Improving Thermal Comfort Regulating Potential in Naturally Ventilated Residential House

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Introduction

Background

→Ventilating houses passively by opening windows

- Common in New Zealand
- Mild Climate
- Occupants→ open or shut the windows based on their perception of thermal comfort
- When they feel hot, they try to open the windows and when they feel cold they try to shut the windows
- Outdoor and indoor conditions → transient in nature
- Requires → manually adjusting → to maintain thermal comfort

Challenge: Identify a **robust** technique/system dealing with **complexity, dynamics, and nonlinearity** associated with the natural ventilation **driving forces** and the **building thermal behaviour**.

Figure 1: Manually opening windows

How to intelligently actuate the window to maintain thermal comfort?

Background

Pokhrel et. Al (2016) →Examined thermal comfort characteristics of naturally ventilated house

Pokhrel et. al. (2017) →the problem can be well approached by Artificial Neural Network (ANN) to address the challenges of the associated complexity and nonlinearity.

These works considered a range of operating conditions sans envelope thermal resistance variation

Ryan et al. (2008) and Bassett (2001): Housing stock of NZ consists of not only a huge variation in airtightness (0.3 to 0.9 Air Changes per Hour (ACH)) but also building fabric characteristics.

This work: Examines the thermal comfort of the room with various Window Opening Fraction (WOF), different air-tightness values and particularly different level of envelope thermal resistance.

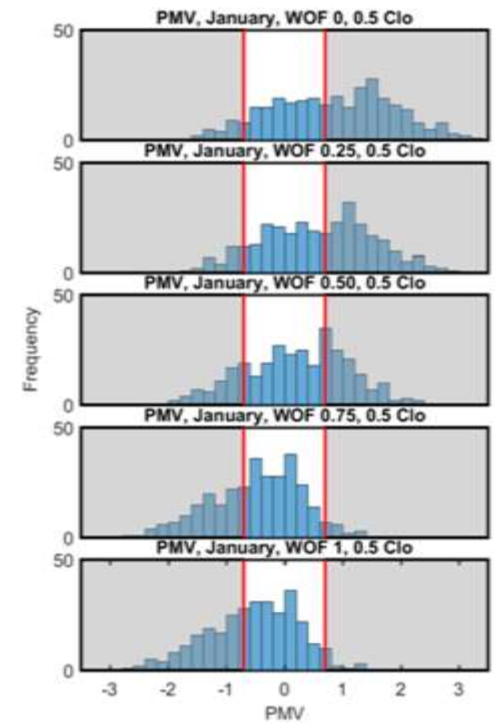


Figure 2: Effect of window opening fraction on thermal comfort condition

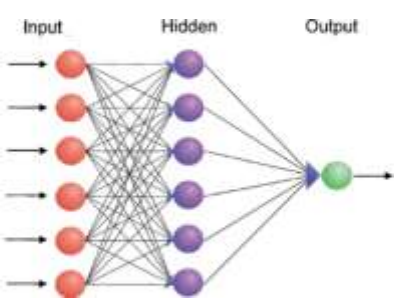


Figure 3: A typical ANN used for solving complexity in natural ventilation

Thermal Comfort

"That condition of mind which expresses satisfaction of thermal environment"

(Fanger, 1970 and EN ISO 7730, 2005)

Fanger's comfort criteria:

$f(M, I_{cl}, v, t_r, t_{db}, p_s)=0$

M : Metabolic Rate (met)
I_{cl} : Cloth Index (clo)
v : Air Velocity (m/s)
t_r : Mean Radiant Temperature (˚C)
t_{db} : Dry bulb Temperature (˚C)
P_s : Water Vapor Pressure (kPa)

Local velocity plays a role in determining thermal comfort in a space.

A complex assessment of these quantities in terms of Predicted Mean Vote (PMV) can be used to indicate thermal comfort status of a residential house.

