Definition of occupant behaviour patterns with respect to ventilation by means of multivariate statistical techniques

Photo: F. Encinas

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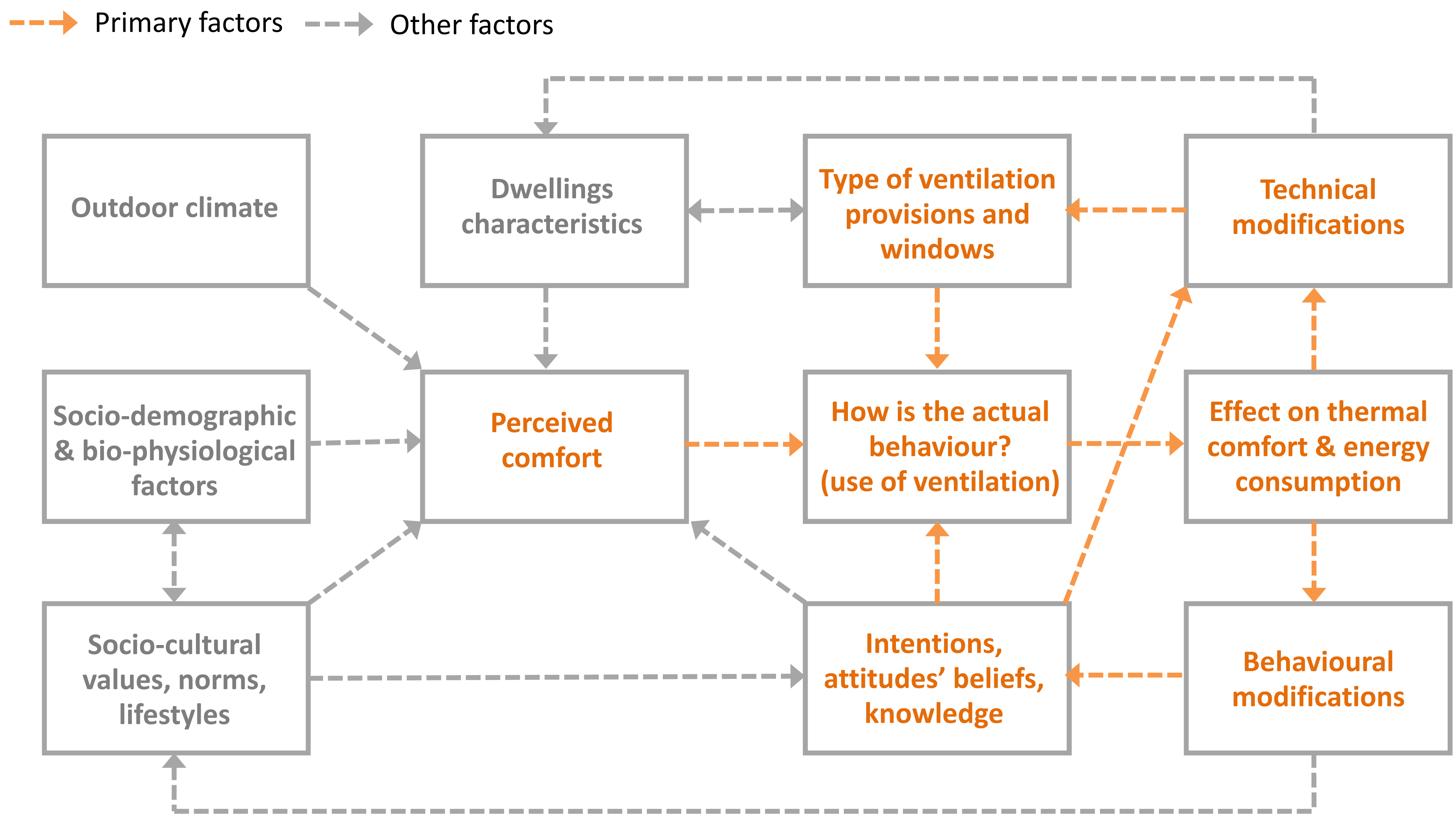
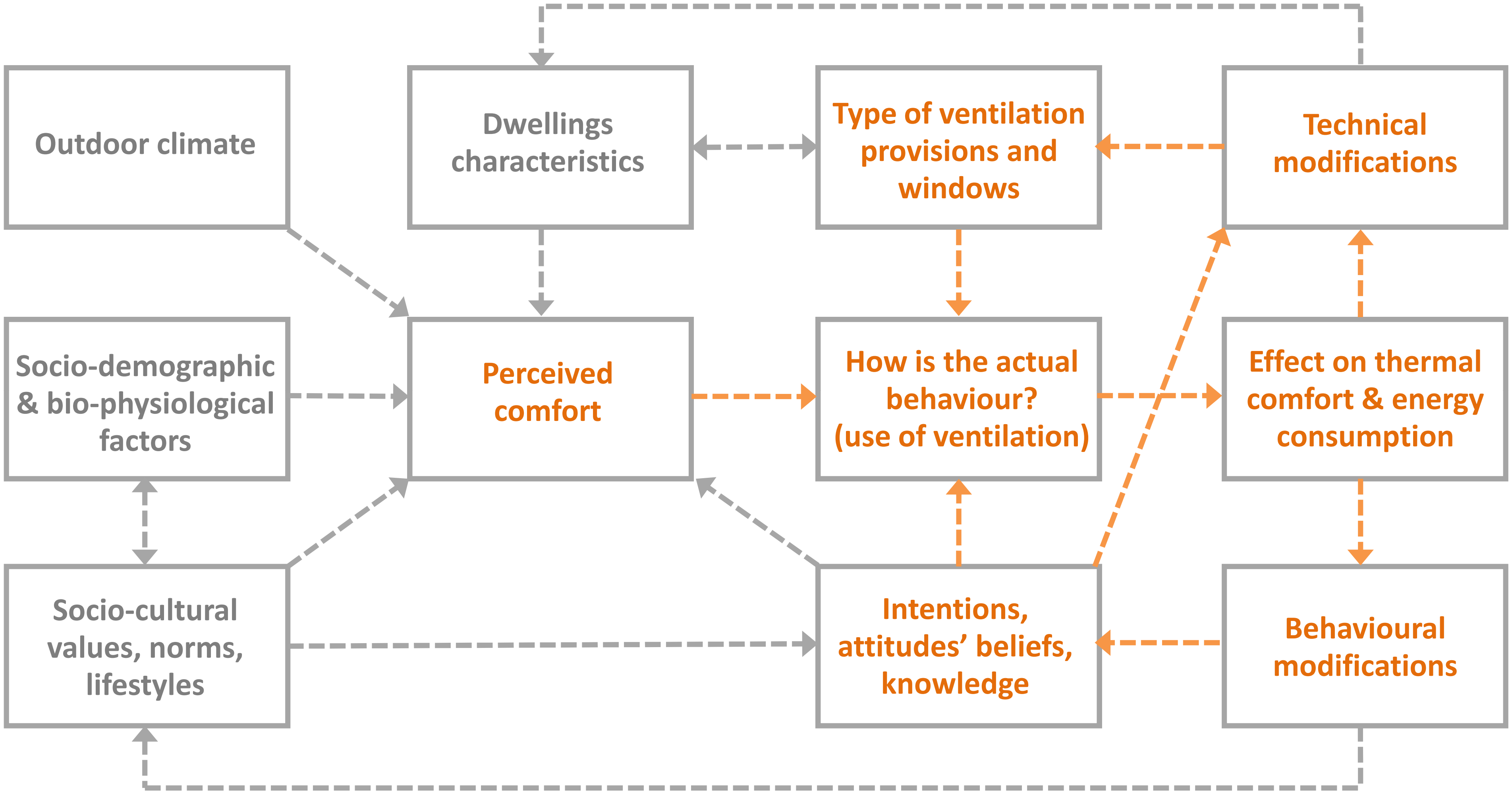
Relationship between occupant behaviour and thermal performance of dwellings

Model of ventilation behaviour by the International Energy Agency (IEA)

