Modeling to predict positive pressurization required to control mold growth from infiltration in a building in College Station, Texas

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ABSTRACT

Commercial buildings are generally designed to operate at a positive pressure to limit the danger of mold growth, material deterioration and other condensation related problems from infiltration in hot and humid climates. Pressurization to limit the entry of untreated outside air also limits discomfort due to humidity from this untreated air. This paper focuses on infiltration modeling to predict the influence of pressurization level on the risk of mold growth. In this model, walls are treated differently depending on their height and the direction they face. Local weather data is utilized to generate the outside pressure field. The simulated results indicate that for an unpressurized building with 3 meter high walls in College Station, TX, only walls on the southwest side risk mold growth due to infiltration if the indoor temperature set-point is at 24°C. When the set-point temperature is lowered to 22°C, walls facing all directions risk mold growth. The model also indicates that 1 Pa positive pressurization should theoretically eliminate the risk of mold growth on all walls for the leakage characteristics considered assuming a 24°C indoor temperature set-point.

INTRODUCTION

One of the major benefits of building pressurization is to limit the danger of mold growth in building envelopes. Since excessive pressurization during the cooling season usually means extra energy consumption, a method to quantify the required minimum pressure level is desirable. To achieve this goal, the location that theoretically has the most severe mold growth potential should be identified first.

Research (Viitanen 1997, Nielsen, Holm et al. 2004, Johansson, Ekstrand-Tobin et al. 2012) indicates that relative humidity (RH) and temperature are two key factors involved in mold growth. Critical RH and temperature conditions are required to create favorable conditions for mold growth. According to psychometric principles, the RH of air goes up when temperature of air goes down if the moisture content of the air is constant. This occurs with infiltrating air when the outside air temperature is higher than indoor air temperature. Likewise, it happens to exfiltrating air when the temperature relationship is reversed. Hence, in hot and humid climates, mold growth and condensation will most likely occur on a building envelope layer that is in contact with the inner space or close to the inner wall surface (where moist infiltrated air reaches its highest RH).

Hukka and Viitanen (1999) proposed a mathematical model to predict mold growth on wooden material, using critical RH as the key factor. Conditions with RH exceeding critical RH are considered favorable for mold growth, otherwise they are unfavorable for mold growth. Critical RH varies with different materials and temperature range. For a gypsum board at 22°C, critical RH is estimated between 89% to 95%. (Johansson, Ekstrand-Tobin et al. 2012) In this paper, 89% is selected to represent the worst case scenario.

Under this model, mold growth intensity is categorized into seven levels called the "mold index M" where, M=0 – 6. A detailed definition of each mold index level is listed in Table 1. Under conditions favorable for mold growth, the following equation applies:

$$\frac{dM}{dt} = \frac{1}{7 * \exp(-0.68 \ln \mathrm{T} - 13.9 \ln \mathrm{RH} + 0.14\mathrm{W} - 0.33\mathrm{SQ} + 66.02)} * \mathrm{k}_1\mathrm{k}_2$$

(Per day)

Where:

T is temperature (°C)

RH is relative humidity

k_1 is intensity of growth

k_2 is calculated based on $\mathrm{M}_{\mathrm{max}}$

W is a wood species factor

SQ is a surface quality factor

For unfavorable mold growth conditions, the following equation is applied:

$$\frac{dM}{dt} = \begin{cases} -0.00133, \text{when } \mathrm{t} - \mathrm{t}_1 \le 6\mathrm{h} \\ 0, \quad \text{when } 6\mathrm{h} < \mathrm{t} - \mathrm{t}_1 \le 24\mathrm{h} \\ -0.000667, \text{when } \mathrm{t} - \mathrm{t}_1 > 24h \end{cases}$$

(Per hour)

Where:

t is the time (h) from the moment t_1 when the conditions changed from favorable to unfavorable conditions.

This model is then expanded to cover other building materials (Viitanen, Viitanen et al. 2010) (Viitanen, Ojanen et al. 2011). The declining model for unfavorable condition is multiplied by a relative coefficient $\mathrm{C}_{\mathrm{mat}}$ for materials different from the pine wood tested originally. This model is utilized to predict mold growth, and the results will be presented in terms of the mold index.

Typically indoor RH is controlled within a range that is unfavorable for mold growth, which means that for building envelope, exfiltration is risk free of mold growth. To find out when exfiltration will occur, both outside and indoor pressure field must be generated first.

