Building Science Graduate Program

Condensation risk assessment of window-wall facades under the effect of different heating systems using THERM (FEM) and CFD simulations

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Research Problem

- Various heating system provides vastly different indoor conditions due to differences in thermal stratification, room air distribution and location of heat sources. These differences have direct impacts on window performance and can potentially increase risk of condensation.

Objective

- To investigate the ways different heating systems interact with window-wall unit through convection and other heat exchanges, and their effects on surface condensation.

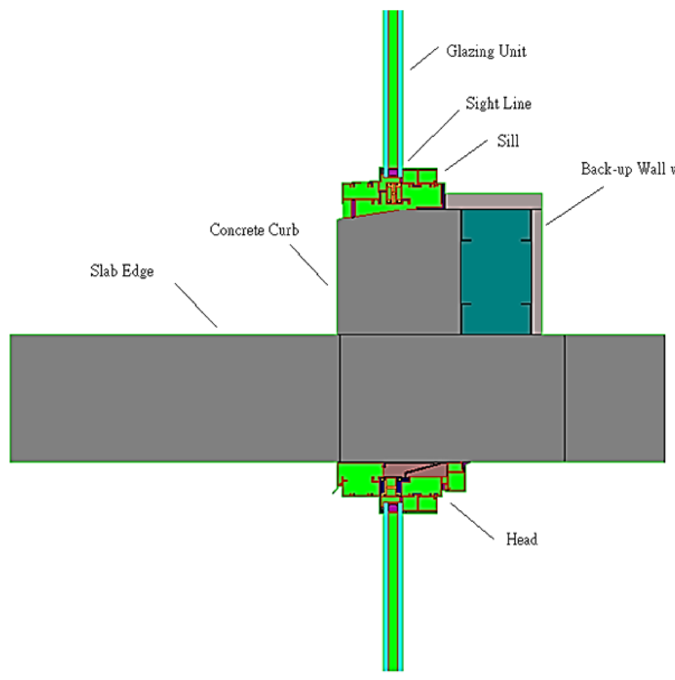
Project Scope

Three most common heating systems for multi-unit residential building (MURB) were investigated and compared:

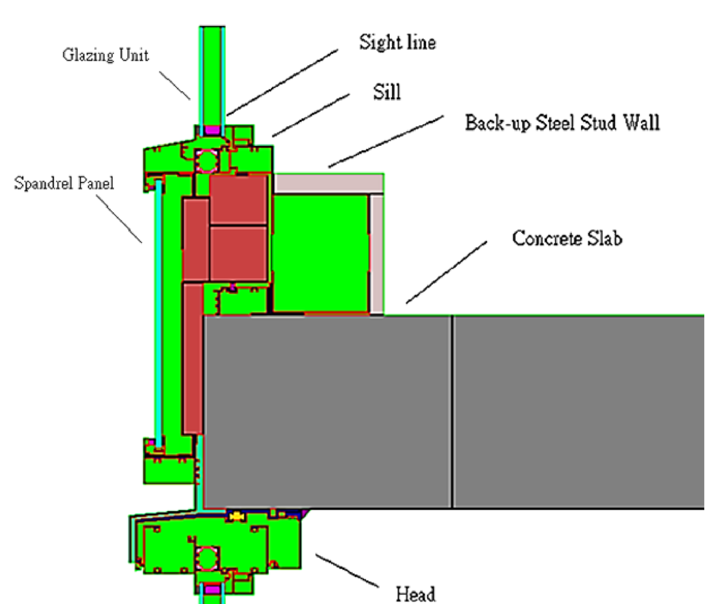
- Electric baseboard
- Hydronic radiant floor
- Forced air system.

Two typical window wall details were selected as study specimen:

- Window wall with extended slab edge ("i.e. eyebrow")
- Window wall with bypass spandrel glass panel



