Thermal comfort and adaptive behaviour in the Sydney residential context

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Context of thermal comfort research

- Over 100 years of thermal comfort research
- Overwhelming majority of that research focused on *office environments*
- It's leap of faith to assume that research findings from one type of environment, like *offices*, can be generalized to other contexts, like *residences*

What's so different about homes?

- Why would *we expect residential comfort to be different?*
  - Greater adaptive opportunities
  - Different and more flexible clothing patterns
  - Energy costs directly affects the comfort consumer
  - Different occupant activities indoors

Why is residential comfort so *under*-researched?

- Logistics!
  - In offices studies one gets permission to obtain objective and subjective comfort evaluations within a concentrated sample (i.e. it's quick and easy!)
  - A sample of homes is geographically dispersed, scheduling and logistics are difficult, issues with long-term installation of equipment, and there are ongoing ethics concerns re. householder privacy

Research Method

- Longitudinal research design (2012-14)
- Sample of 42 households (humid-subtropical Sydney-Wollongong)
- *Subjective* "right-here-right-now" thermal comfort evaluations (smartphone)

  plus simultaneous and contiguous
- *Objective* indoor (and outdoor) temperatures

Longitudinal design required questionnaires to be very quick
(<1 minute to complete)

Sent to householders ca once per week except during extreme weather events
(up to 3 times per week)

12:34 PM

Comfort Survey

Welcome

Thank you for participating in this study of residential comfort and air conditioning use.

Please take a moment to complete the survey - it will take less than one minute.

Start

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12:34 PM

Comfort Survey

Are you currently at home?

Yes

Back Next

Step: 1 of 5

12:34 PM

Comfort Survey

Where are you right now?

Living Room

Back Next

Step: 2 of 5

12:34 PM

Comfort Survey

How do you feel, here and now?

- Hot
- Warm
- Slightly warm
- Neutral
- Slightly cool
- Cool
- Cold

Back Next

Step: 3 of 5

12:34 PM

Comfort Survey

In this room here and now, do you have:

(you may select more than one)

- [ ] Open windows / doors
- [ ] Ceiling / desk fans operating
- [ ] Air-conditioning on (cooling)
- [ ] Air-conditioning on (heating)
- [ ] Other heating appliances on
- [ ] None

Back Next

Step: 4 of 5

12:34 PM

Comfort Survey

Which best describes your clothing now:

Very Light | Light | Casual | Heavy

Back Submit

Step: 5 of 5

Indoor measurements

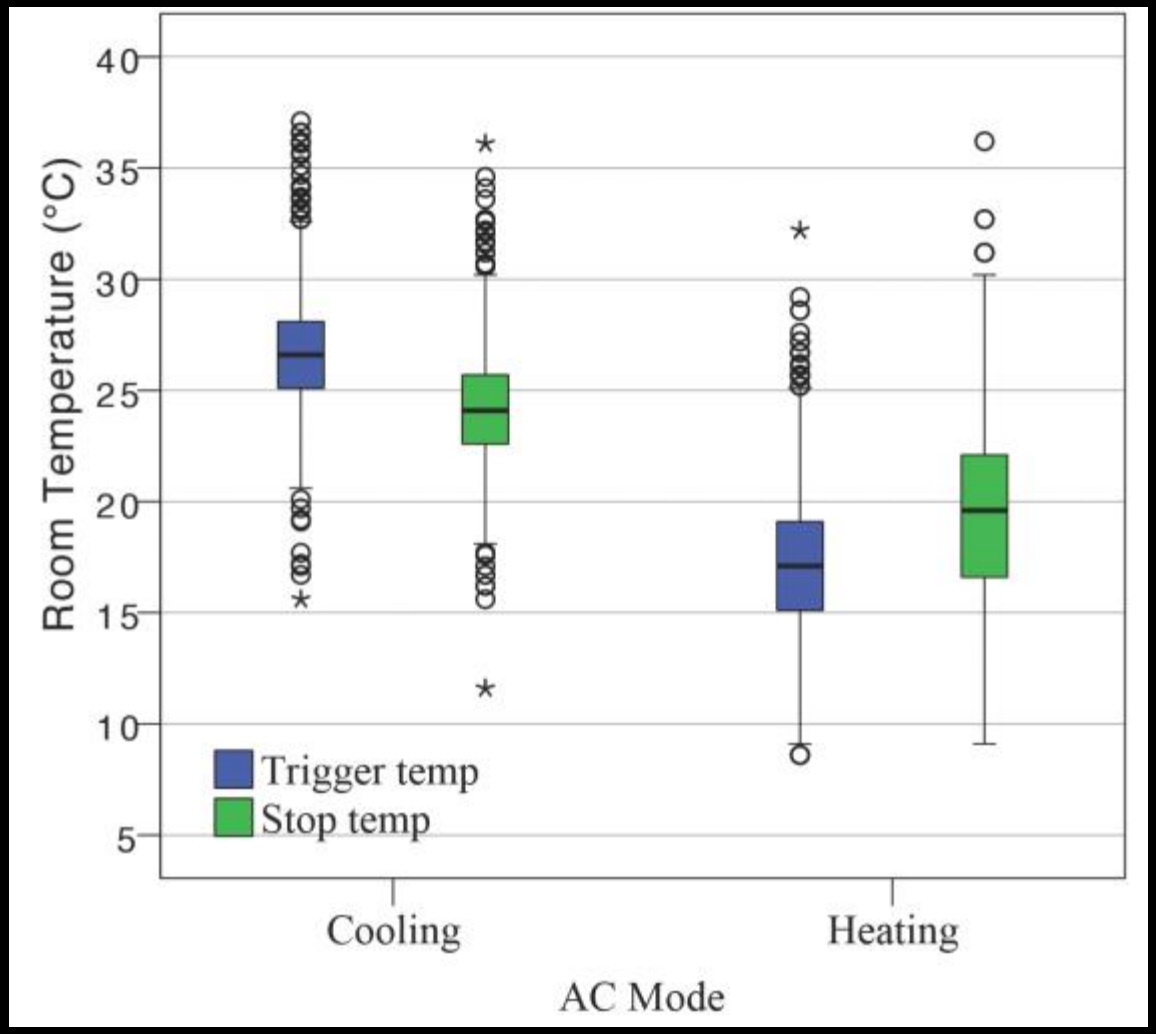
- iButtons were placed within the *occupied zone* of different rooms of each house
- An iButton was also installed in the *supply air vent* of the AC terminal unit