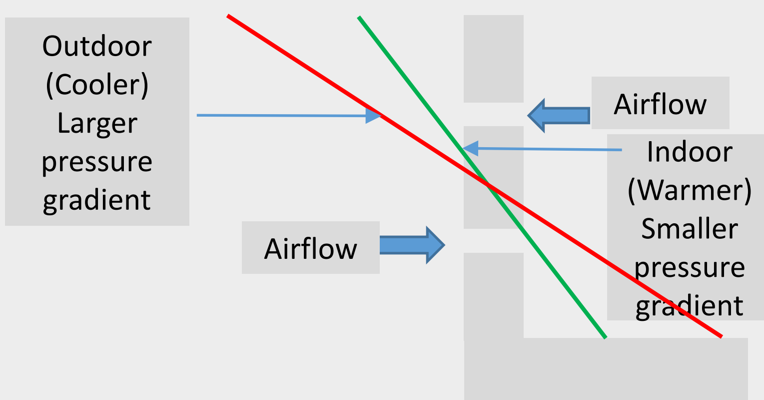
Categories	PMV	PPD
A	± 0.2	< 6
B	± 0.5	< 10
C	**± 0.7**	**< 15**

(EN ISO 7730, 2005)

Natural Ventilation

"Natural process by which clean outdoor air is intentionally provided to a space and stale air is removed" including "uncontrolled exchange through unintentional gaps and cracks in building envelope"

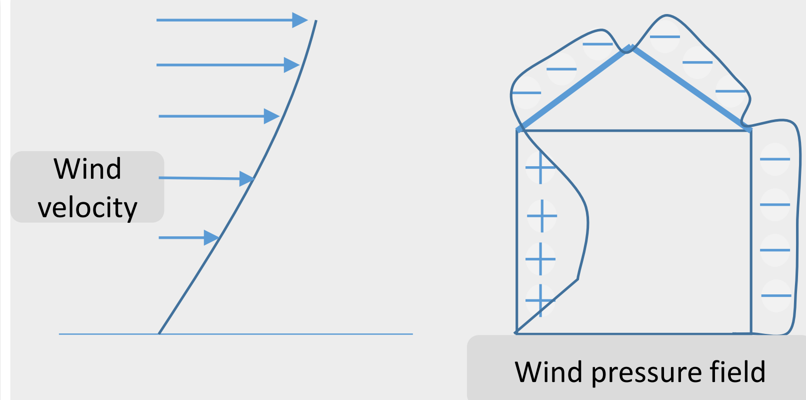
Thermal buoyancy



Warm air is less dense than cool air creating the airflow

Figure 4: Airflow due to thermal buoyancy effect

Wind



Varying surface pressure around the building creating the airflow

Figure 5: Airflow due to wind pressure

The natural ventilation driving forces involve complex non linear phenomena of heat and mass transfer depending on multiple factors

Methodology

Building model and the assessment criteria

Location	Auckland, NZ
External Size	3 m. x 3 m. x 3 m.
Internal Volume	19.75 m^3
Assessment Period	8760 hours