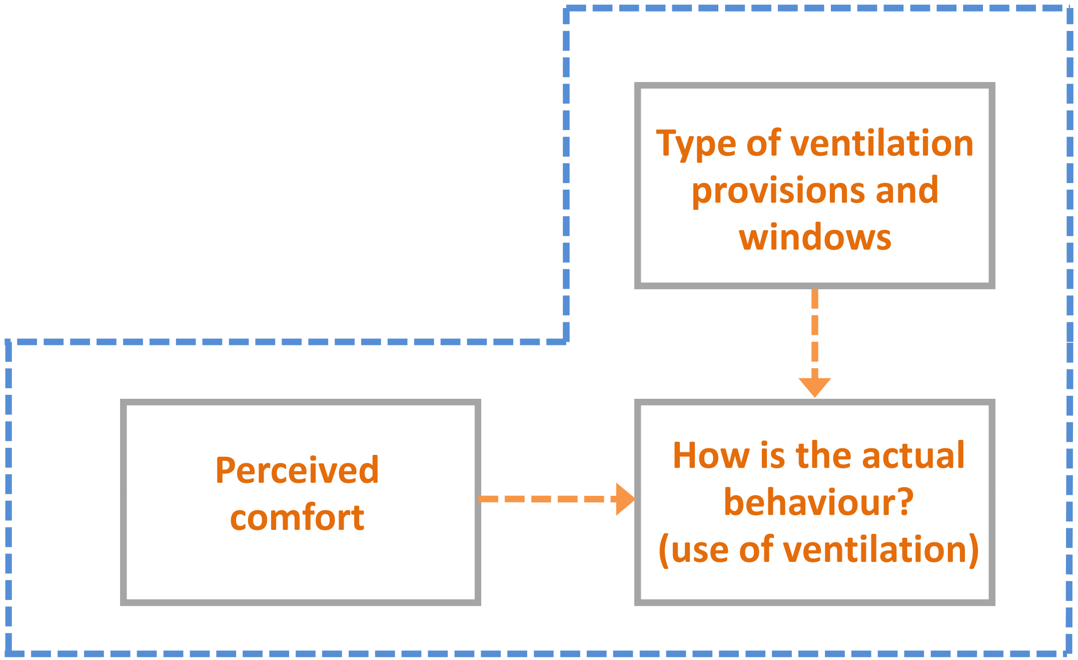


Source: IEA, 1988

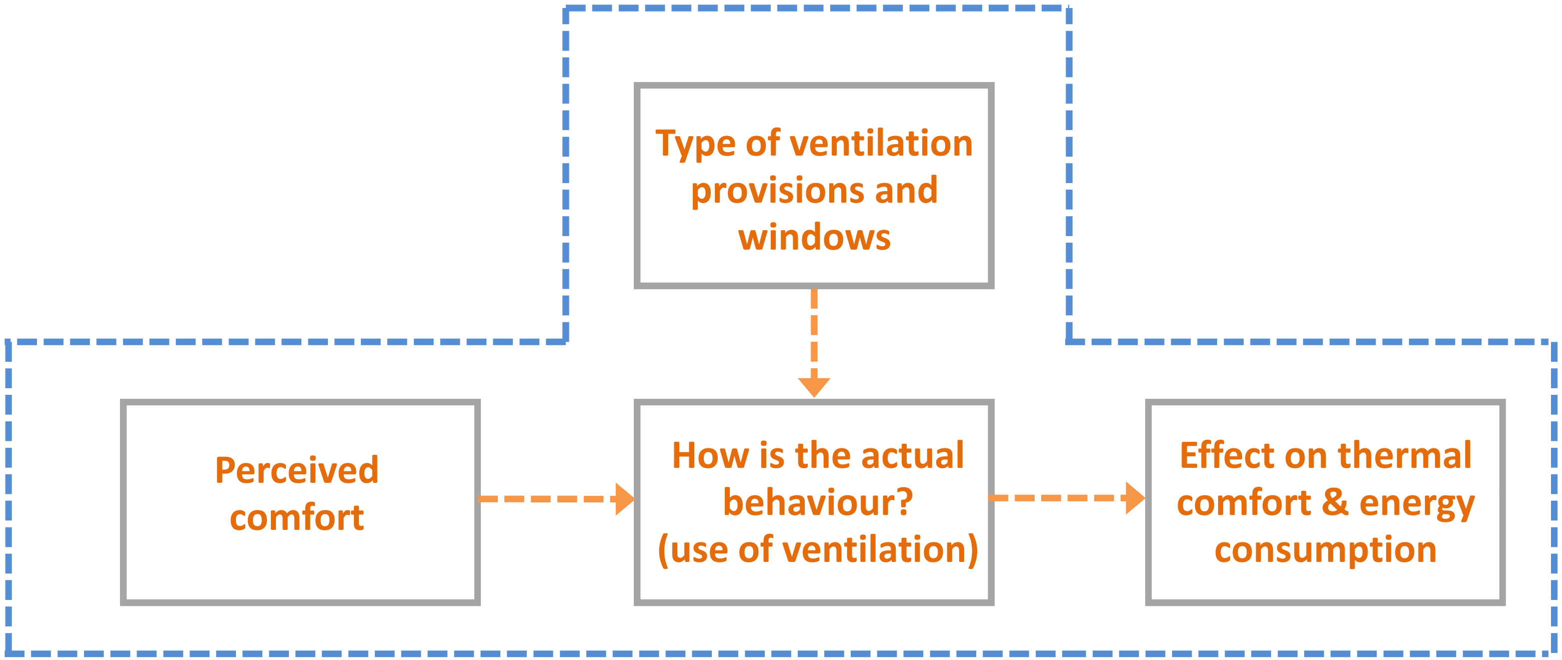
This study tries to establish **occupant behaviour patterns** **for apartments from the real estate market of Santiago de Chile** based on field data and also determining their impact on the summer thermal comfort.



Source: IEA, 1988



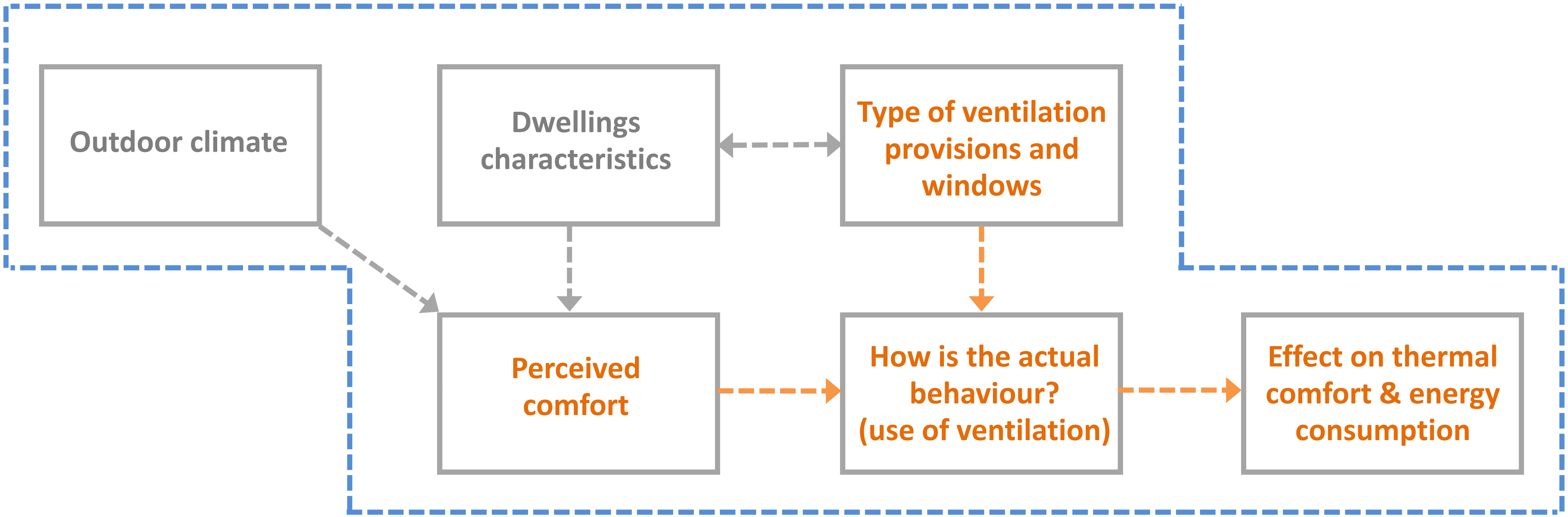
(1) Do patterns of occupant behaviour exist with respect to perception of thermal comfort and ventilation (by means of windows opening)?



(1) Do patterns of occupant behaviour exist with respect to perception of thermal comfort and ventilation (by means of windows opening)?

(2) Do different occupant behaviour patterns lead to significant differences in the thermal comfort of the apartments in summer?

(3) Which are the most important variables in terms of their influence with respect to the ventilation rate / window operation in each one of the occupant behaviour patterns?