Results using this method…

- 42 homes (27 in Sydney, 15 in Wollongong)
- 7.65 million data points
- 2,100 at-home questionnaire responses
- 4,900 AC events (“switch-on”)
- 11,800 hours of AC use

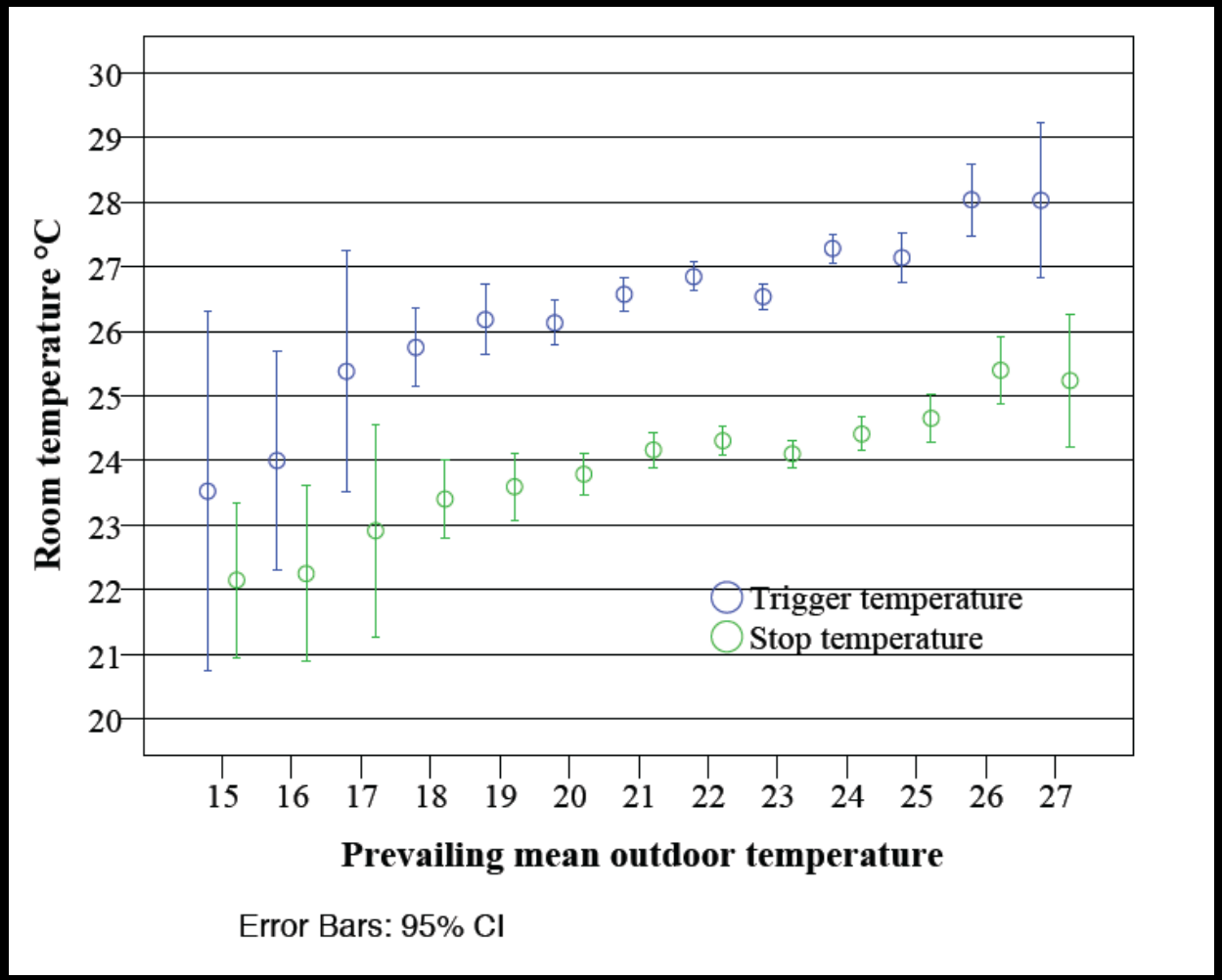
AC use patterns

- AC switch on / off room temperatures



Adaptive thermostat control?