Outside pressure field is mainly affected by two factors: stack effect and wind effect, by assigning outside ground level as reference point, stack effect is calculated by the following equation:

$$\mathrm{P}(h) = 0 - \rho g h$$

Where:

$P(h)$ is outside pressure (Pa.) at height h (meters)

ρ is the density of air (kg/m^3)

g is gravity constant $(9.81\mathrm{m}/s^2)$

Wind effect is calculated by the following equation: (Sherman 1980)

$$\Delta P_{\mathrm{j}}^{\mathrm{w}} = \mathrm{C_j} * \frac{1}{2}\rho V^2$$

Where:

$\Delta P_{\mathrm{j}}^{\mathrm{w}}$ is the exterior pressure rise due to the wind for the jth face

ρ is the density of air (kg/m^3)

V is the actual wind speed (m/s)

$\mathrm{C_j}$ is the shielding coefficient for the jth face.

For V, Following equation is applied:

$$\mathrm{V} = \mathrm{V_o}\alpha\left[\frac{\mathrm{H}}{10}\right]^{\gamma}$$

Where:

V is the actual wind speed

$\mathrm{V_o}$ is the wind speed measured at the nearest 10 meter high weather station

α and γ are constants that depend on terrain class.

Assuming Class III terrain (rural areas with low buildings, trees, etc.), $\alpha = 0.85$ and $\gamma = 0.2$ are applied.

For shielding coefficient (or pressure coefficient), the following equation is applied with typical values $\mathrm{C_p}(1) = 0.6, \mathrm{C_p}(2) = -0.3, \mathrm{C_p}(3) = \mathrm{C_p}(4) = -0.65$ (ASHRAE 2009):

$$\begin{aligned} C_p(\phi) = 1/2\{&[C_p(1) + C_p(2)](\cos^2\phi)^{1/4} \\ &+ [C_p(1) - C_p(2)](\cos\phi)^{3/4} \\ &+ [C_p(3) - C_p(4)](\sin^2\phi)^2 \\ &+ [C_p(3) - C_p(4)]\sin\phi\} \end{aligned}$$

where

$C_p(1)$ = pressure coefficient when wind is at 0°

$C_p(2)$ = pressure coefficient when wind is at 180°

$C_p(3)$ = pressure coefficient when wind is at 90°

$C_p(4)$ = pressure coefficient when wind is at 270°

ϕ = wind angle measured clockwise from the normal to wall 1

Indoor pressure field is also affected by stack effect; however, when the building achieves steady state, the infiltration/exfiltration flow should be equal. The flow through a leakage path is calculated by the following equation (Sherman 1980):

$$Q = C(\Delta P)^n$$

Where:

Q is the air flow (m^3/sec)

C is the flow coefficient

n is the pressure exponent

ΔP is the pressure difference (Pa.)

While C and n should be determined by experiment, in this paper, leakage area is assumed evenly distributed on walls, C and n are assumed constant and n is assumed 0.65. Under these assumptions, ΔP can be determined as well as the indoor pressure field. After both outside and indoor pressure fields are available, the infiltration or exfiltration condition at a specific wall/roof section can be determined.

When a section is determined to be under infiltration condition, RH of infiltration air is then calculated as its temperature reaches indoor temperature; for example, assuming indoor temperature is 24°C, saturation vapor pressure at 24°C is then calculated by the following equation (Wagner and Pruß 2002):

When T>0°C

$$\ln\left(\frac{p_\sigma}{p_c}\right)=\frac{T_c}{T}(a_1\vartheta+a_2\vartheta^{1.5}+a_3\vartheta^3+a_4\vartheta^{3.5}+a_5\vartheta^4+a_6\vartheta^{7.5}),$$

with $\vartheta=(1-T/T_c)$, $T_c=647.096\,\mathrm{K}$, $p_c=22.064\,\mathrm{MPa}$, $a_1=-7.859\,517\,83$, $a_2=1.844\,082\,59$, $a_3=-11.786\,649\,7$, $a_4=22.680\,741\,1$, $a_5=-15.961\,871\,9$, and $a_6=1.801\,225\,02$.

When T<0°C

$$\ln\left(\frac{p_{\mathrm{subl}}}{p_n}\right)=-13.928\,169(1-\theta^{-1.5})+34.707\,823\,8(1-\theta^{-1.25}), \qquad (2.21)$$

with $\theta=T/T_n$, $T_n=273.16\,\mathrm{K}$, and $p_n=0.000\,611\,657\,\mathrm{MPa}$.

Infiltration vapor pressure is then calculated by the following equation:

$$P_w=P_s*RH$$

Where:

P_w is vapor pressure

P_s is saturation vapor pressure

RH of infiltration air at 24°C is then calculated by the following equation:

$$RH_{24°C}=P_w/P_{s@24°C}$$

Either declining or increasing mold growth is then applied to calculate mold level change.