Building Model

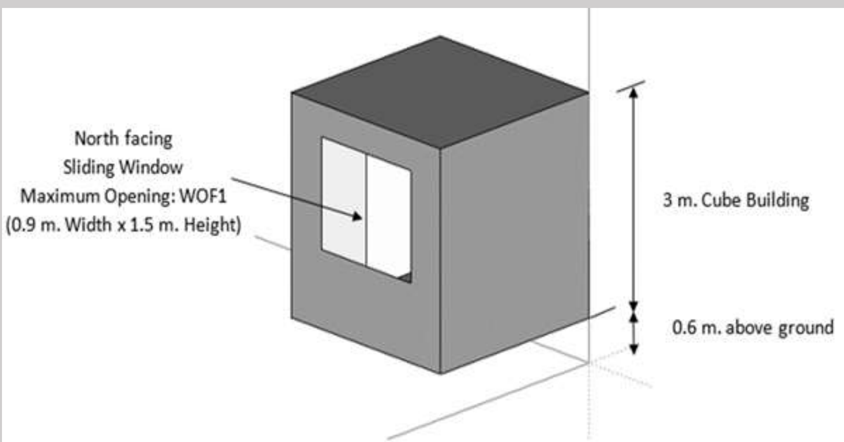


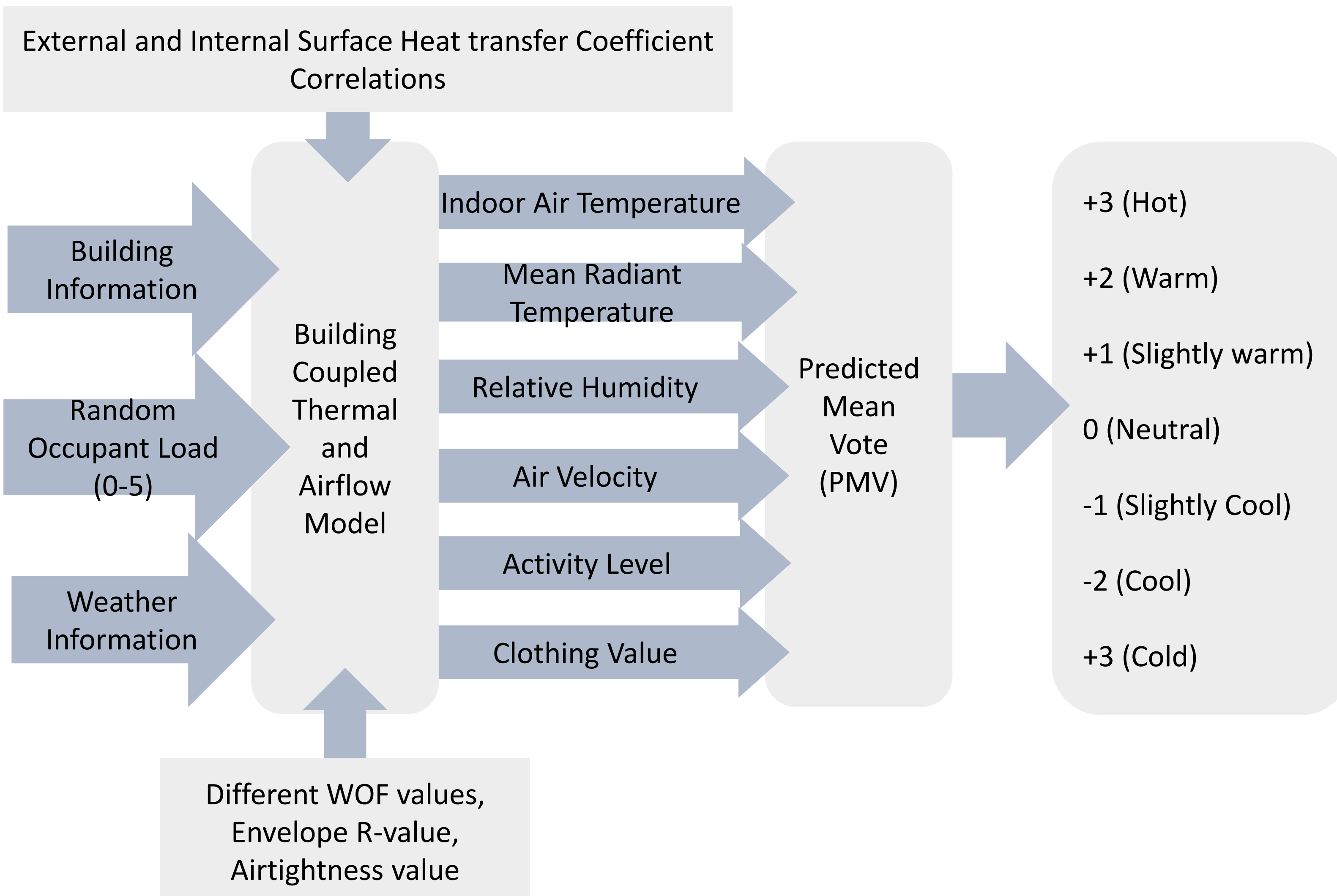
Figure 6: Building Model considered for assessment

Thermal Comfort Status	
Comfort	-0.7<PMV<+0.7
Hot or warm	PMV>+0.7
Cold or Cool	PMV<-0.7

Envelope Airtightness	
Ultra Airtight house	0.03 ach
Airtight	0.3 ach
Average	0.5 ach
Leaky	0.7 ach
Drafty	0.9 ach

Window Opening Fraction (WOF)	
Shut	WOF 0
Open	WOF 1

Overall Modelling strategy



Envelope Thermal Resistance for assessment

Building Facade	Description	R-Values			
		Case 1 R~NZBC	Case 2 R 2.6	Case 3 R 3.2	Case 4 R 3.6
External Wall	Timber frame direct fixed cladding	1.9	2.4	3.1	3.2
Floor	Suspended floor with lining under the joists and gap between insulation and lining	1.3	3.1	3.5	3.8
Roof	Timber frame skillion roof	2.9	3	3.4	3.8
Window	Vertical double glazed sliding window (1.8 m. width x 1.5 m. height) Northern wall	0.34	0.34	0.34	0.34
Area weighted average envelope resistance (R_{avg})		2.01	2.6	3.22	3.44