Bypass Window-wall detail



Extended Slab Edge detail

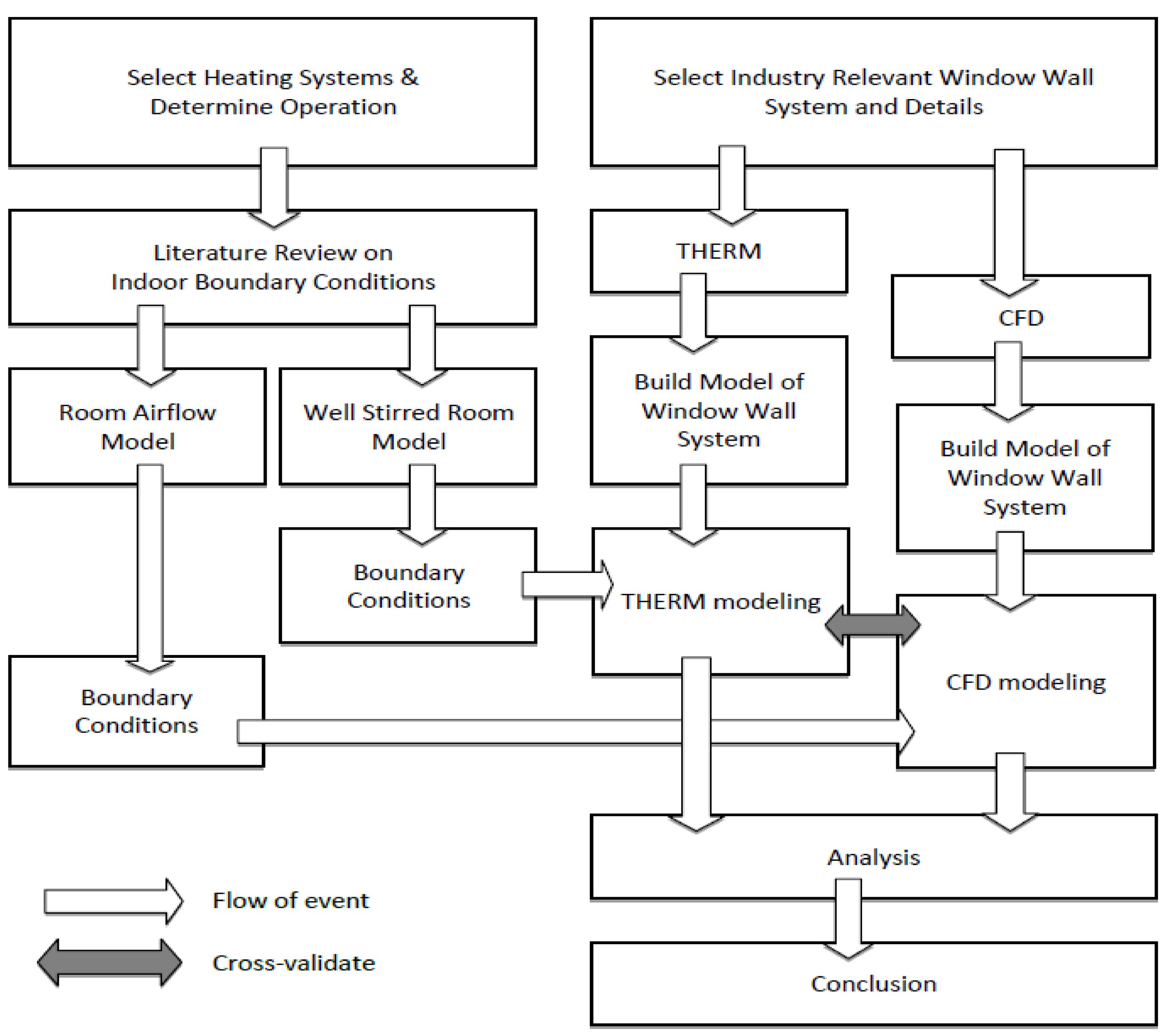
Research Methodology

While conduction and radiation can be modeled accurately in heat transfer simulation, it is not the case for convection due to its high sensitivity to buoyant and mechanically induced air movements.

Three different methods to model convection coefficient were employed:

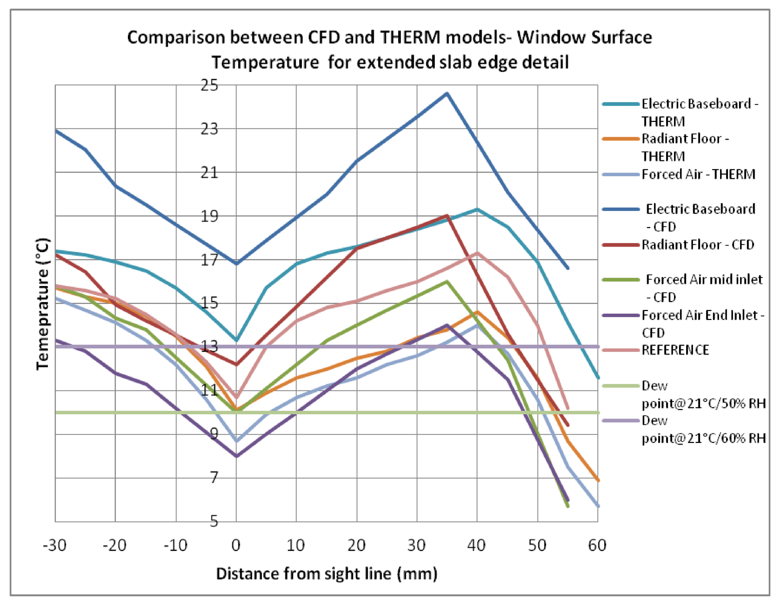
- Constant coefficient that is based on standard such as ASHRAE Handbook (2009)
- Correlation-based coefficient under various scenarios that are developed by past research
- Computational fluid dynamic simulation