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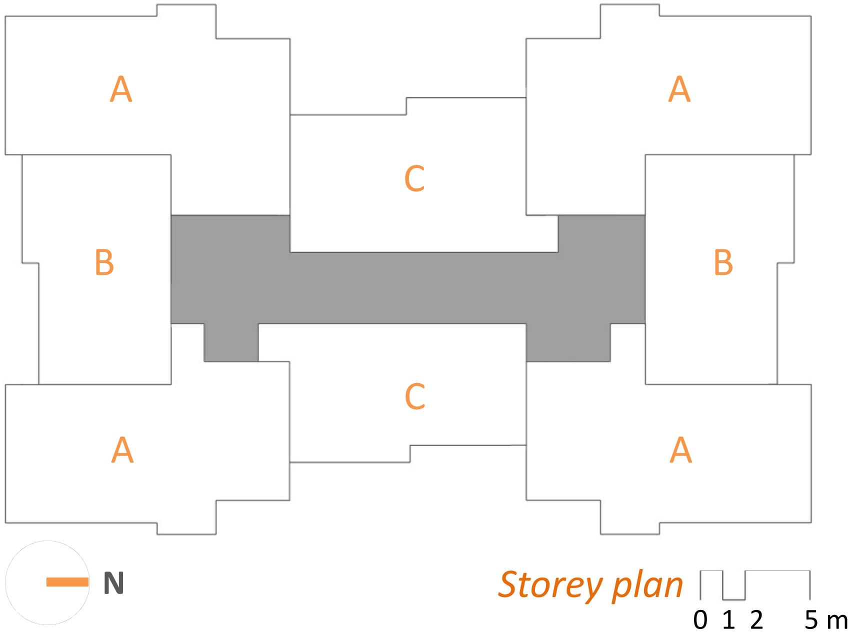
Description of the pilot case study



Storey plan

Survey frame:
survey of perception of thermal comfort and occupant behaviour in apartment buildings of Santiago de Chile

Population	166 apartments
Sample size	91 apartments
Margin of error	6%
Estimate % of the sample	50%
Confidence level	90%

Edificio Don José (1993-94)

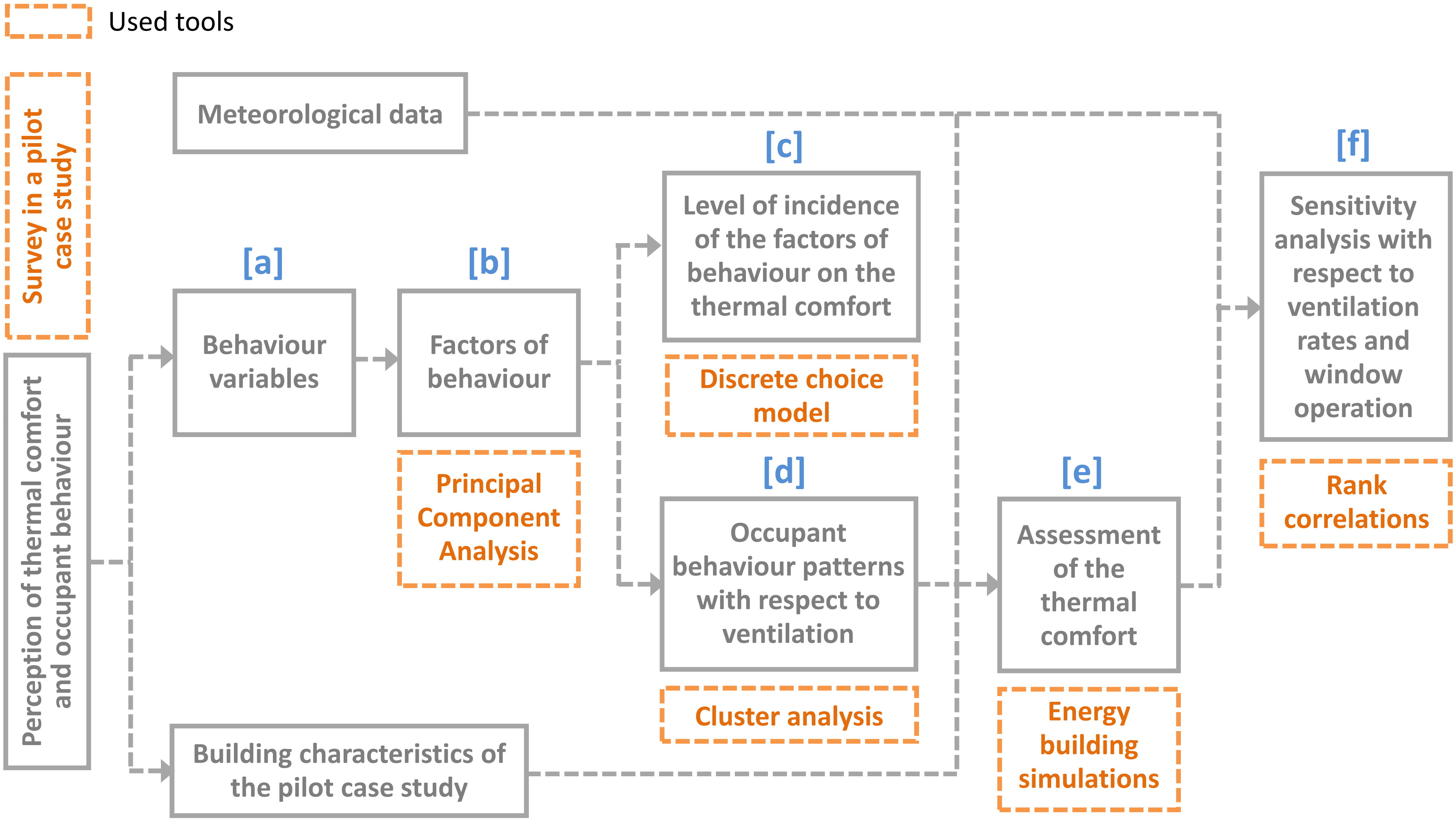
22-storey apartment building in Santiago de Chile

Type	Living area	Number of bedrooms
A	87.0 m²	3
B	70.0 m²	2
C	71.5 m²	2

South facade

East facade (main entrance)

Approach - methodological scheme



Factors of behaviour by means of a Principal Component Analysis (PCA)

[a] Definition of behaviour variables for the PCA

Subject	Behaviour variables	
	Survey questions	Items
Perception of thermal comfort	Q6	Thermal sensation in winter [1]
	Q10	Thermal sensation in summer [1]
Ventilation	Q16	Daytime ventilation in winter
	Q20	Daytime ventilation in summer
	Q24	Use of night ventilation in summer
Strategies and systems	Q13	Presence of external solar protection
	Q27	Use of heating systems in winter

Note:

[1] To define the categories of these questions, the 7-point subjective scale of EN 15251:2007 was considered:

- **+3** Hot
- **+2** Warm
- **+1** Slightly warm
- **±0** Neutral
- **-1** Slightly cold
- **-2** Cool
- **-3** Cold

Factors of behaviour by means of a Principal Component Analysis (PCA)

[b] *Components loadings and communalities based on the PCA*

Behaviour variables		Components				Communalities
		C_1	C_2	C_3	C_4	
Q6	Thermal sensation in winter		0.85			0.76
Q10	Thermal sensation in summer			0.65		0.52
Q16	**Daytime ventilation in winter**	**0.76**				0.75
Q20	**Daytime ventilation in summer**	**0.86**				0.81
Q24	Use of night ventilation in summer			0.84		0.74
Q13	Presence of external solar protection				0.90	0.82
Q27	Use of heating systems in winter		-0.71			0.72

Rotation method: Varimax with Kaiser normalization

Note: component loadings <0.6 are suppressed according to the sample criterion established by Hair et al.(2005)

The components of the rotated matrix with their proportions of explained variance are:

C_1

***Daytime ventilation*, both in winter and summer [21.3%]**

[b] *Components loadings and communalities based on the PCA*

Behaviour variables		Components				Communalities
		C_1	C_2	C_3	C_4	
Q6	**Thermal sensation in winter**		**0.85**			0.76
Q10	Thermal sensation in summer			0.65		0.52
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Rotation method: Varimax with Kaiser normalization

Note: component loadings <0.6 are suppressed according to the sample criterion established by Hair et al.(2005)

The components of the rotated matrix with their proportions of explained variance are:

C_2

***Perception of favourable thermal comfort in winter and avoiding the use of heating appliances* [18.7%]**

Factors of behaviour by means of a Principal Component Analysis (PCA)

[b] Components loadings and communalities based on the PCA

Behaviour variables		Components				Communalities
		C_1	C_2	C_3	C_4	
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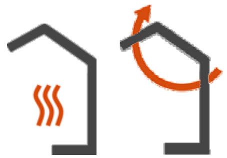
Rotation method: Varimax with Kaiser normalization

Note: component loadings <0.6 are suppressed according to the sample criterion established by Hair et al.(2005)

The components of the rotated matrix with their proportions of explained variance are:

C_3



***Perception of unfavourable thermal comfort in summer and use of night ventilation* [17.4%]**

Factors of behaviour by means of a Principal Component Analysis (PCA)