MODEL DESCRIPTION

The building is assumed to be a square structure 3 meters high, facing South-East. The material of the target layer is assumed to be gypsum board, which has critical RH of 89% (Johansson, Ekstrand-Tobin et al. 2012). The third Typical Meteorological Year data set (TMY3) from Easterwood Airport (College Station, TX) is utilized to calculate the outside pressure field. Figure 1 represents the flow chart for how the mold index level change is calculated.

The building envelope is divided into 9 sections, Top South West, Top South East, Top North West, Top North East, Bottom South West, Bottom South East, Bottom North West, Bottom North East, and Roof; all sections are assumed to have the same specific leakage area, but the floor is assumed airtight.

The hourly mold index level changes throughout the year are summed up to show the predicted mold index level change for a year, as well as infiltration time percentage (hours of infiltration within a year divided by 8760). Conditions for both 22°C and 24°C are simulated.

The building operation schedule is assumed to be operating 24/7 for both settings.

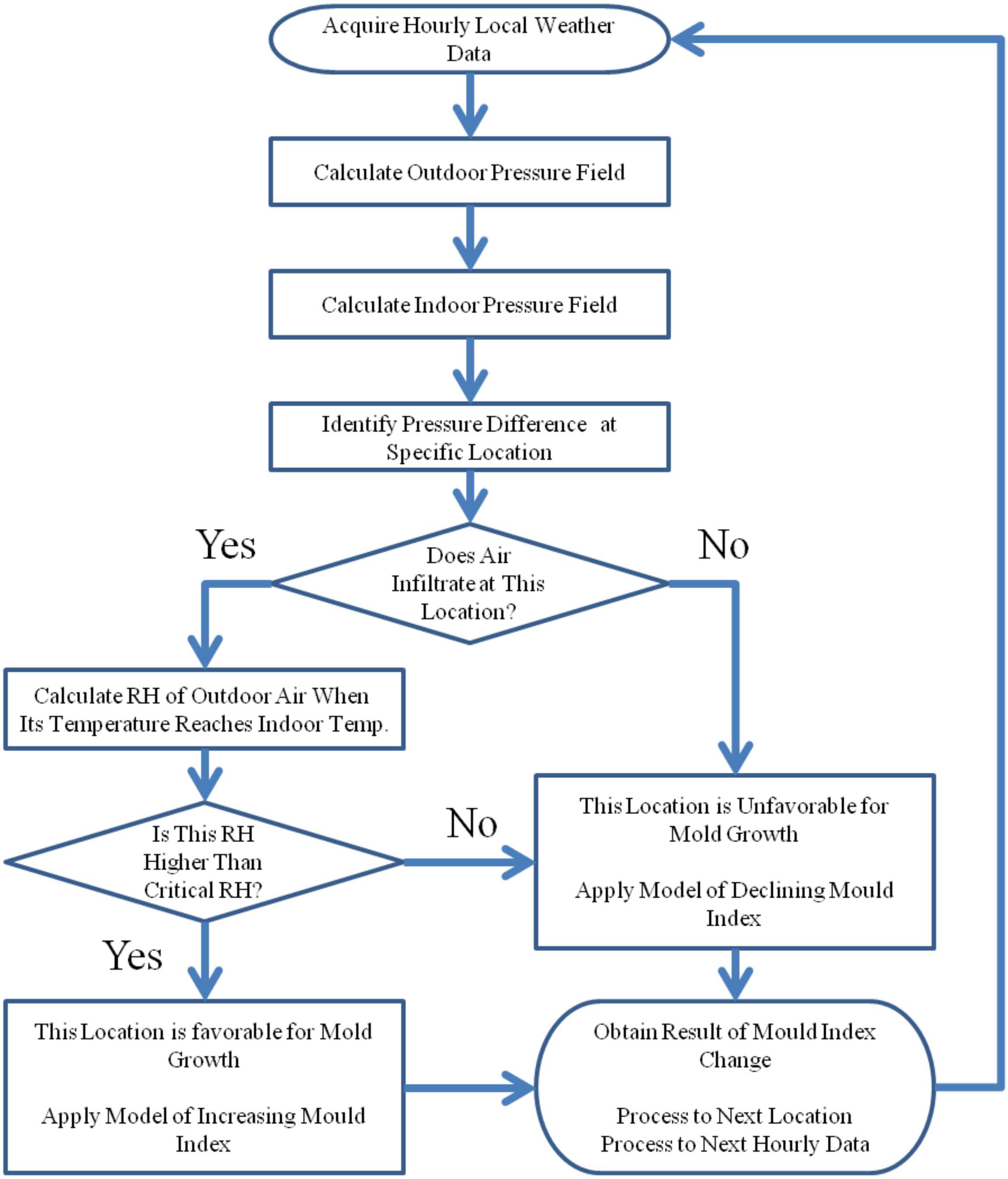

Figure 1. Flow chart of the model

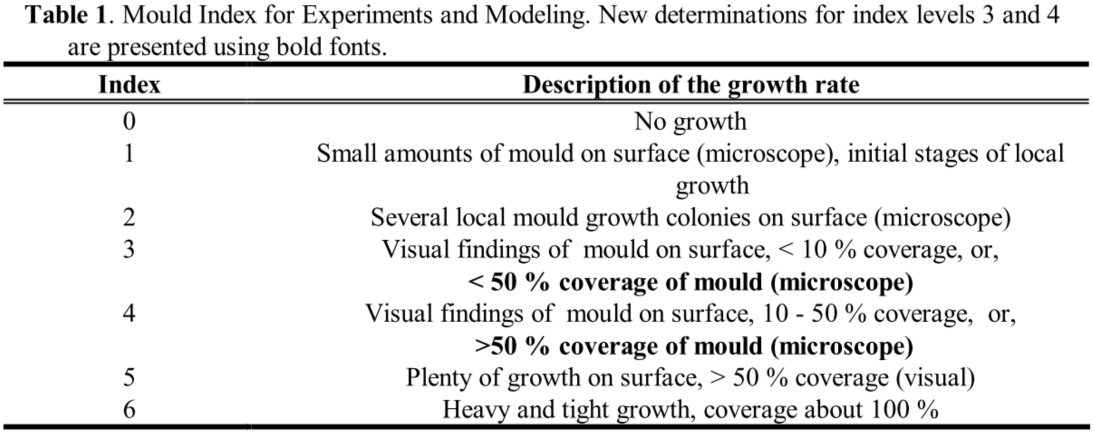

Table 1. Mould Index for Experiments and Modeling. New determinations for index levels 3 and 4 are presented using bold fonts.

Index	Description of the growth rate
0	No growth
1	Small amounts of mould on surface (microscope), initial stages of local growth
2	Several local mould growth colonies on surface (microscope)
3	Visual findings of mould on surface, < 10 % coverage, or, **< 50 % coverage of mould (microscope)**
4	Visual findings of mould on surface, 10 - 50 % coverage, or, **>50 % coverage of mould (microscope)**
5	Plenty of growth on surface, > 50 % coverage (visual)
6	Heavy and tight growth, coverage about 100 %