Simulating the model house in TRNSYS-COMIS coupled platform

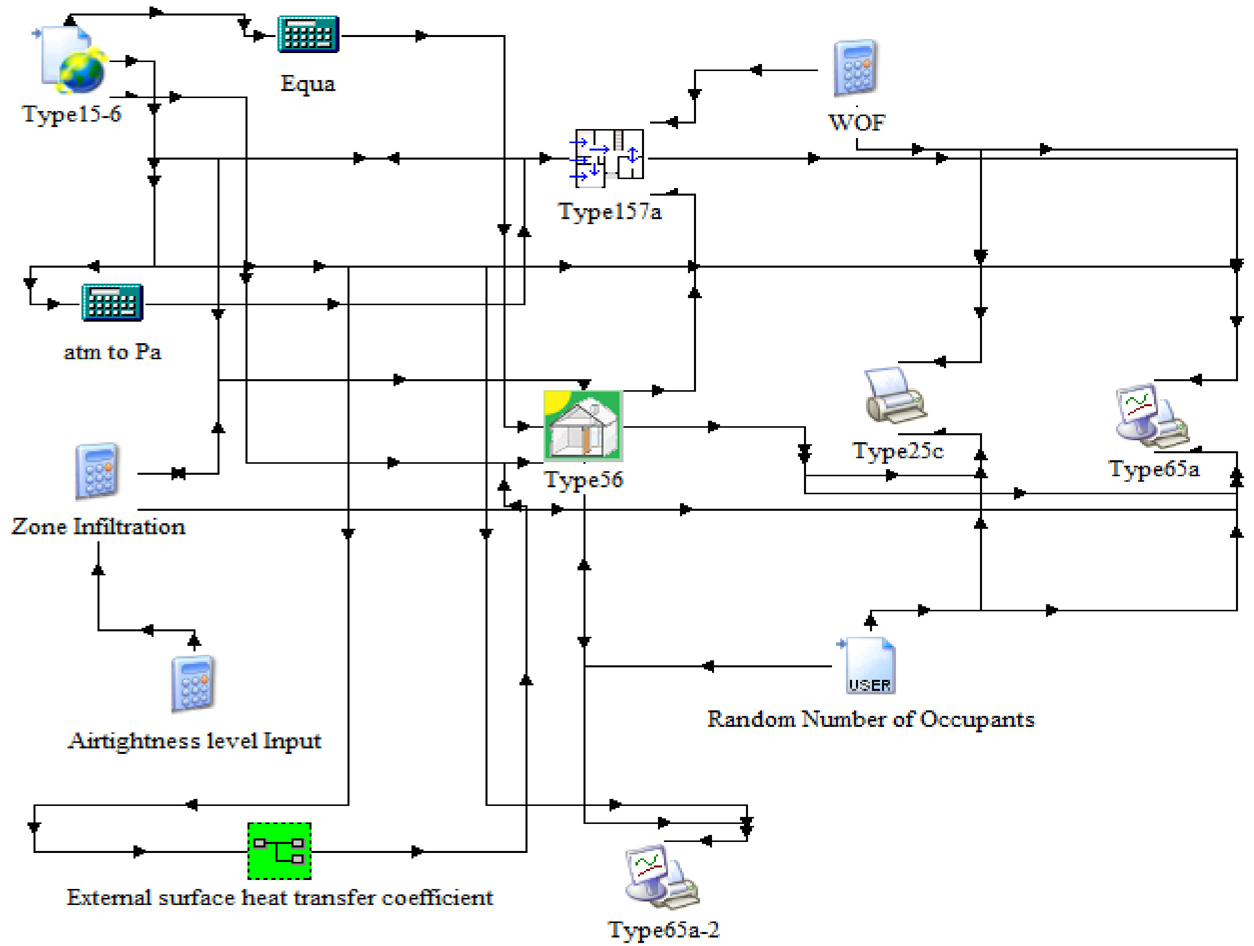


Figure 7: Coupled thermal and airflow simulation model of Building in TRNSYS/COMIS platform

Results

How thermal resistance, airtightness and WOF can influence the thermal comfort periods?