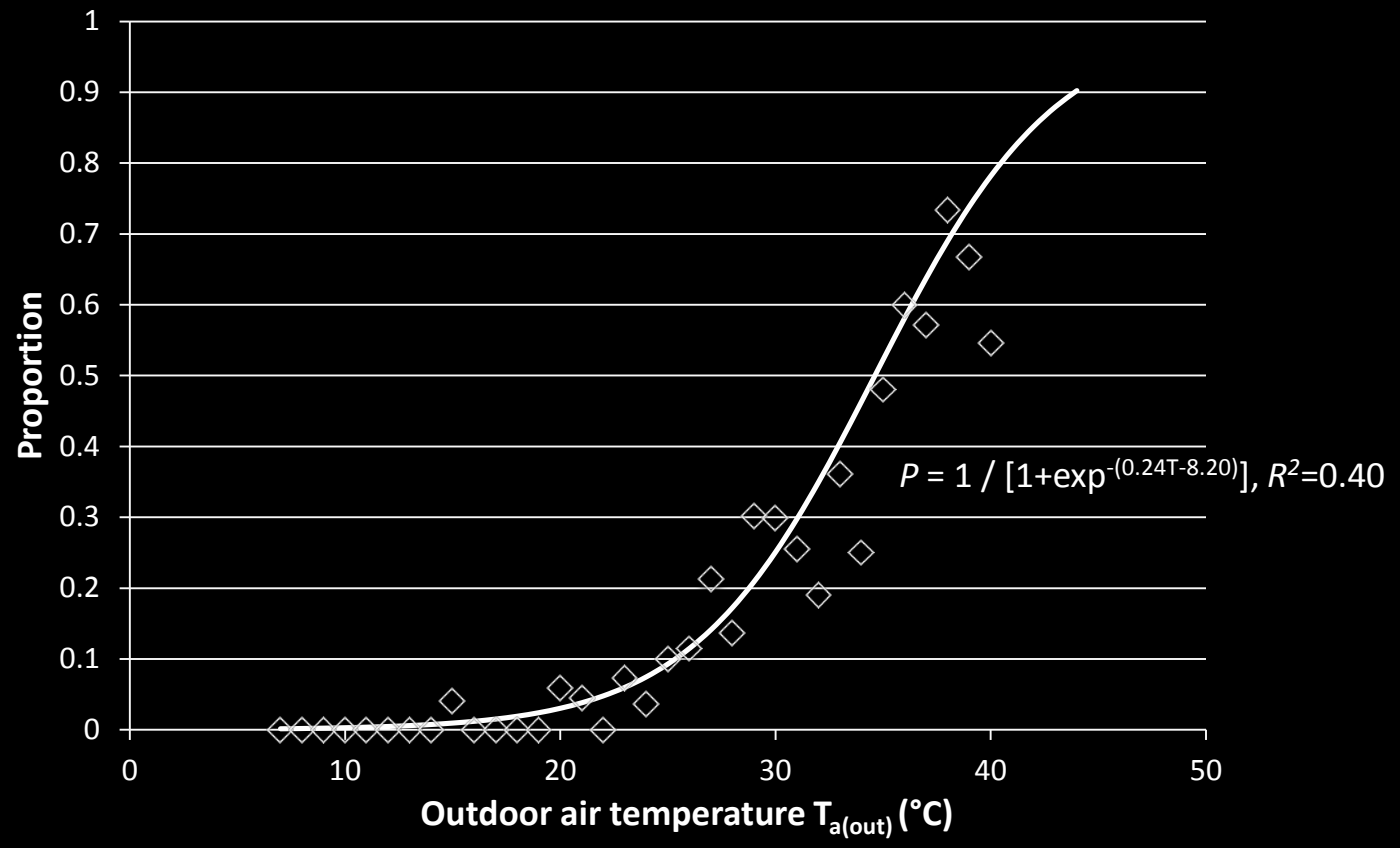
- AC cooling in summer



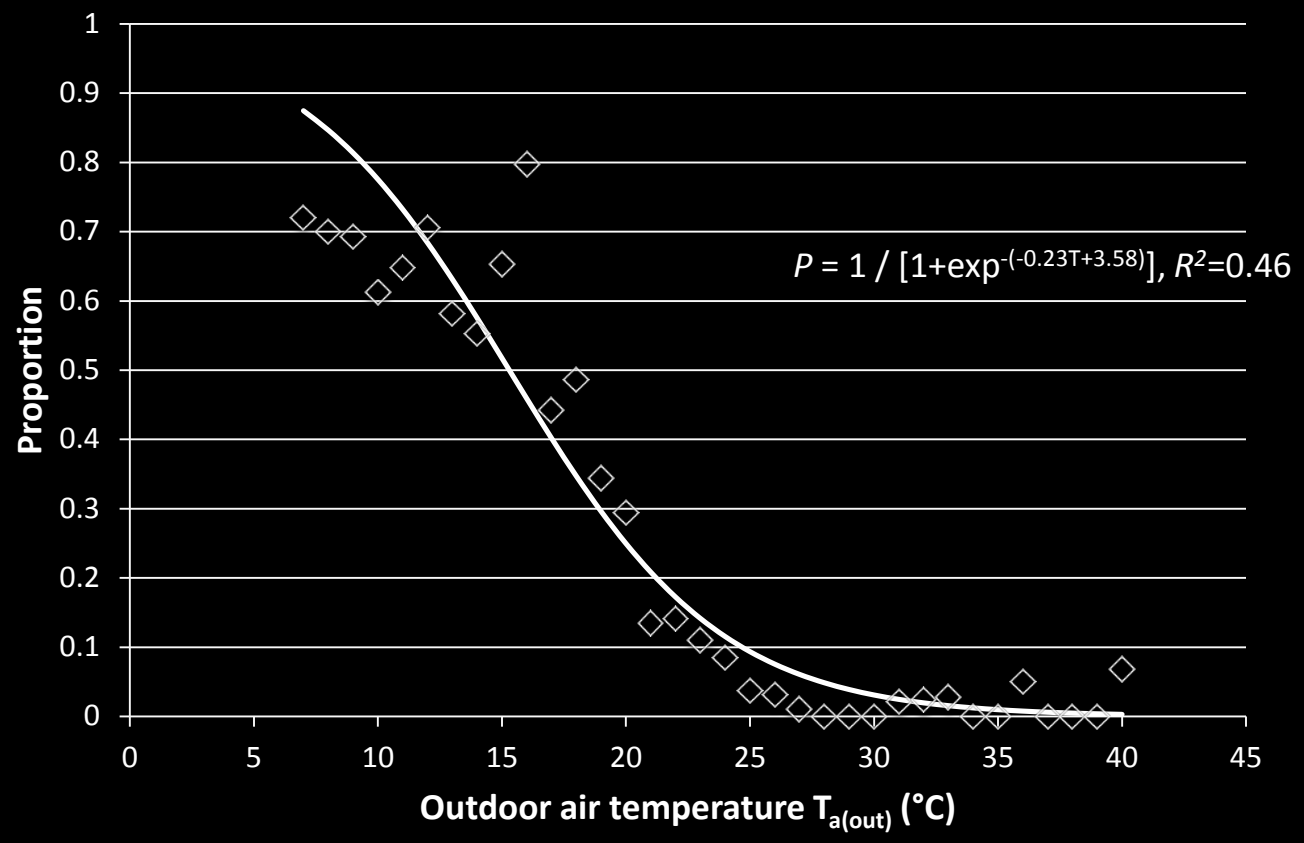
% adaptive strategies

Open windows/doors	39.5%
Heating appliances on	23.1%
AC (cooling) on	13.6%
Fans (ceiling/desk) on	12.6%
None	13.9%