Table 1. Mold Index (Viitanen, Ojanen et al. 2011)

RESULTS

Three types of results will be presented. Infiltration time percentage is the percentage of time a specific section of wall is under infiltration condition. Each section will have three results that represent unpressurized, 1 Pa positive pressure, and 2 Pa positive pressure conditions, respectively.

Mold index level change is the net change of mold index for whole year at specific sections. There are also results under different pressurization levels.

Risky infiltration time is the percentage of time during each month that infiltration is favorable for mold growth. The result is available for both 22°C and 24°C indoor temperatures.

For indoor temperature at 24°C, the results of infiltration time percentage, mold level change per year, and risky infiltration time percentage are shown as Figure 2, Figure 3 and Figure 4. For indoor temperature at 22°C, the results are shown as Figure 5, Figure 6 and Figure 7.

As expected, higher indoor temperatures induce more infiltration through the bottom portions of walls. The maximum infiltration time percentage occurs on the bottom SW wall, which is 69.0% at 24°C indoor temperature and 63.3% at 22°C, 2 Pa positive pressurization can reduce the values to 21.9% and 20.6%, respectively.

Under unpressurized conditions, only the SW side wall risks mold growth for 24°C indoor temp., but all side walls risk mold growth when it is 22°C. 1 Pa pressurization is enough to make the whole year mold index change on all walls negative for 24°C, but for 22°C, 2 Pa pressurization is required to achieve this protection.

It may also be noted that infiltration is risk free from November to April for 24°C indoor temperature, but this period is shortened to December to March for 22°C set-point. June has the highest risky infiltration times, which are 77.9% and 94.3%, respectively.