A total of sixteen two-dimensional models were built to incorporate the selected heating systems and window-wall details using THERM (FEM) and Autodesk CFD simulation.

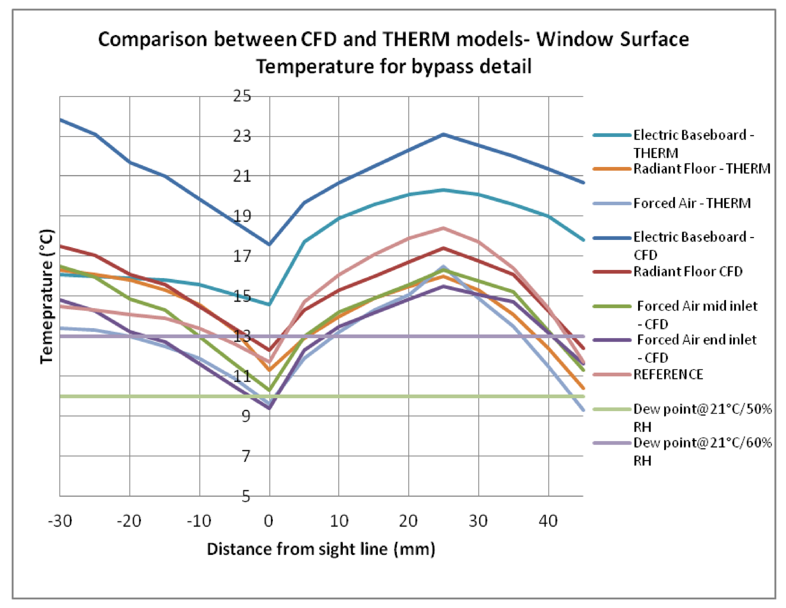


Methodology Flow Chat

Result



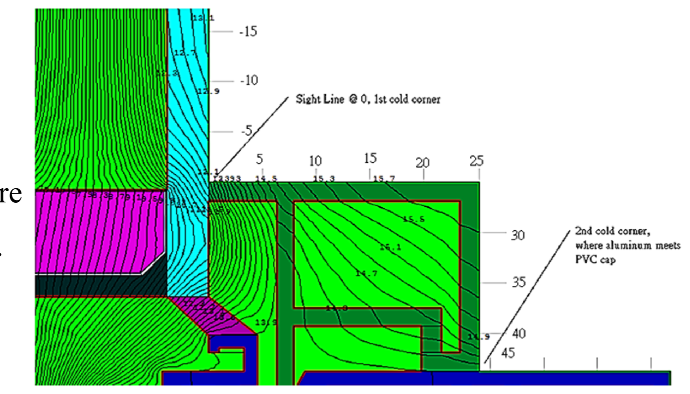
Extended slab edge detail



Bypass detail

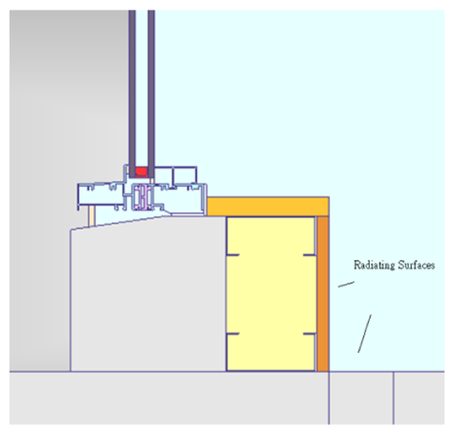
Data Collection

- Surface temperatures of the interior window wall unit were collected to assess condensation resistance.
- The origin point (at 0) of above graph was set at the location where the window glass and the frame met at the sill section (sight line).

