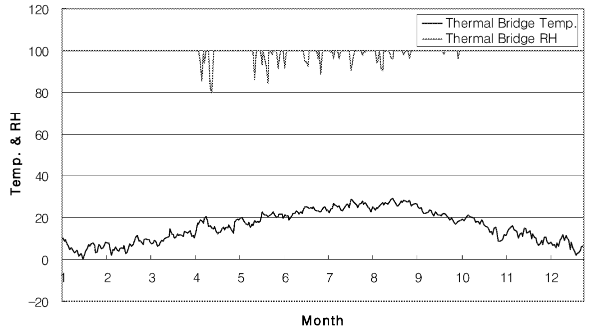

Figure 8. Recalculated surface temperature and relative humidity in the thermal bridge location (Point A, f=0.35)

KOBRA simulations are conducted with outdoor temperature of 0°C and indoor temperature of 20°C. According to the simulation result, the surface temperature of Point A is calculated 7.1°C, and temperature factor is 0.35. Mold growth risk with the result of KOBRA simulation shows 211 days, and the risk in summer were higher than the one in winter. Table 4 shows mold growth risk on point A with KOBRA simulation results.

Table 4. Result of mold growth risk analysis on point A with the consideration of thermal bridge effect(days)

KOBRA Result	Total	Winter	Summer
Risk Days (Germination Graph)	211	36	175

Table 5 shows the analysis result of mold growth risks according to the relative distance from the door frame. As shown in the table, mold growth risks vary with the distance. Mold growth risk is highest at point B (317 days). In the case of point A, mold germination would be retarded, due to the low surface temperature. Although surface temperature at point C is higher than other points, relatively low surface humidity is out of the favorable condition for mold germination, which leads to lower mold risk.

On the other hand, the condensation risk is highest at point A (321 days) and is getting lower as the distance from the door frame increases.

Table 5. Mold growth risks and condensation risks at each point

	Surface Temp.(°C)	Temp factor	Mold Risk days	Condensation days
Point A	7.1	0.35	211	321
Point B	17.1	0.85	317	53
Point C	19.6	0.98	198	0

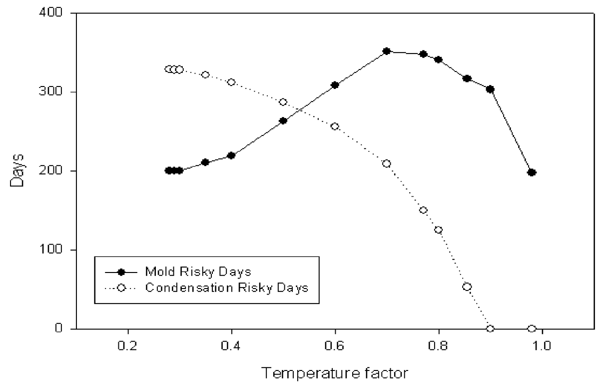

Figure 9. Mold growth risks and condensation occurrence days with the temperature factor

Figure 9 shows mold growth risk and condensation occurrence days with various temperature factors. Condensation occurrence day is getting lower as the temperature factor increases. Condensation does not occur when the temperature factor is 0.9 or higher.

Thus, the surface condensation can be prevented when temperature factor rises after installation of a condensation-proof insulation board on the wall (table 5 and figure 9). However, mold growth risk shows the highest figure when the temperature factor is around 0.7. If the temperature factor is too high or too low, mold growth risks are reduced. Thus, this result indicates that mold risks can be increased, even with lower condensation risk. Also, 0.9 or higher temperature factor is required to avoid condensation and reduce mold growth risks.

4. CONCLUSION

In this study, we analyzed mold growth risk on the corner wall near an entrance door, which is one of the trouble spots in apartment buildings. The findings from this study are as follows.

First, mold growth risks vary with the relative distance from the door frame. Mold growth risk is highest at the temperature factor of 0.7. However, Condensation risk is getting lower when the temperature factor goes up.

Second, 0.9 or higher temperature factor is required at the corner wall to reduce mold growth risk and condensation occurrence day together.

An important next step in the research is to improve and modify the detailed design for the trouble spot. Future research also includes mold growth risks in the other trouble spots with different physical characteristics of apartment buildings, e.g., location, stories, ventilation rates, and number of occupants.

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