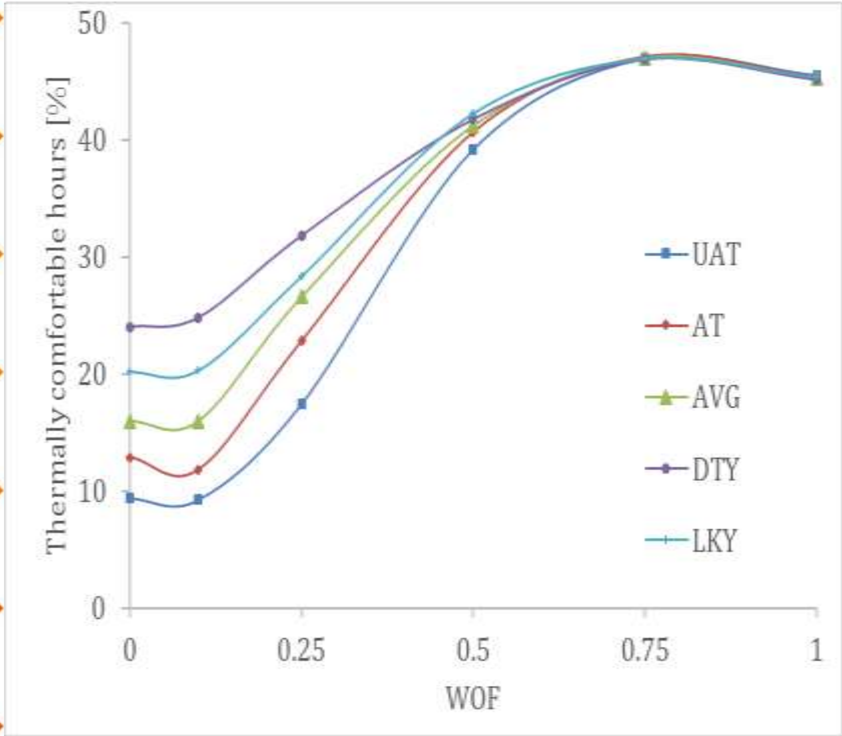


Figure 8: Percentage thermal comfort duration (-0.7<PMV<0.7) with respect to WOF (January, R_{avg} 2.01)

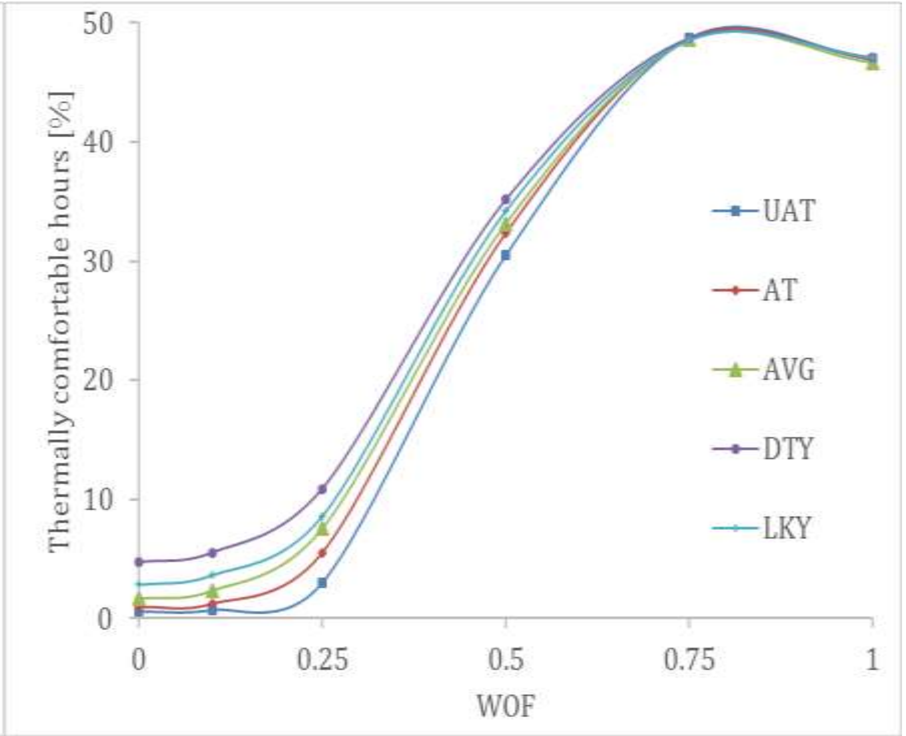


Figure 9: Percentage of thermal comfort duration (-0.7<PMV<0.7) with respect to WOF (January, R_{avg} 3.4)

How thermal resistance, airtightness and WOF can influence the thermal un-comfortable hot periods?