[b] *Components loadings and communalities based on the PCA*

Behaviour variables		Components				Communalities
		C_1	C_2	C_3	C_4	
Q6	Thermal sensation in winter		0.85			0.76
Q10	Thermal sensation in summer			0.65		0.52
Q16	Daytime ventilation in winter	0.76				0.75
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Rotation method: Varimax with Kaiser normalization

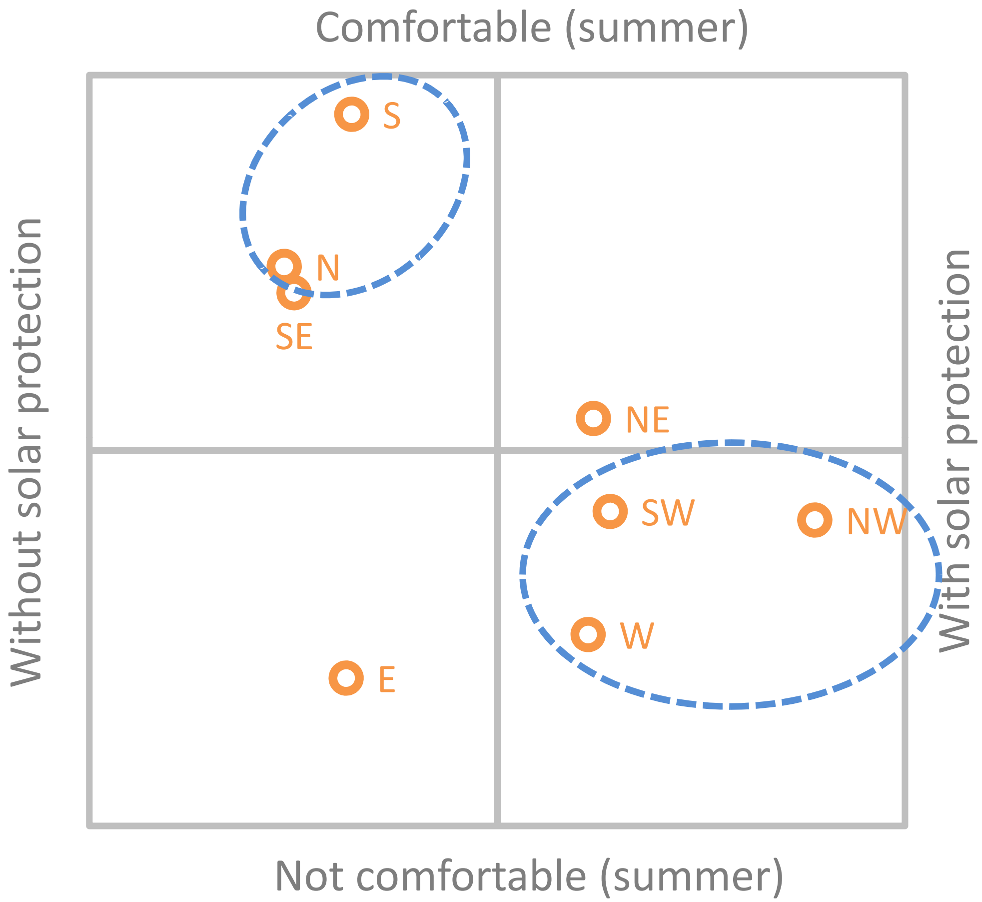
Note: component loadings <0.6 are suppressed according to the sample criterion established by Hair et al.(2005)

The components of the rotated matrix with their proportions of explained variance are:

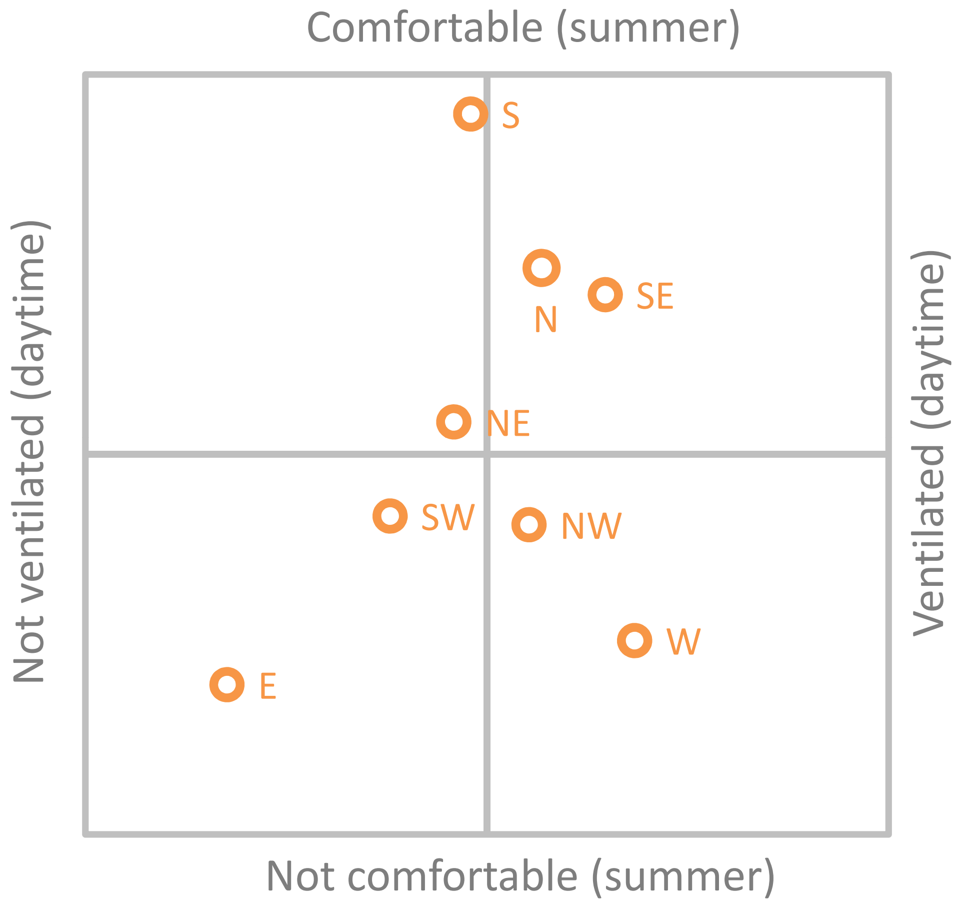
C_4  ***Presence of solar protection*** **[15.8%]**

Factors of behaviour by means of a Principal Component Analysis (PCA)

Perceptual map of C_3 vs. C_4 by orientation



Perceptual map of C_3 vs. C_1 by orientation



Incidence of the factors of behaviour on the overall thermal comfort by means of a discrete choice model

[c] *Application of a discrete choice model*

The model that predicts the dependent dichotomic variable Y in probabilistic terms from multivariate independent variables X_k is:

Multivariate logistic regression:

$$P_{\left(Y=\frac{1}{X_k}\right)} = \frac{1}{1 + e^{-(a + b_1 x_1 + \ldots + b_k x_k)}}$$

Applying the equation to the previous obtained components, it is possible to predict the behaviour of last question of the survey as function of these independent variables.

Q41 Do you feel comfortable in your apartment in terms of thermal comfort?

Yes (Y=1)
No (Y=0)

$$P_{\left(Q41=\frac{1}{C_{i,i=1\ldots4}}\right)} = \frac{1}{1+ e^{-(a + b_1 C_1 + b_2 C_2 + b_3 C_3 + b_4 C_4)}}$$

where C_1, C_2, C_3 and C_4 are the factor scores that were obtained through the PCA, b_1, b_2, b_3 and b_4 are the coefficients for these variables, a is a coefficient of the model and e is the base of natural logarithms

Incidence of the factors of behaviour on the overall thermal comfort by means of a discrete choice model

Obtained coefficients from the multivariate logistic regression

$$P_{\left(Q41=\frac{1}{C_{i,i=1\ldots4}}\right)} = \frac{1}{1+e^{-(1.97+0.30\,C_1+0.62\,C_2-0.89\,C_3+0.97\,C_4)}}$$

Coefficients		Standard error	Z value	p-value
a	1.97	0.48	4.09	4.38E-07***
b_1	0.30	0.30	1.01	0.313
b_2	0.62	0.35	1.77	0.076*
b_3	-0.89	0.45	-2.00	0.046**
b_4	0.97	0.49	1.99	0.046**

Significant variables for:
*** p<0.01; ** p<0.05; * p<0.1

Not significant variable for 90% confidence interval

Goodness-of-fit:

The number of cases correctly predicted was 76 (86.4%).

