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# Dynamic evaluation method for assessing households' thermal sensation using parametric statistical analysis: A longitudinal field study in the South-eastern Mediterranean climate


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University of East London

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5. Conclusions: Roadmap to the development of ASHRAE Thermal comfort database II
6. Outputs: Publications and Contribution to global research databases

# Overview:

## **Research context:** Case study location and Archetype housing stock

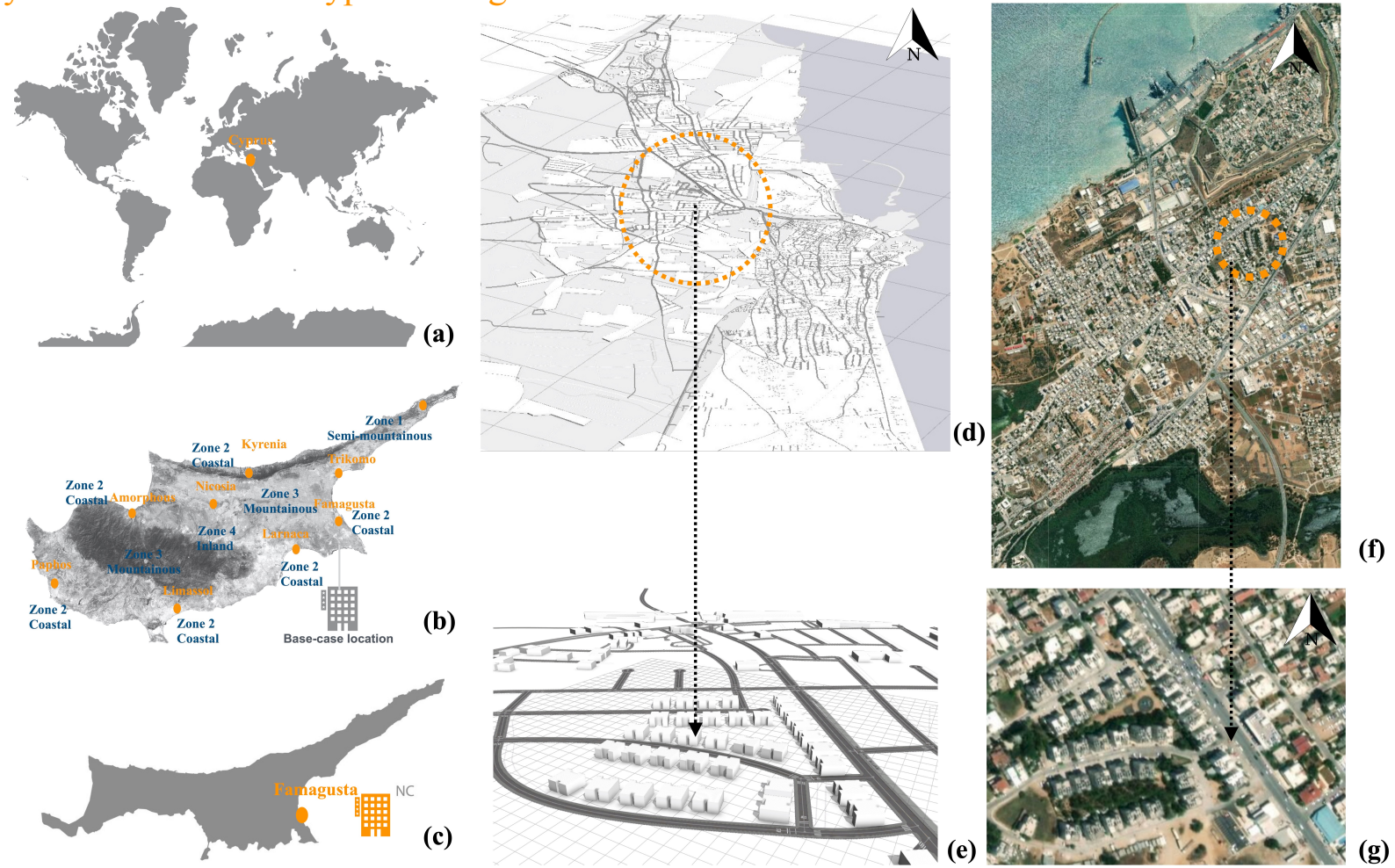
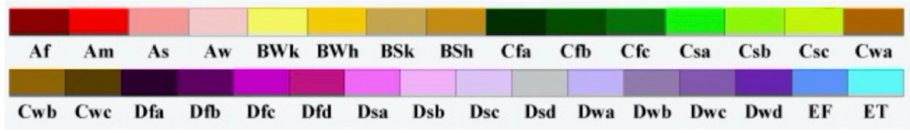