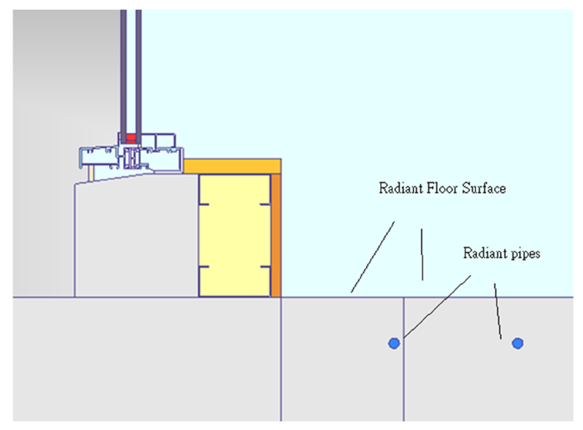


Configuration and assumption of each heating system

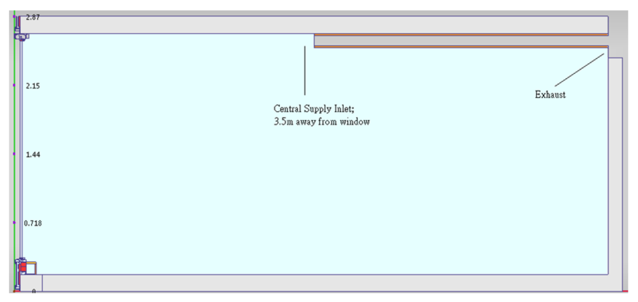
Assumptions were made to temperature of the adjacent surface for electric baseboard system, radiant floor surface and radiant pipes for radiant system, and inlet temperature for forced air system. Sensitivity analyses were carried out to assess the effect of input parameters.



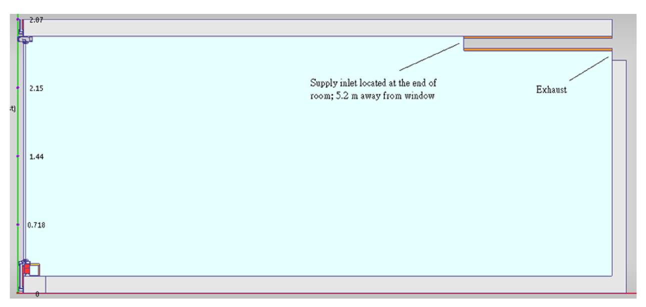
Electric Baseboard system



Radiant Floor system



Mid inlet Forced Air system



End inlet Forced Air system

Boundary Conditions

Detail	Heating system	Source	Hc	Reference temperature
Extended Slab Edge	Reference	ISO 15099	6.8 (Fixed)	Average room air temperature
Extended Slab Edge	Electric baseboard	Khalifa and Marshall	Hc = 8.07*ΔT ^0.11	Average room air temperature
Extended Slab Edge	Radiant Floor	Khalifa and Marshall	Hc = 7.61*ΔT ^0.06	Average room air temperature
Extended Slab Edge	Forced Air	Goldstein and Novoselac	Hc = 0.103(V/L)0.8	Supply air temperature
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- V/L equals volumetric flow rate per unit of length of an external wall with ceiling slot diffusers, where units are given in m^3/h*m
- Outdoor boundary condition is set at 0 degree Celsius for both THERM and CFD models

Difference between THERM (FEM) and CFD model

THERM (FEM)

- 2-D heat transfer finite element model using well-stirred (or well-mixed) room air assumption: convective heat transfer coefficients are used to model heat transfer between surfaces and the room air.

Computational Fluid Dynamic (CFD) Analysis

- Fluid (Air Flow) and heat transfer finite control model using room air flow model assumption: capable of predicting local heat flow patterns, thermal stratification and air distribution.