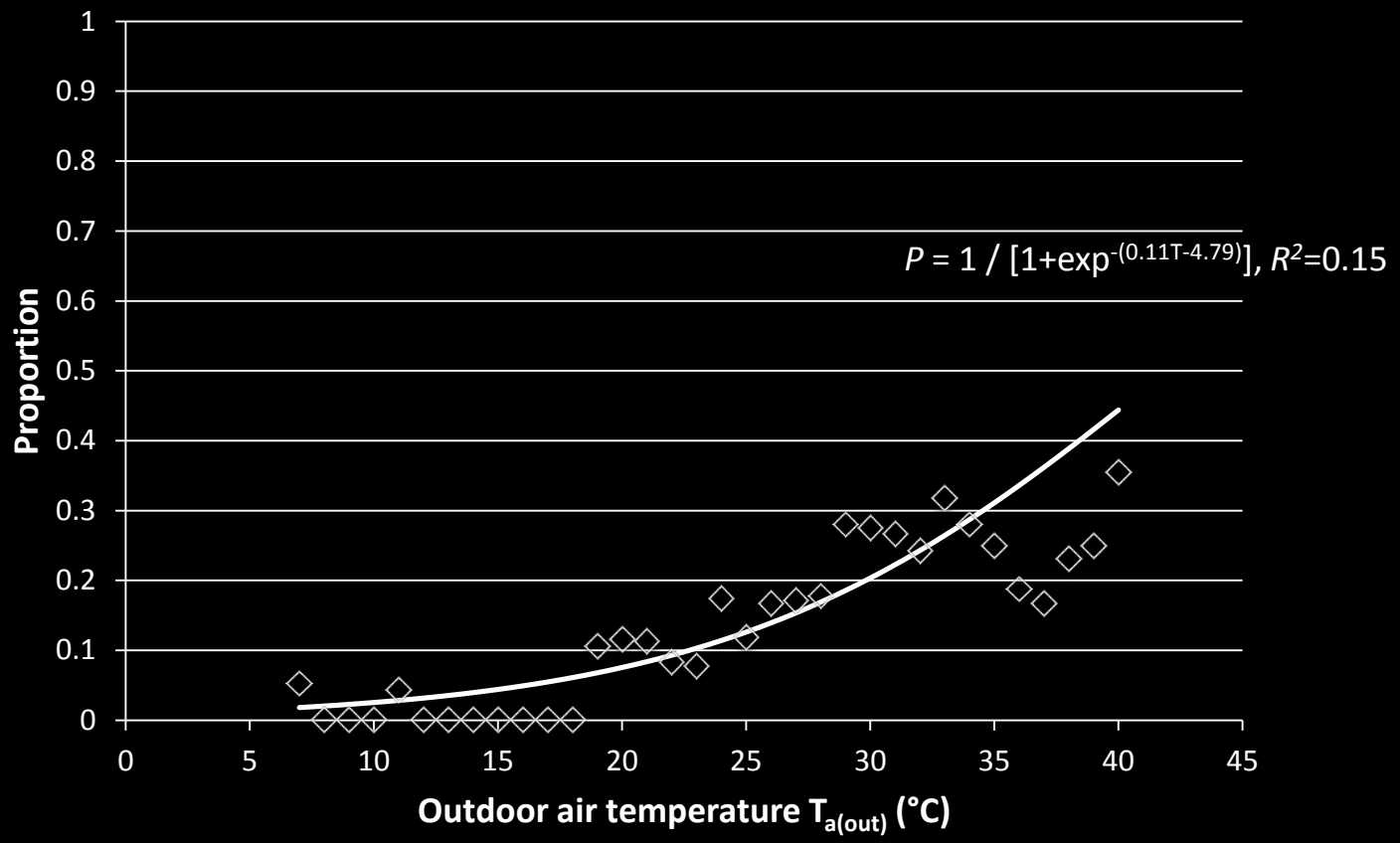
AC (cooling) on



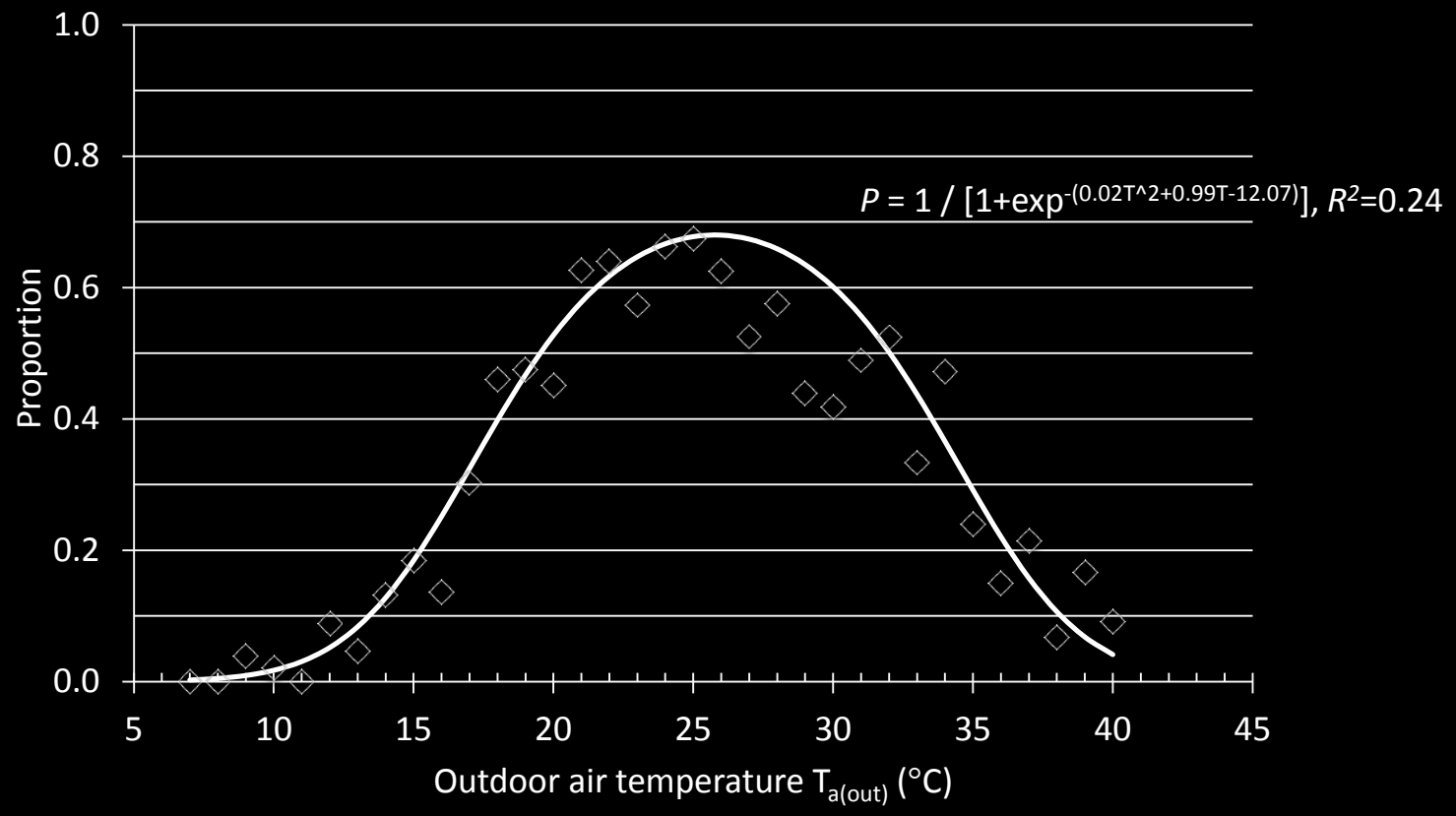
Heating on


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion
0
5
10
15
20
25
30
35
40
45
Outdoor air temperature $T_{a(out)}$ (°C)