**Figure 1:** **(a)** Cyprus geographic position and **(b)** geological characteristics; **(c)** Northern Cyprus; **(d)** Famagusta vulnerable neighbourhood, **(e)** 3D model of medium-rise RTBs and **(f)** residential area urban tissue; **(g)** base-case morphology characteristics.

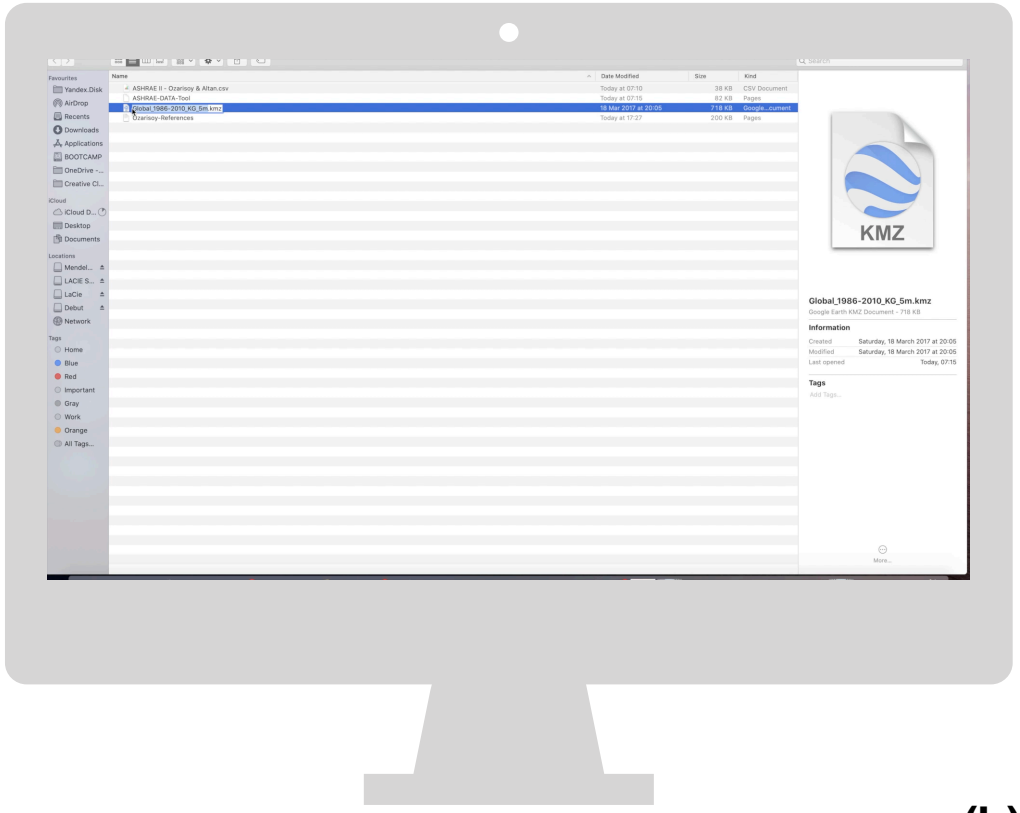
# Overview: South-eastern Mediterranean climate