Applied Research Project completed by Derek Yan

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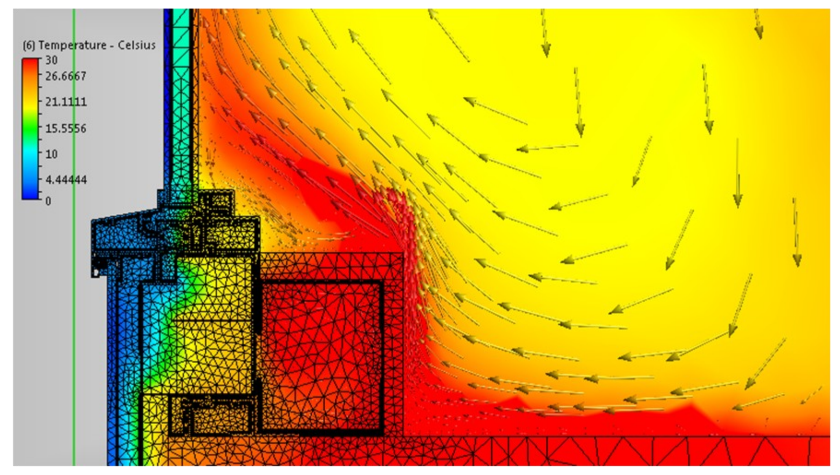
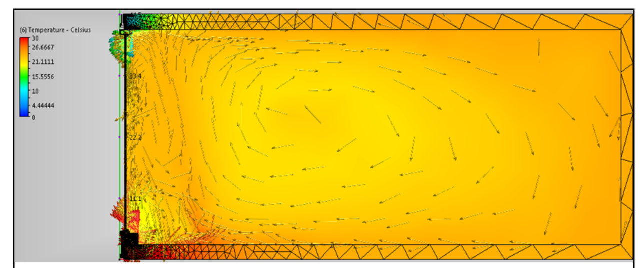
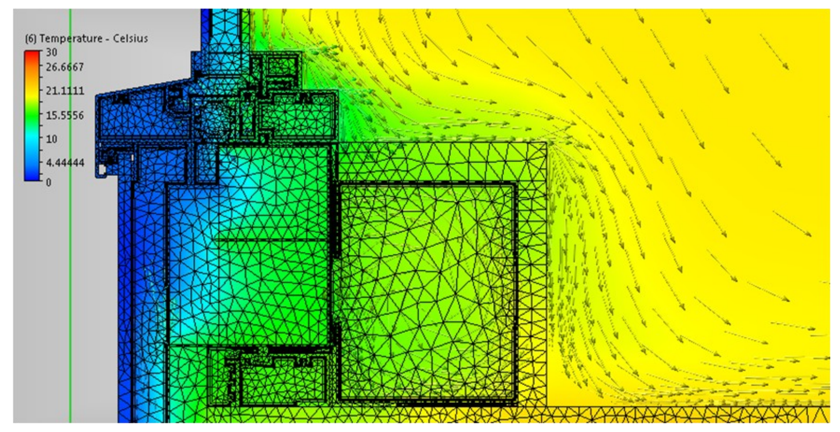
CFD graphical presentation result

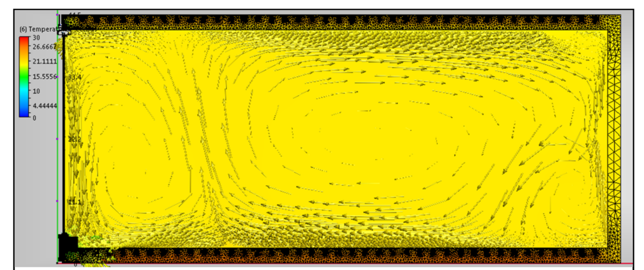




- An upward convective heat flow due to the heat sources on the radiating surfaces
- Downward recirculation flow was able to warm up the cold corners and their surrounding surfaces; not at risk of condensation