$P = 1 / [1+\exp^{-(-0.23T+3.58)}]$, R^2=0.46

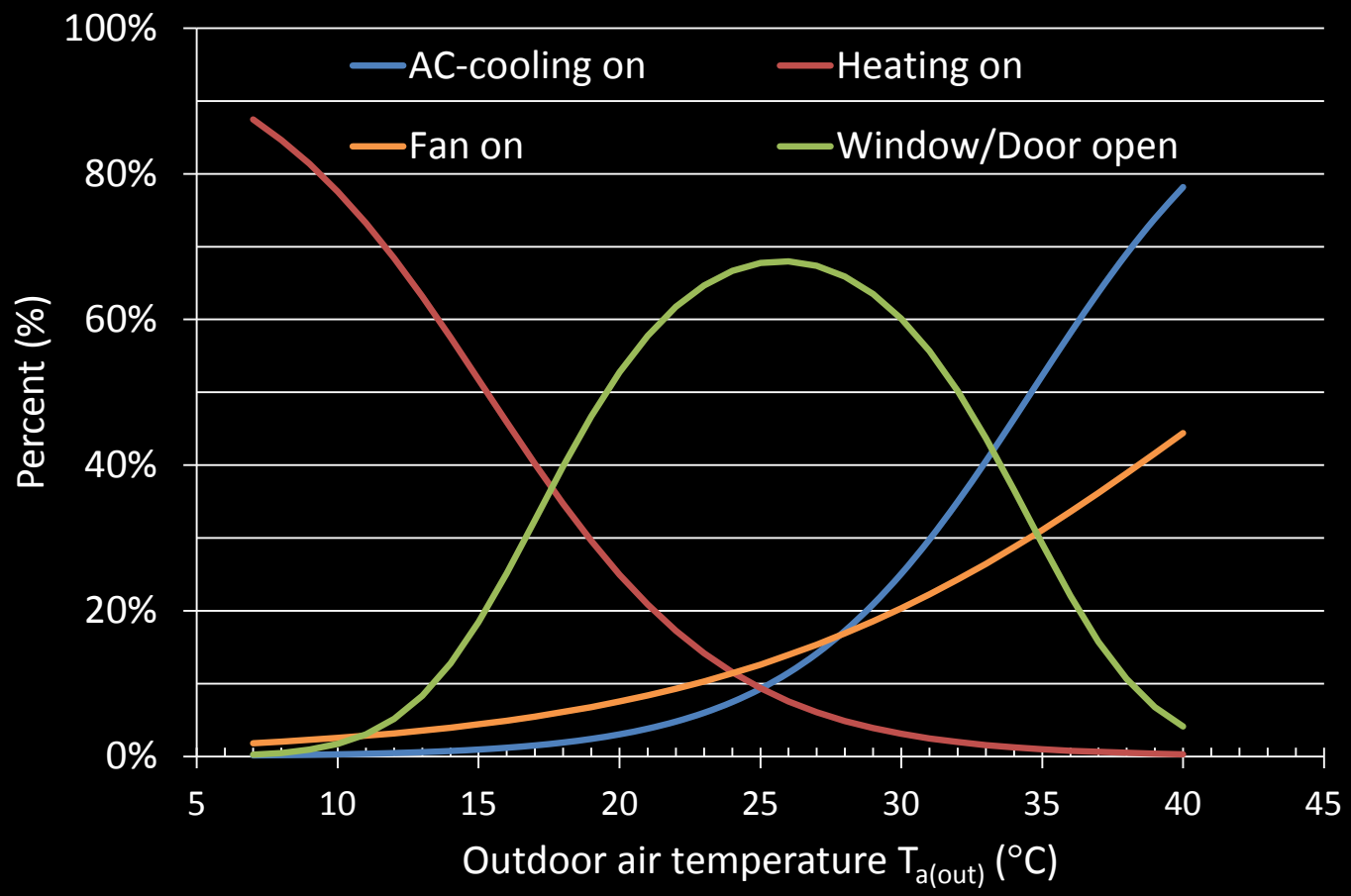
Fan on


$P = 1 / [1+\exp^{-(0.11T-4.79)}]$, R^2=0.15
Proportion
Outdoor air temperature $T_{a(out)}$ (°C)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45