**Climate:** South-eastern Mediterranean basin


**World Köppen - Geiger climate map**

Cyprus: Csa - warm temperate - subtropical - hot summer Mediterranean
Famagusta coastline region: Bsh - arid - subtropical - hot arid



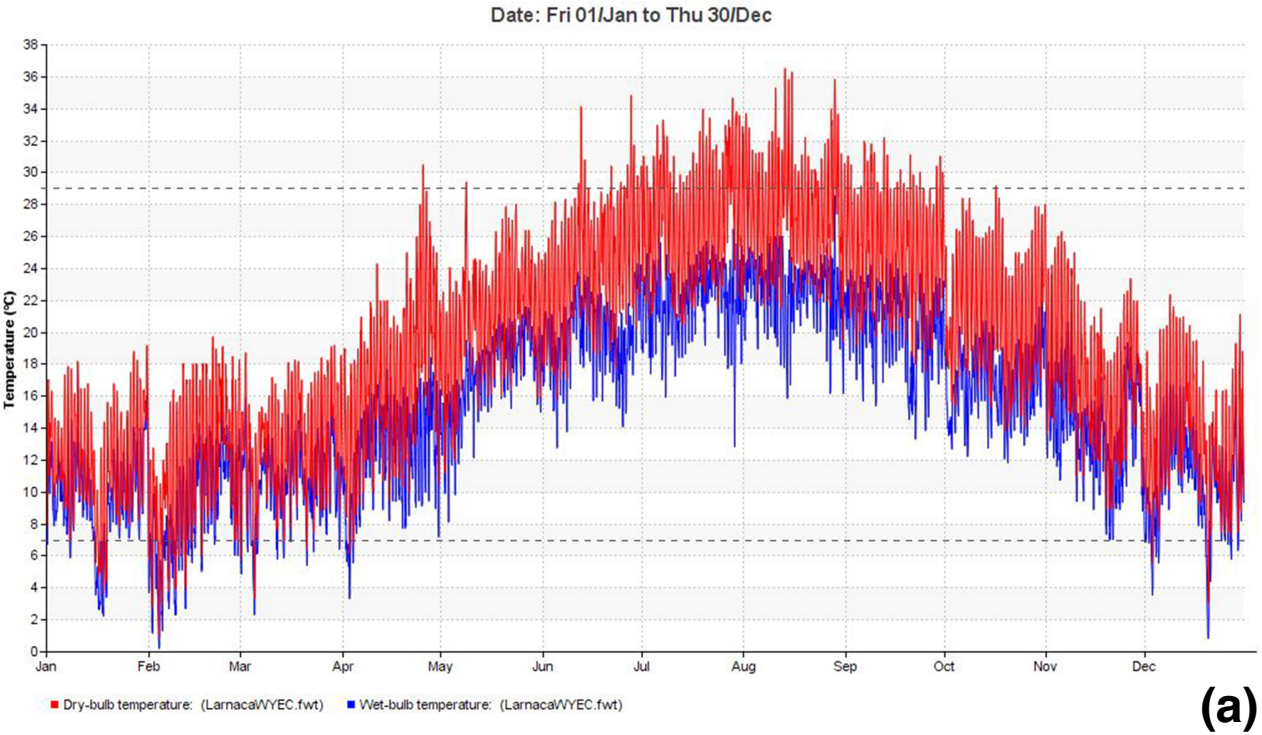

**(a)** **(b)**

**Figure 2: (a)** The map of Köppen-Geiger climate classification in the Mediterranean region; **(b)** Integration of raw dataset files into Google Earth Pro software suite to demonstrate the World climate classification.