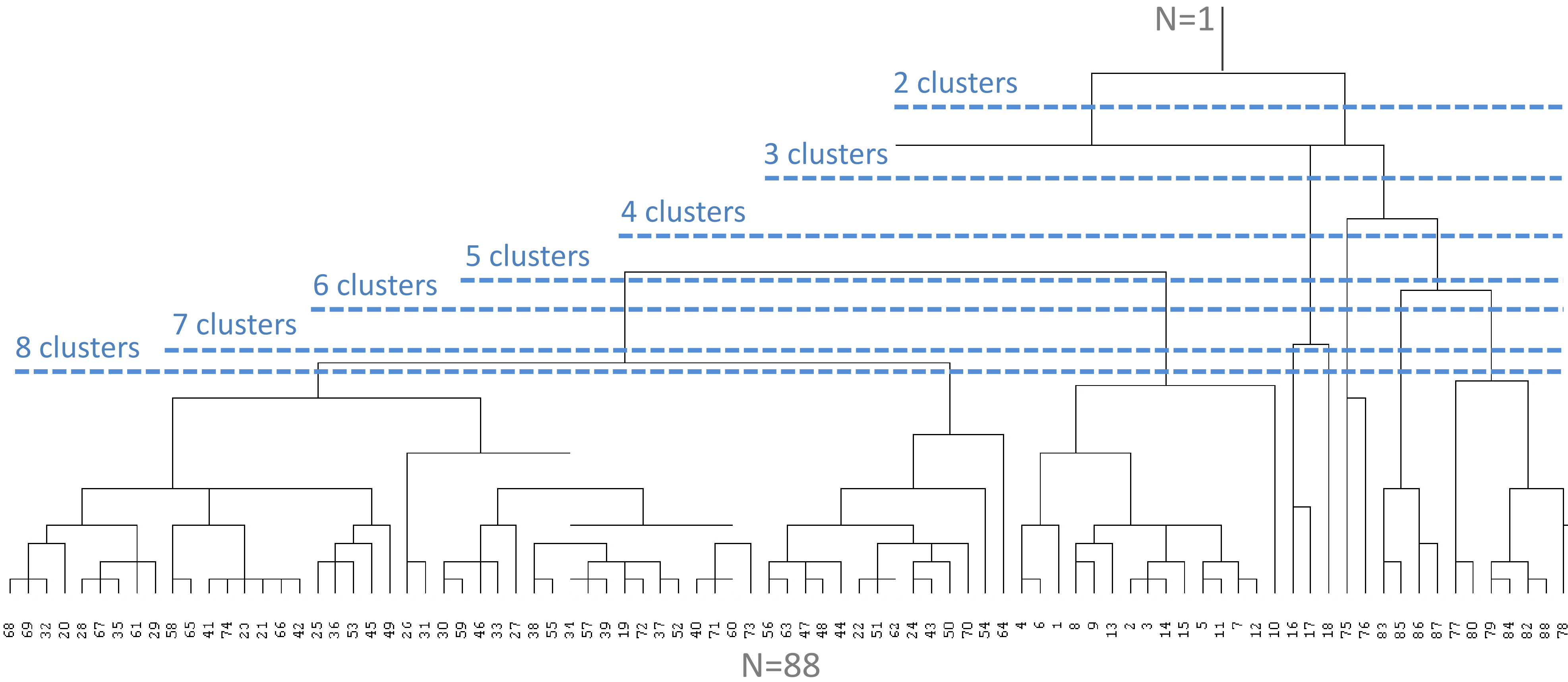
Also, the McFadden's R^2 was 0.293 above the minimum value of 0.28 (for a proportion of 80/20 in the answers of the dependent variable)

Obtained odd ratios for the independent variables considered

Independent variables	C_1	C_2	C_3	C_4
Odd ratio (e^{bi})	NS	1.9	0.4	2.6

The *odd ratio* can be understood as the number of times that the probability of occurrence P (Y = 1) increases when the independent variable increases one unit.