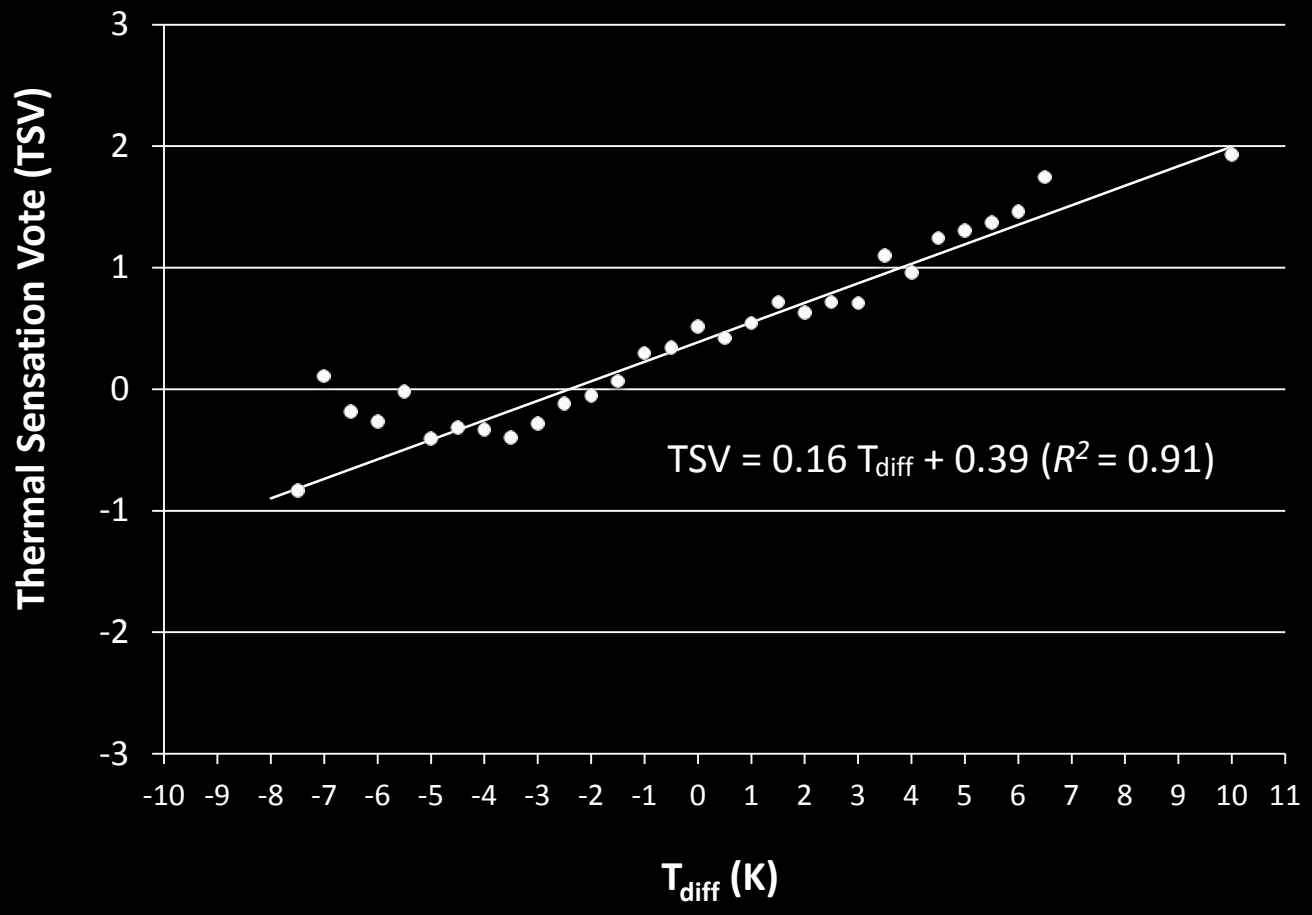
Window open


1.0
0.8
0.6
0.4
0.2
0.0
Proportion
$P = 1 / [1+\exp^{-(0.02T^2+0.99T-12.07)}]$, $R^2=0.24$
5
10
15
20
25
30
35
40
45
Outdoor air temperature $T_{a(out)}$ (°C)