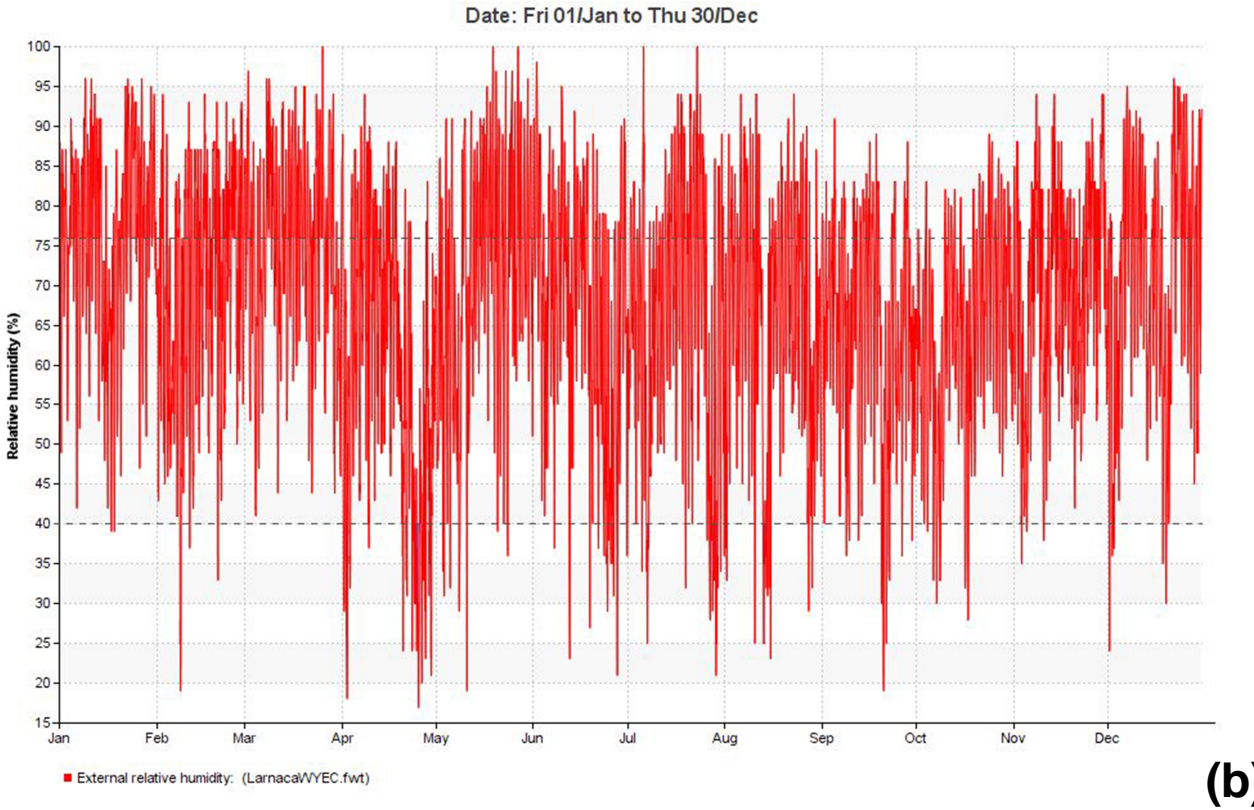
***Source:*** Rubel et al., (2017) - Interactive mapping of world-climate data accessed at http://koeppen-geiger.vu-wien.ac.at (April 14, 2021)

# Overview: Climate characteristics of Cyprus

**Local climate parameters:** Temperature, Relative Humidity Index, Solar radiation and Solar irradiance




(a)




(b)

**Figure 3:** Environmental conditions of case study location: **(a)** Average hourly air temperature fluctuations **(b)** relative humidity fluctuations; ***Sources: (a)-(b)*** Integrated Environmental Solutions (IES) software suite version 2021.1.0. ***(c)-(d)*** Meteonorm version 8; software suite developed by Meteotest AG in 2020 (Germany).