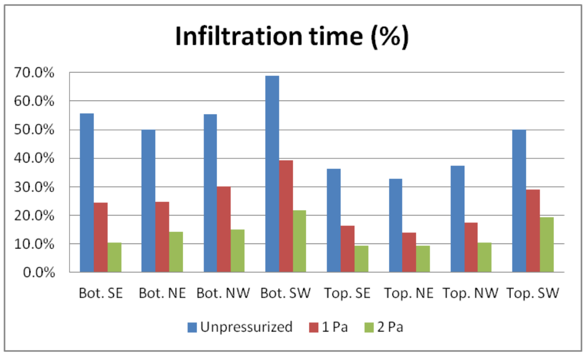

Figure 2. Infiltration time (%) (Indoor=24°C)

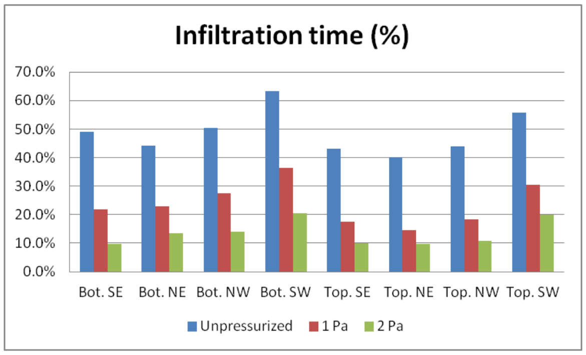

Figure 5. Infiltration time (%) (Indoor=22°C)

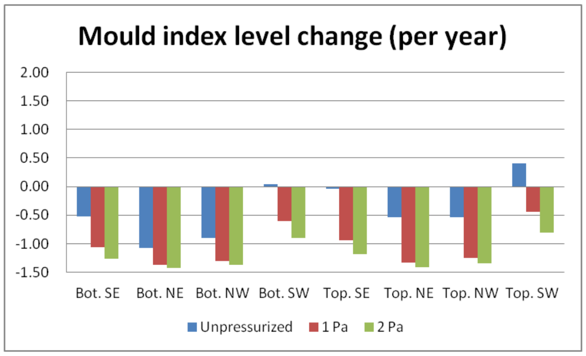

Figure 3. Mold index level change (Indoor=24°C)

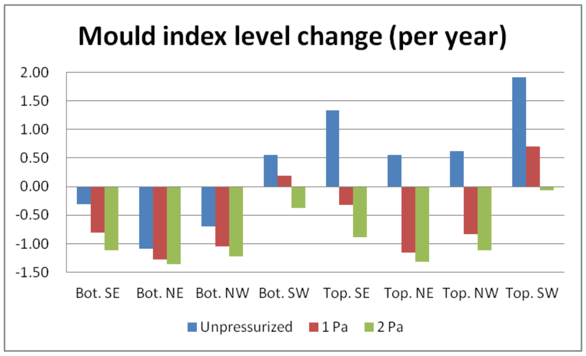

Figure 6. Mold index level change(Indoor=22°C)

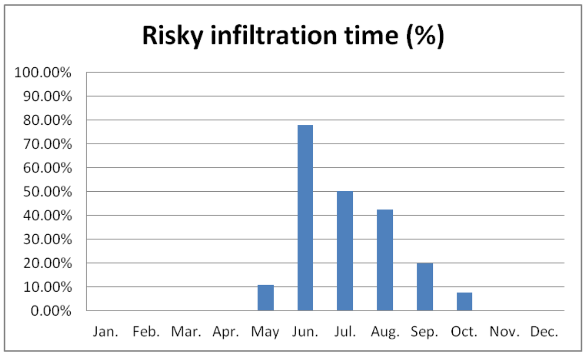

Figure 4. Risky infiltration time (Indoor=24°C)

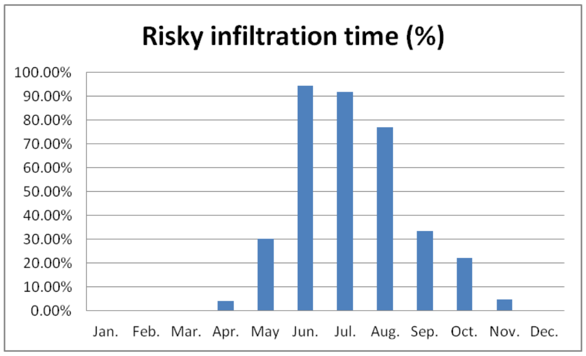

Figure 7. Risky infiltration time (Indoor=22°C)

CONCLUSIONS

Positive pressurization and higher indoor temperature set-points both were found capable of eliminating mold growth in for the configurations modeled. Pressurization is not necessary during colder months to control mold growth, but is quite necessary from June to August. A higher indoor temperature set-point requires lower positive pressurization to become theoretically risk free of mold growth, but for the assumptions modeled, 2 Pa is sufficient for a building that has a set-point as low as 22°C if the target material is assumed to be gypsum board.

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