Adaptive behaviour patterns

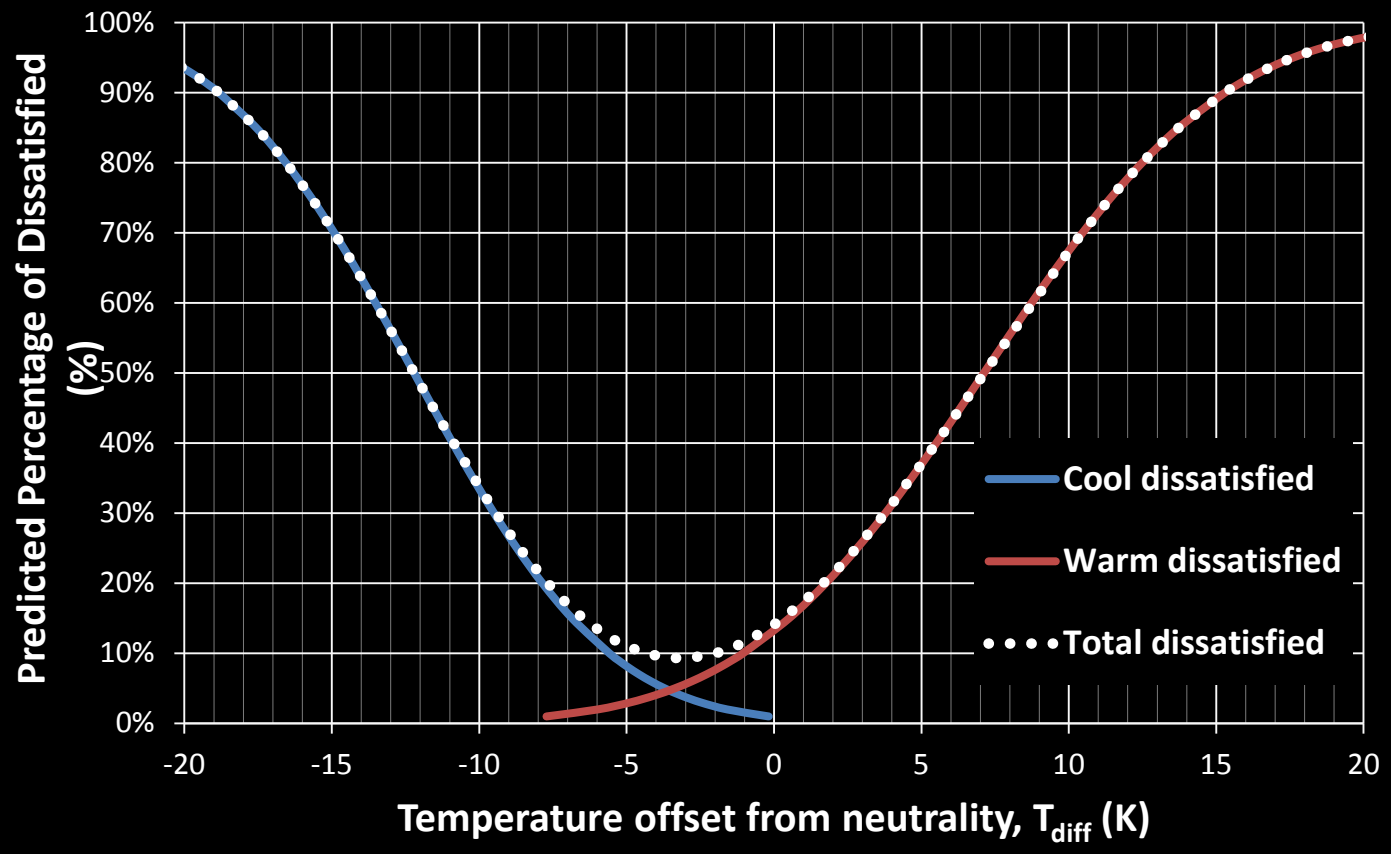


Thermal Sensation v Room Temperature



*T_{diff} (K) = offset from Adaptive model's neutrality, i.e. T_{room} - $T_{neutral}$