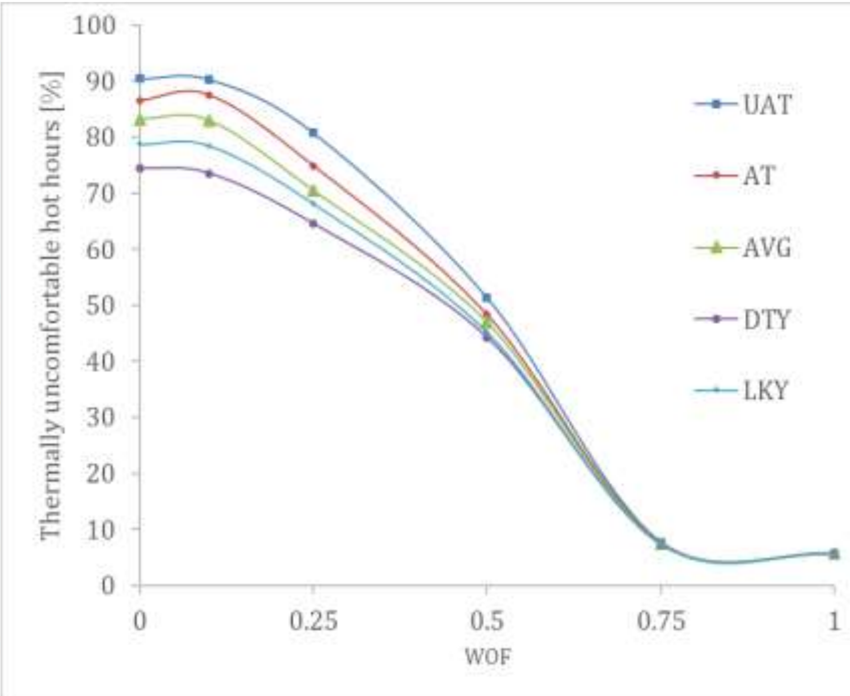


Figure 10: Percentage of thermally uncomfortable hot duration (PMV>0.7) w.r.t WOF & airtightness (January, R_{avg} 2.01)

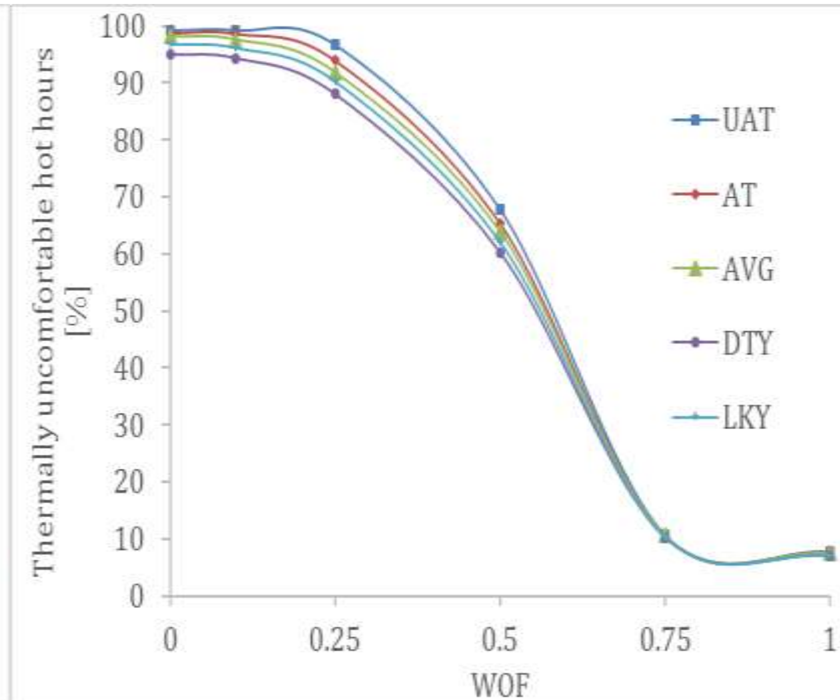


Figure 11: Percentage of thermally uncomfortable hot duration (PMV>0.7) w.r.t WOF & airtightness (January, R_{avg} 3.4)

How thermal resistance, airtightness and WOF can influence the thermal un-comfortable cold periods?