[d] *Dendogram for hierarchical cluster analysis*

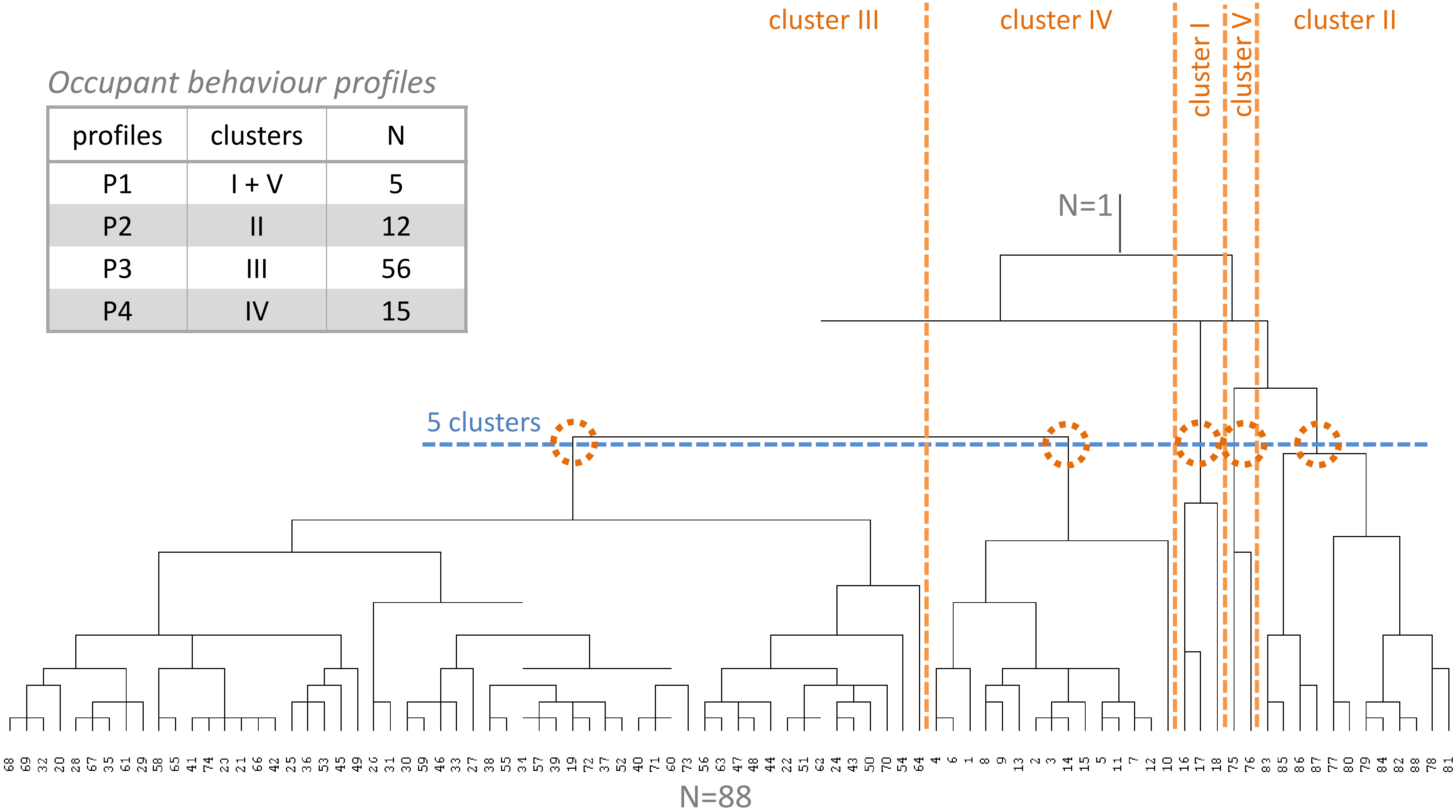


Definition of occupant behaviour patterns by means of a cluster analysis

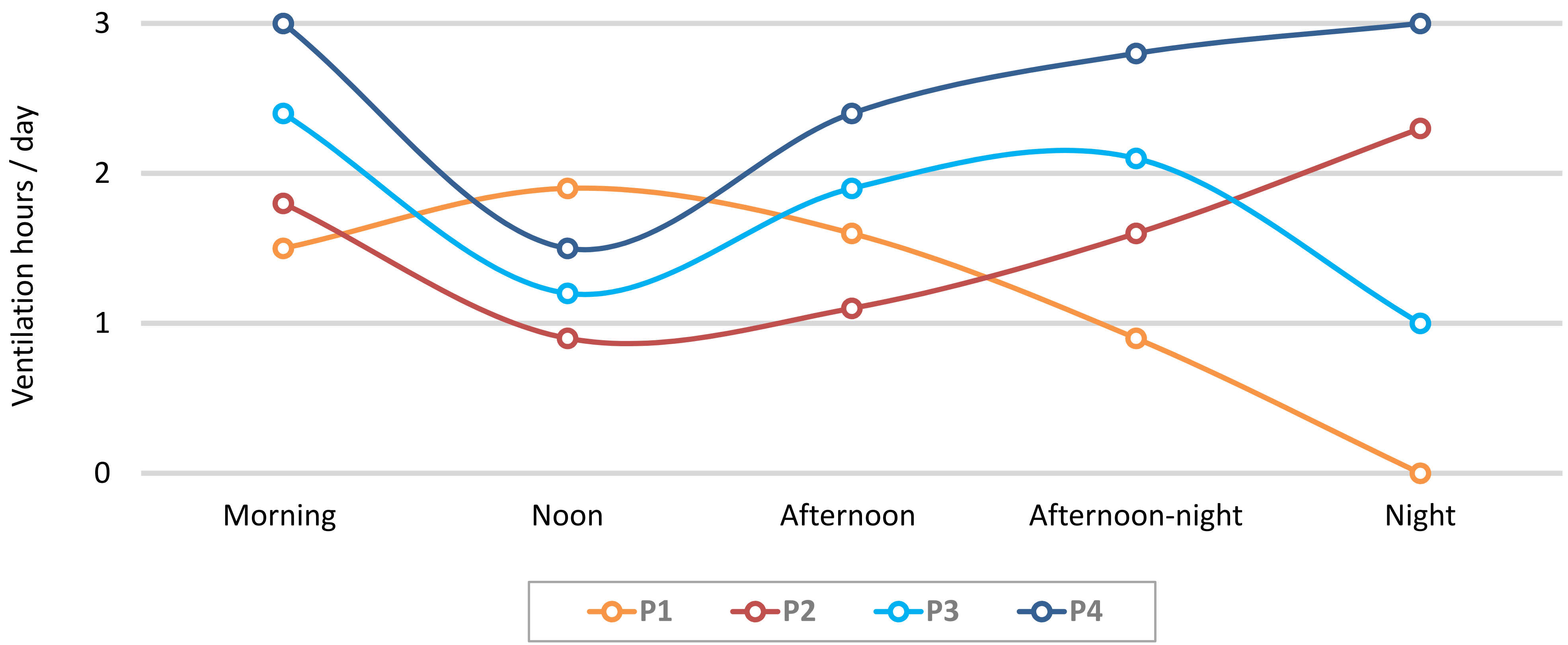
[d] *Dendogram for hierarchical cluster analysis*

Occupant behaviour profiles

profiles	clusters	N
P1	I + V	5
P2	II	12
P3	III	56
P4	IV	15

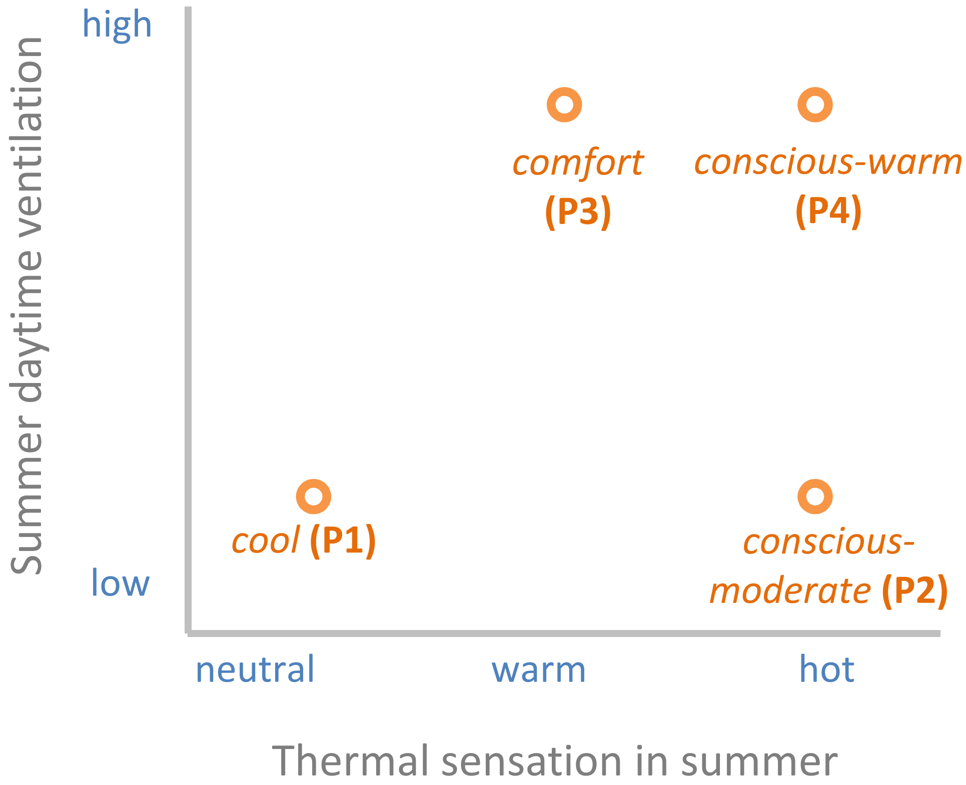


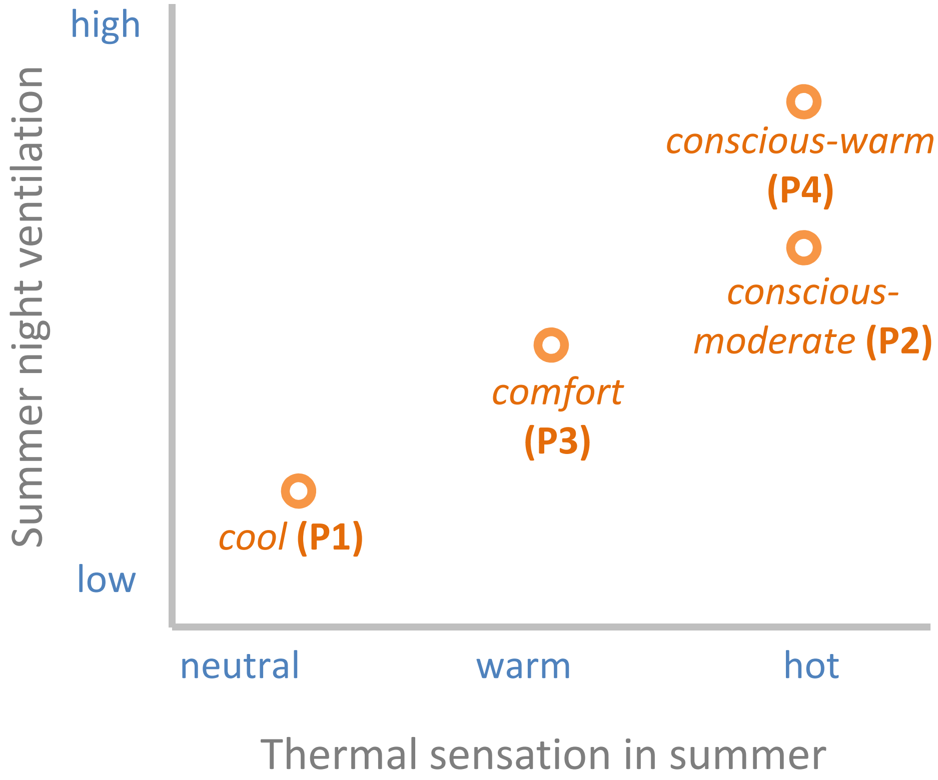
[d] *Quantitative characterization of profiles in terms of number of ventilation hours (by means of manually operable windows) per day in summer (mean values)*



Note: 3-hours periods are defined as morning (9:00-12:00), noon (12:00-15:00), afternoon (15:00-18:00), afternoon-night (18:00-21:00) and night (21:00-24:00)