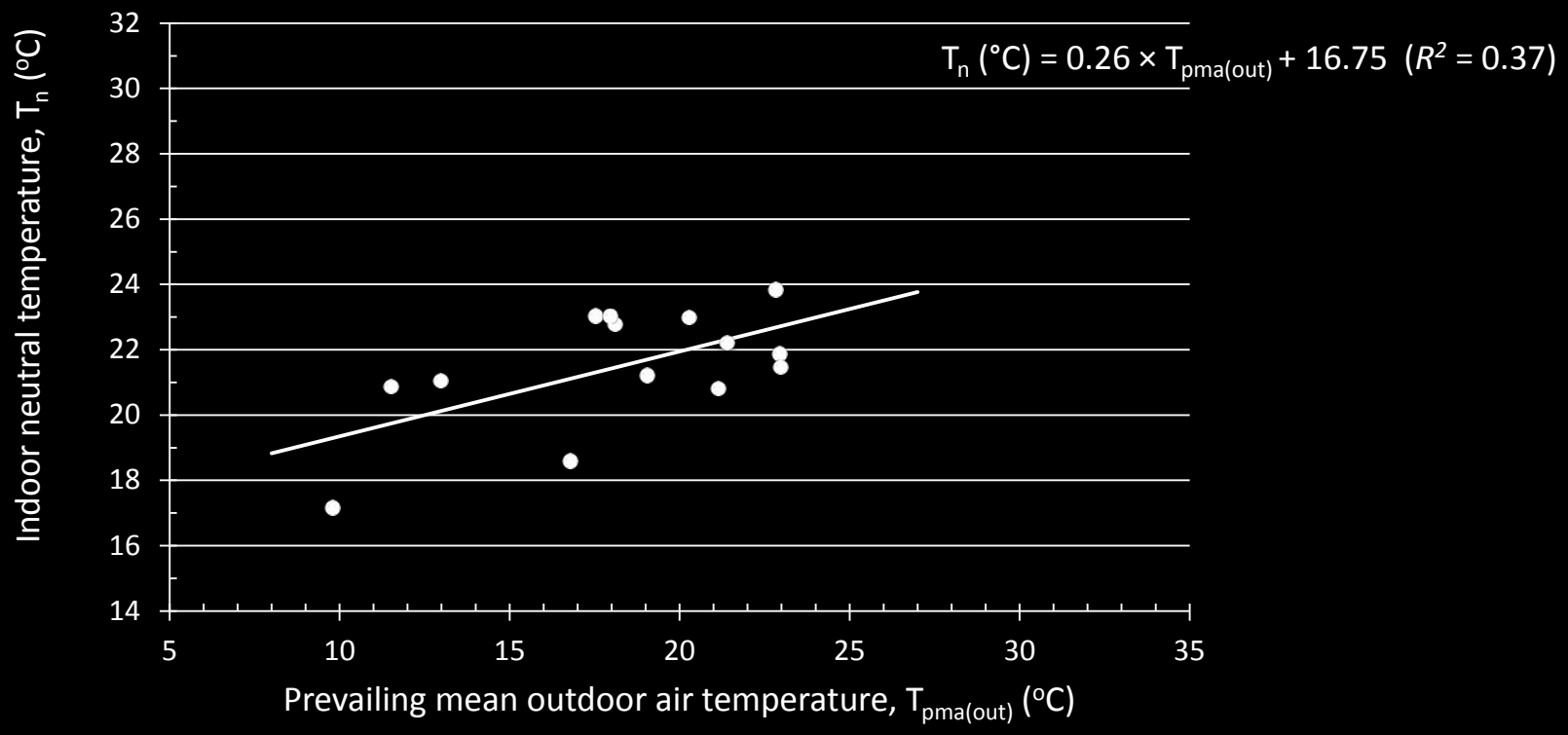
% Dissatisfied v Room Temperature



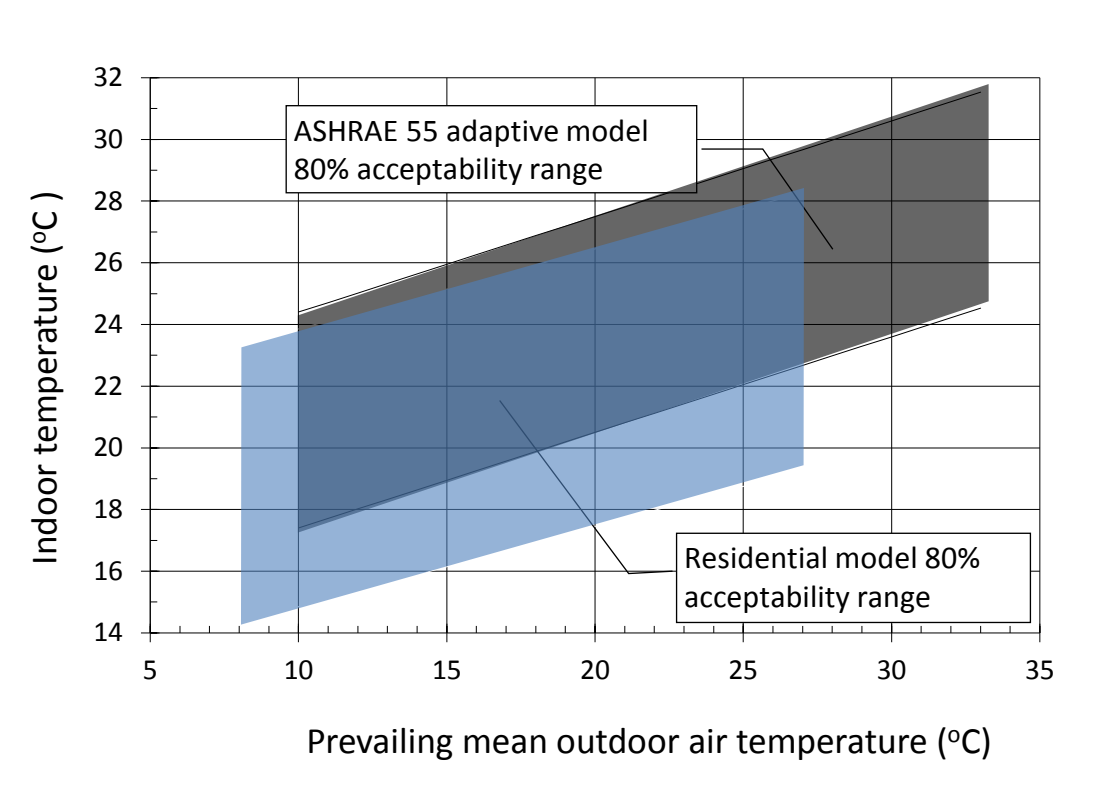
- Warm discomfort: TSV > +1.5, i.e. *warm* or *hot*
- Cool discomfort: TSV < -1.5, i.e. *cool* or *cold*
- 80% Acceptable Range is 9K

Residential Adaptive Model

- Sample divided by Month/City, resulting in 24 sub-groups
- Weighted regression fitted for each of the 24 sub-groups ($TSV = bT_{room} + c$)
- T_n calculated from 14 significant regression models matched with $T_{pma(out)}$



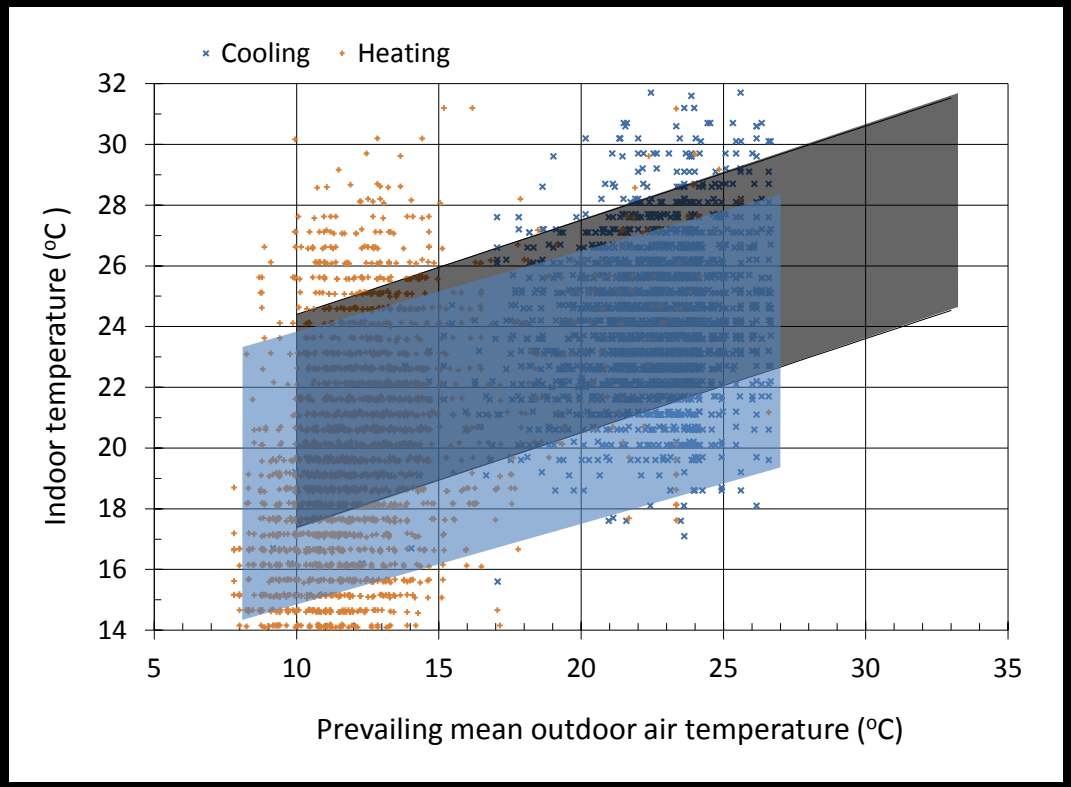
80% Acceptability Range



- Upper 80% limit (°C) = $0.26 \times T_{pma(out)} + 21.25$
- Lower 80% limit (°C) = $0.26 \times T_{pma(out)} + 12.25$

80% Acceptable?

- AC ‘switch-off’ temperatures against 80% acceptability range



	ASHRAE 55 Adaptive Model	Present Residential Model
Within range	70.4%	80.4%
Above 80% limit	**5.1%**	**10.1%**
Below 80% limit	**24.5%**	**9.5%**

Conclusions

- The most common trigger temp for AC was *28°C (cooling)* and *18°C (heating)*
- ΔT about *3 degrees*
- Outdoor temp of *25°C*: maximised use of window and minimised reliance on AC
- Outdoor temp of *21* and *28°C*: thresholds to keep mechanical *heating* and *cooling* below *20%*
- Australian home residents showed *greater adaptability* (*b*=0.16) than office workers (*b*=0.27, *de Dear and Brager 1998*)
- 80% comfort zone width: *9K* (2K wider than ASHRAE 55 Adaptive Model)
- People in their homes are *more adaptive* to, and *tolerant* of wider temperature variations
- The study was extended to Tianjin *China* last year and *Brazil* this year

Acknowledgements

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Thank you for your attention!