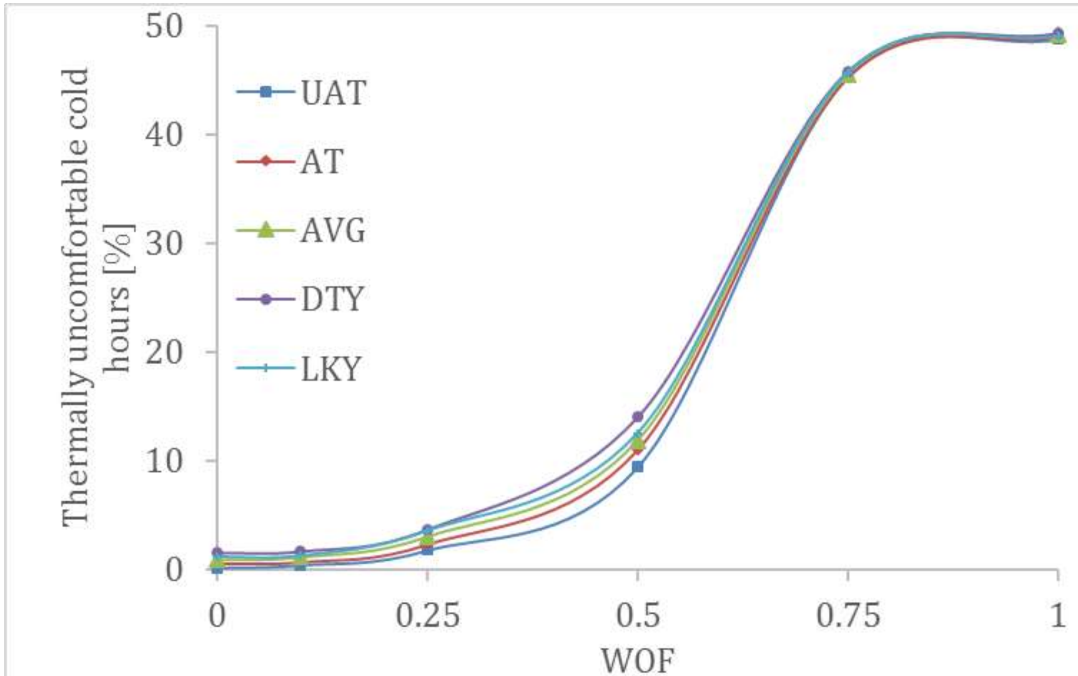


Figure 12: Percentage of thermally uncomfortable cold (PMV<-0.7) duration with respect to WOF & airtightness (January, R_{avg} 2.01)

	Uncomfortably cold period [%]				
WOF	UAT	AT	AVG	DTY	LKY
0	0.28	0.28	0.27	0.28	0.28
0.1	0.14	0.15	0.15	0.14	0.14
0.25	0.41	0.55	0.68	1.08	1.08
0.5	1.76	2.3	2.96	4.58	3.64
0.75	40.55	40.68	40.81	41.08	41.08
1	45.25	45.38	45.78	45.92	45.78

Table 2. Percentage of thermally uncomfortable cold (PMV<-0.7) periods with respect to WOF & airtightness (January, R_{avg} 3.4)

Conclusion

Conclusions and Recommendation

- A coupled thermal and airflow modelling and simulation with TRNSYS-COMIS can be used to capture the effect of the natural ventilation on the thermal comfort status of a residential house.
- The scope for regulating the thermal comfort behavior of a naturally ventilated residential house improves with relatively **insulated** and **airtight envelope**
- Different values of WOF → different window openable areas →Different potential for natural ventilation and indoor thermal comfort
- Manual adjusting the WOF can attain a maximum of less than 50% of thermally comfortable period→ Not practical
- A technique to intelligently actuate the windows and regulate the values of WOF for maximizing the percentage of thermal comfort period by minimizing both thermally uncomfortable hot and cold period needs to be investigated further

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Thank You!