# Overview: Residential-building stock characteristics - II

## Classification of high-density social housing estates in Cyprus: Demand on high-, medium- and low- rise residential tower blocks

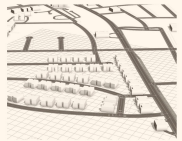
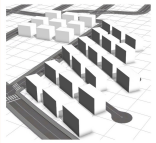
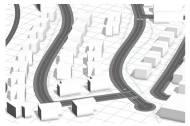
| | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 |
|---|---|---|---|---|---|
| A - Construction period | 1950-1974 | 1980-1997 | 1997-2002 | 2002-2004 | 2005 - Today |
| B - Urban context | Free standing | Free standing | Free standing | Detached | Free standing |
| C - Roof potential | Flat roof | Flat roof | Flat roof | Sloped / Flat roof | Flat roof |
| D - Façade potential | High-rise | 4 or 5 floors | 4 or 5 floors | 1 or 5 floors | High-rise |
| E - Architectural quality Level of protection | Dilapidated | Poor in quality | Poor in quality | Vacant | Poor in quality |
| Categories of residential buildings |  |  |  |  |  |
| Urban tissue | Shoreline | Urban/Suburban | Urban agglomeration | Suburban | Urban (city centres) |
| Typology | High-rise Residential Tower Block | Social housing Middle-income Apartments | Medium-rise Middle-income Apartments | Mass scale Housing estates | High-rise Residential Tower Block |
| Urban block configuration |  |  |  |  |  |

**Figure 4:** National representativeness of high-, medium- and low- rise residential tower blocks (RTBs) in Cyprus.
***Source:*** Data extracted from the State Planning Organisation: https://www.devplan.org/index_en.html (Accessed on 21/01/2021)

# Overview: Housing stock

## National representativeness of housing stock

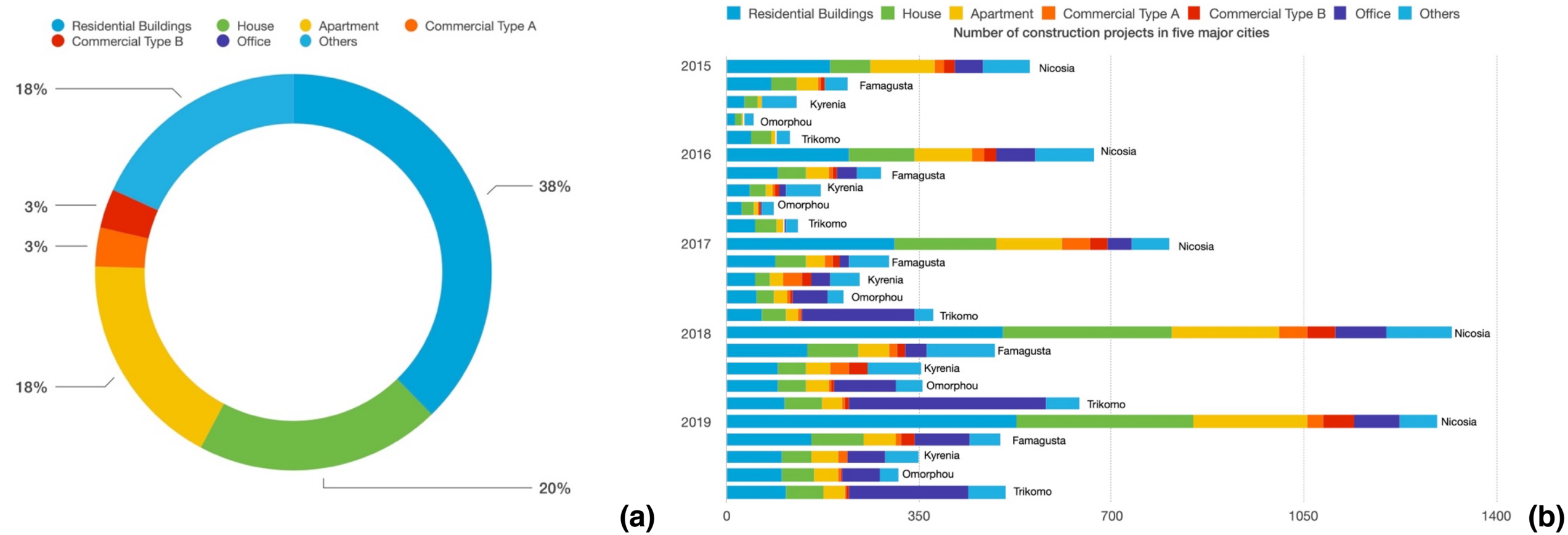



**Figure 5: (a)** Proportional percentages of building types constructed in Famagusta between 2015-2019; **(b)** Number of buildings constructed between 2015-2019 in five major cities: Nicosia, Famagusta, Kyrenia, Omorphou and Trikomo.