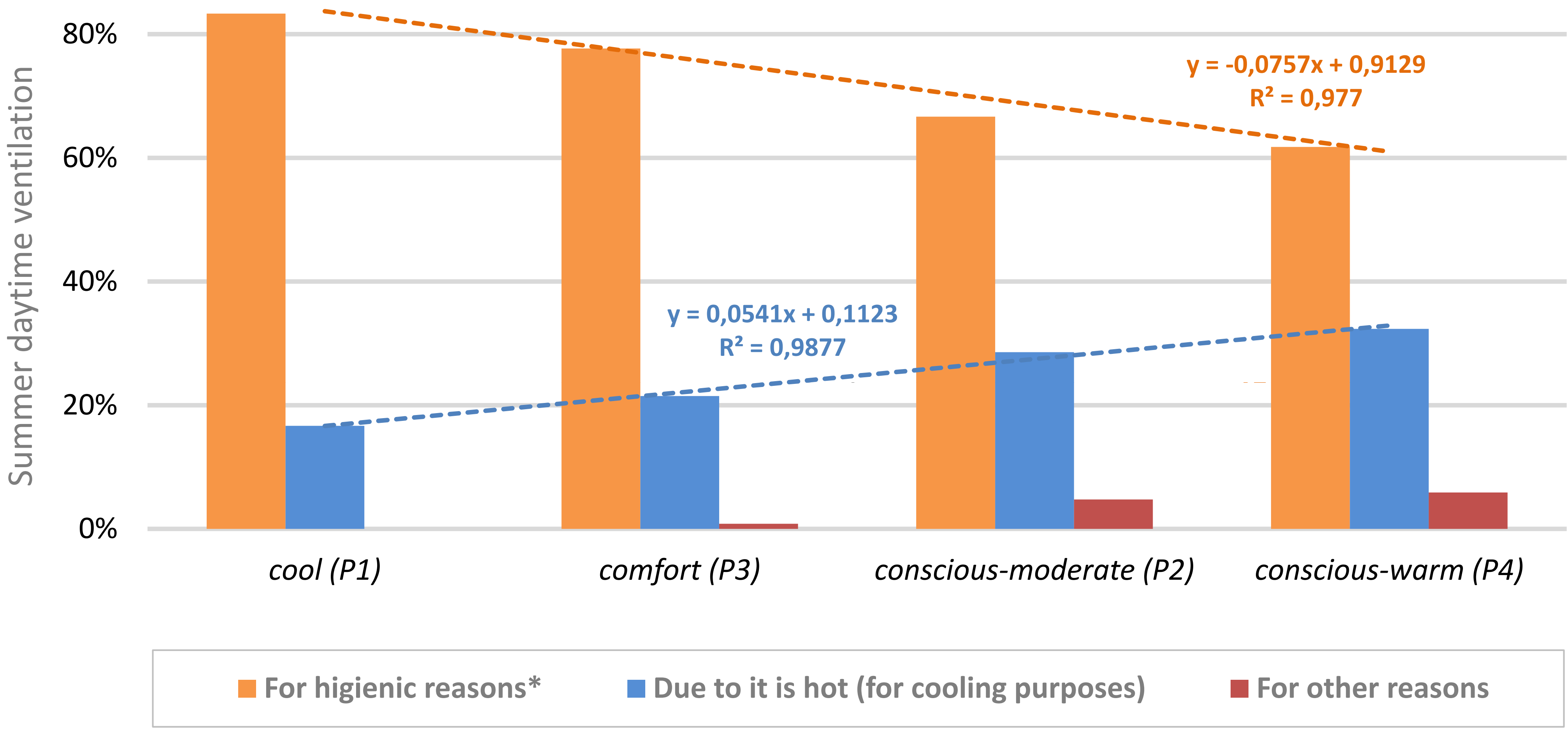
[d] *Qualitative characterization of profiles in terms of thermal sensation in summer vs. summer daytime ventilation (left) and summer night ventilation (right) (median values)*





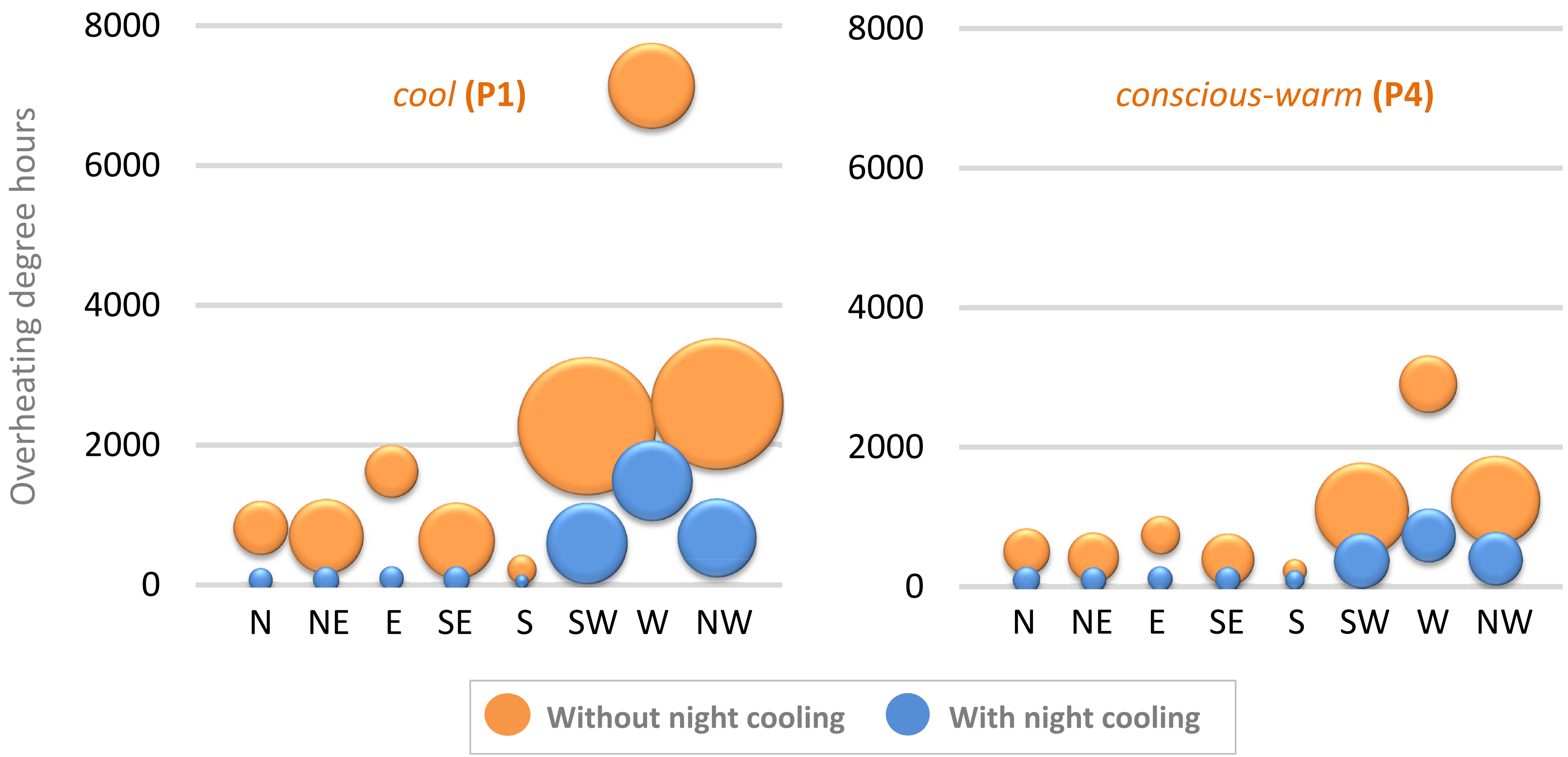
Definition of occupant behaviour patterns by means of a cluster analysis

[d] *Column chart of results for the question Q22 (percent with regard to the total number of mentions): "Which are the reasons for opening windows in your apartment in summer?" by behaviour profiles*



* Corresponding to the answers of the survey: "for entering fresh air" and "while the rooms are cleaned"