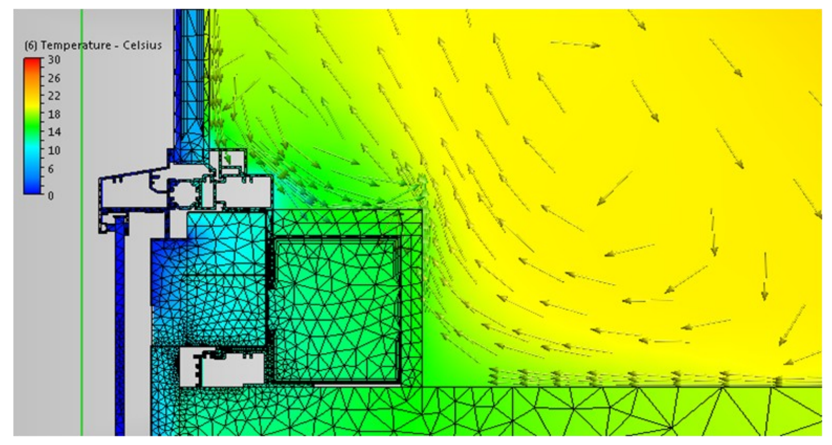
CFD Electric Baseboard system model

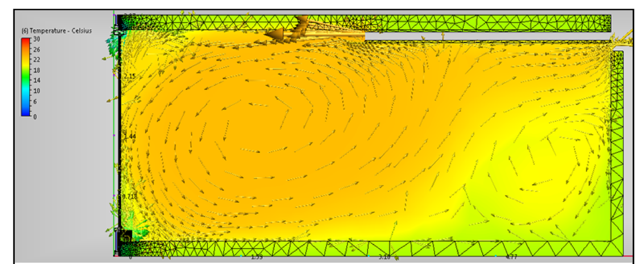




- A draft was carried by downward momentum, traveling along the window to the cold corners.
- Cold corners were not significantly warmed up
- At some risk of condensation at these corners.

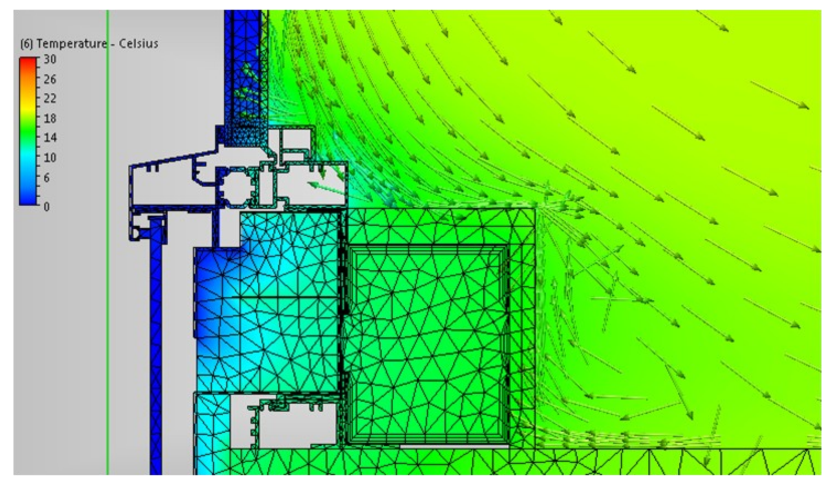
CFD Radiant Floor system model

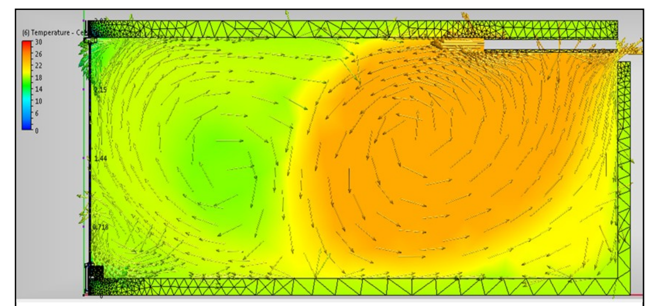




- A draft carried by upward momentum, traveling along the frame and towards the window surface
- A recirculation zone took place at the cold corners of the frames
- Cold corners were not warmed up by the forced air sufficiently and were at risk of condensation.

CFD Forced Air model with mid inlet





- A draft carried by downward momentum, traveling along the window to window-wall cold corners.
- A recirculation zone between the back-up wall and slab
- Cold corners of the glazing units were not warmed up and at high risk of condensation.

CFD Forced Air System model with end inlet

Conclusion

Based on simulation results, the following conclusions were made:

- Validated that electric baseboard system had the least problem with surface condensation.
- Radiant floor system was under condensation risk when indoor relative humidity was above 55%.
- Forced air system was considerably more susceptible to condensation risk due to its typical location of supply inlet and uneven thermal stratification within the room.
- Extended slab edge detail performed worse than bypass detail due to thermal bridging.
- Sensitivity analysis showed that both electric baseboard and forced air models were more susceptible to changes in input parameter than radiant floor model.
- THERM (FEM) models provided consistent trend as CFD models, but they attained as much as 30% margin of difference.
- THERM analysis showed that constant convective coefficient method (REFERENCE model), did not sufficiently characterize realistic indoor boundary conditions for some cases.

Further work

In general, THERM models perform reasonably in condensation risk assessment. Preliminary results from CFD models showed promising accurate result that considered room air flow. More importantly, CFD model has the potential to advance this area of study in both accuracy and realism by incorporating three dimensional model and transient analysis. It is also capable of including other factors such as moisture load, dynamic weather condition, occupants and obstructions within a room model.

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