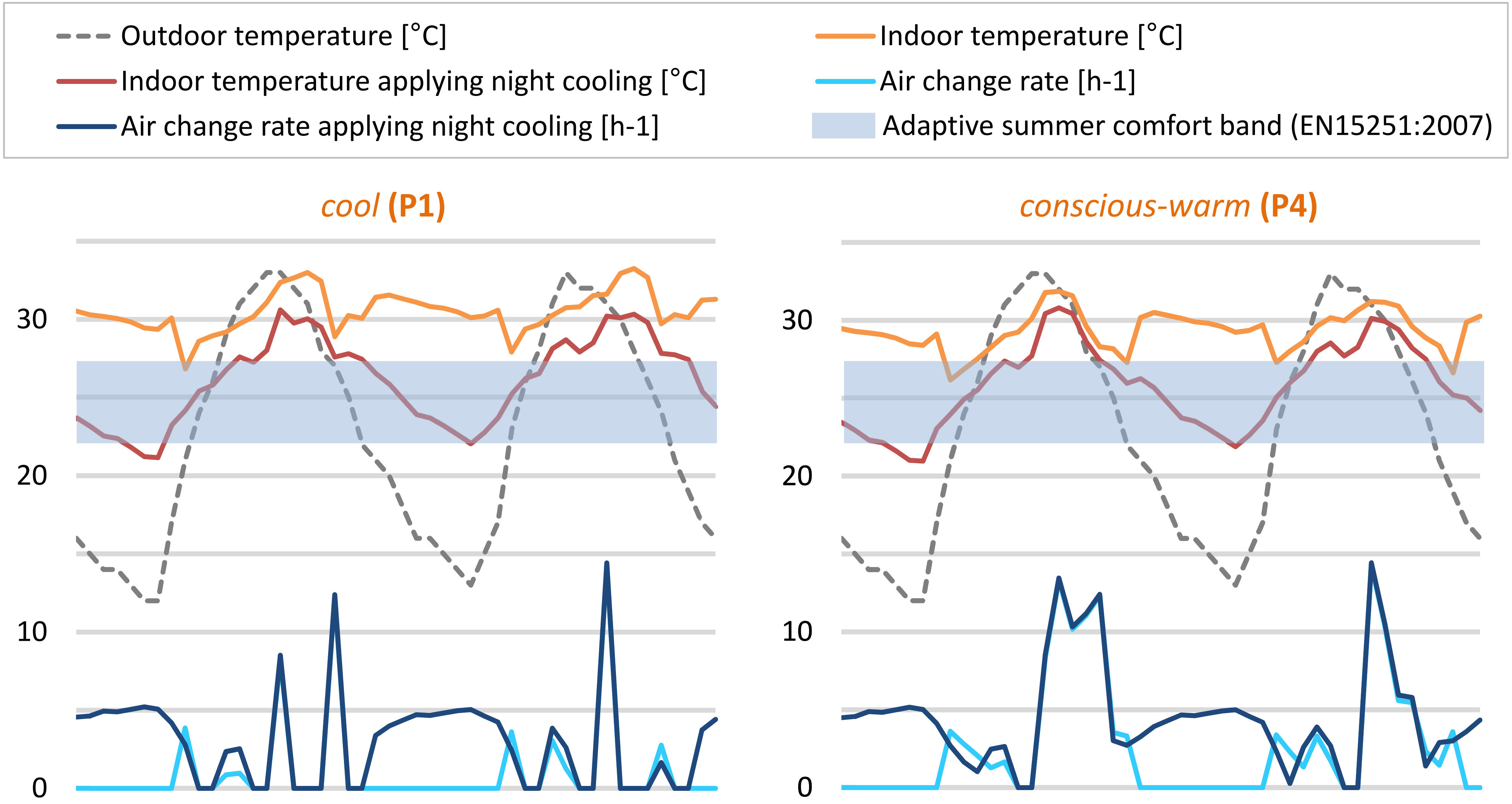
[e] *Bubble plots for overheating degree hours in summer according to the adaptive comfort model of the EN 15251 for* ***cool*** **(P1)** *and* ***conscious-warm*** **(P4)** *profiles by orientation*



Note: The centre point of each bubble is the extent of overeating measured in degree hours (mean value).
The area of the bubble represents the standard deviation for the distribution of values including the same rooms.

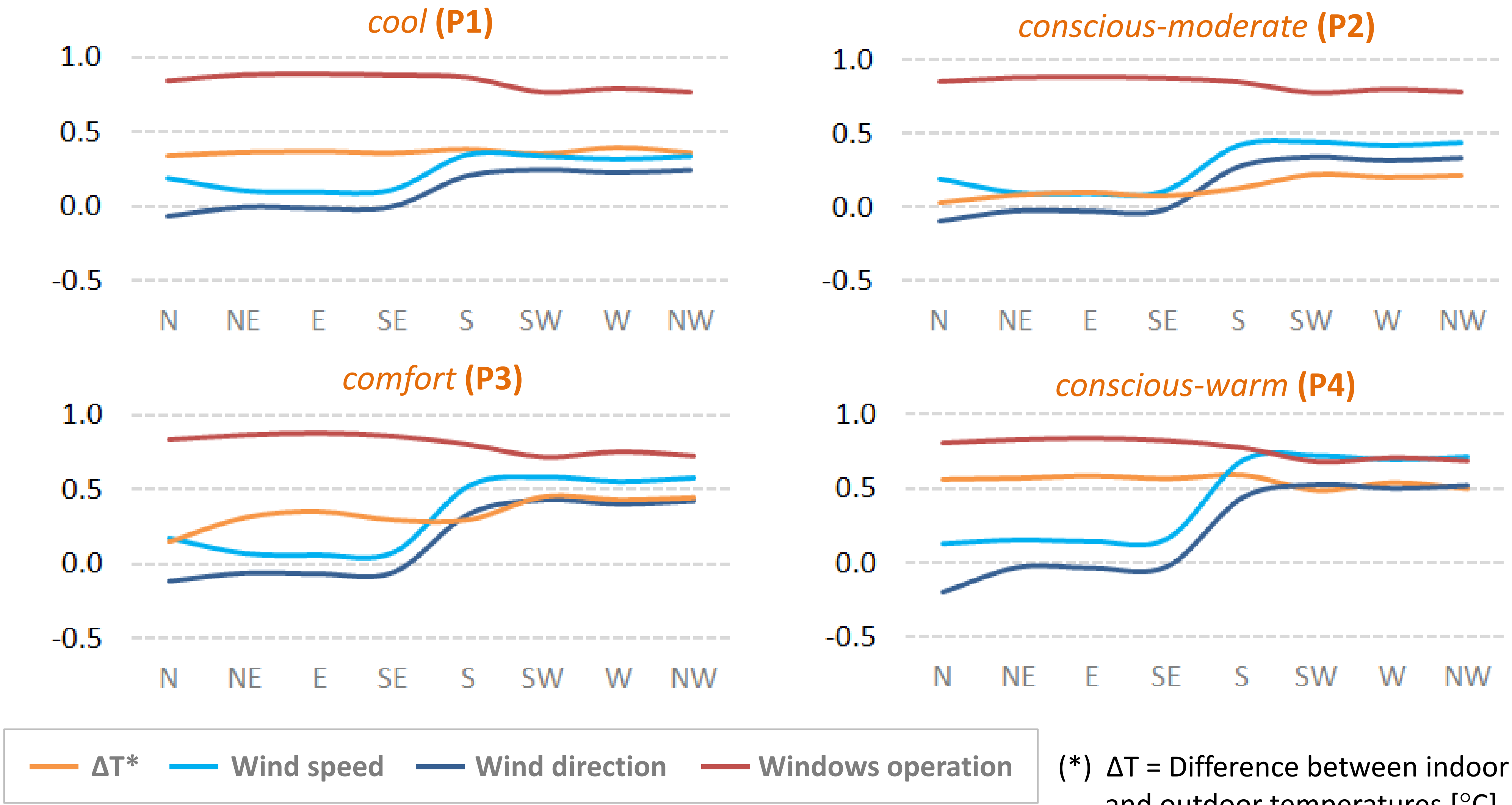
Assessment of the summer thermal comfort applying the behaviour profiles

[e] *Curves of temperature [°C] and air change rate [h^{-1}] in two summer days for the main bedroom of the western apartment for* ***warm*** **(P1)** *and* ***conscious-cool*** **(P4)** profiles



Sensitivity analysis of physical parameters with respect to ventilation rate

[f] Rank correlation coefficients for different parameters in all profiles with respect to ventilation rate [h^{-1}] in the main bedroom per orientation



(*) ΔT = Difference between indoor and outdoor temperatures [°C]

[1] *Role of ventilation in the thermal sensation of the occupants*

Explanatory analysis

Principal Component Analysis

Discrete choice model

- Daytime ventilation → hygienic purposes
- Night ventilation → passive cooling

[Established the relative importance of the different variables that determine the perception of thermal comfort]

Explanatory analysis

Principal Component Analysis

Discrete choice model

[2] *Definition of occupant behaviour patterns with respect to the perception of thermal comfort and ventilation.*

- Daytime ventilation → hygienic purposes
- Night ventilation → passive cooling

Cluster Analysis

- *cool* (P1)
- *conscious-moderate* (P2)
- *comfort* (P3)
- *conscious-warm* (P4)

[3] *Assessment of the summer thermal comfort regarding occupant behaviour patterns*

Energy building simulations ← **Cluster Analysis**

- *cool* (P1)
- *conscious-moderate* (P2)
- *comfort* (P3)
- *conscious-warm* (P4)

It was observed as these different occupant behaviour patterns lead to significant differences with respect to the summer overheating degree hours

[5] *Windows operation, difference between indoor and outdoor temperatures, wind speed and wind direction were established as sensitive parameters with respect to ventilation rate by means of a sensitivity analysis*

[4] *Night ventilation presents a high potential as passive cooling technique, considering also the climatic conditions of Santiago*

[3] *Assessment of the summer thermal comfort regarding occupant behaviour patterns*

Energy building simulations ← Cluster Analysis

- *cool* (P1)
- *conscious-moderate* (P2)
- *comfort* (P3)
- *conscious-warm* (P4)

Towards a multidimensional segmentation of the real estate market of apartments in Santiago de Chile:

A probabilistic approach from the energy building simulation

Photo: F. Encinas

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