***Source:*** Data extracted from the State Planning Organisation: https://www.devplan.org/index_en.html (Accessed on 21/01/2021)

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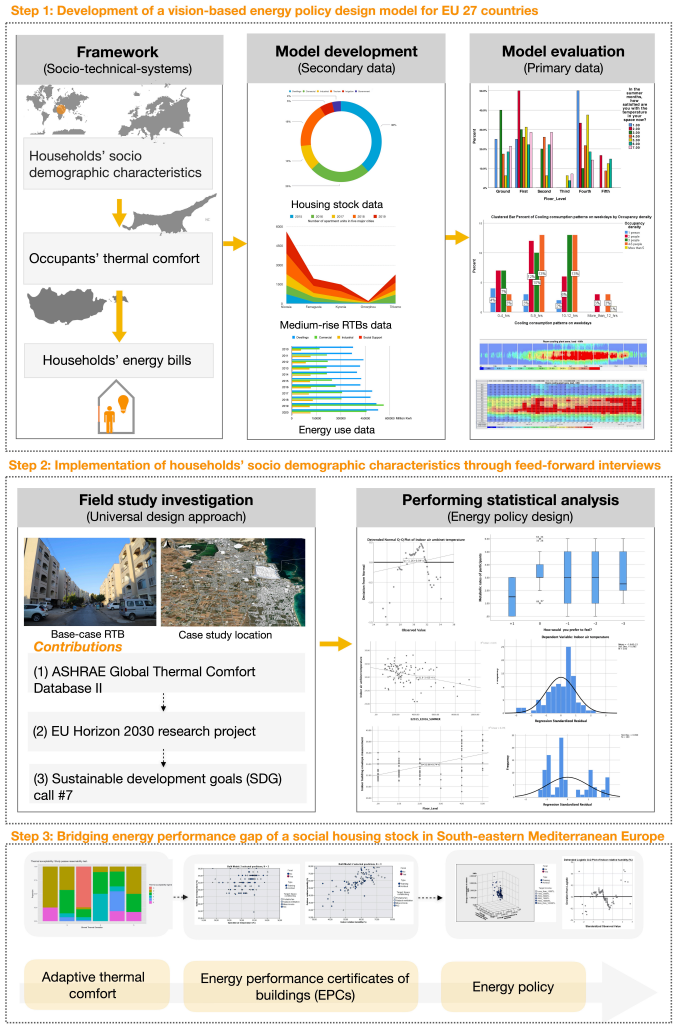
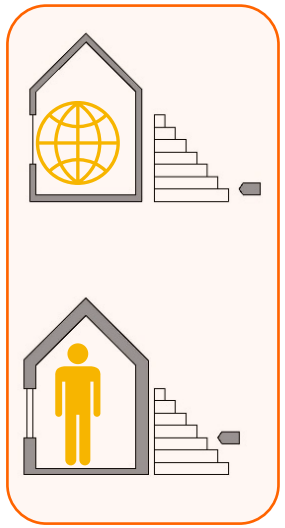
# 1. Introduction: Knowledge gap in energy-policy framework and Retrofitting existing housing stock

## Setting the context: Energy governance in the South-eastern Mediterranean basin




## Aim and Objectives



The main aim of this research is to fill the knowledge gap in the area of an evidence-based framework for energy-policy decision-making mechanisms related to the integration and implementation of the EPBD regulations at the conceptual and national levels.

- To examine the significance of occupancy patterns and habitual adaptive household behaviour on home-energy performance by conducting feed-forward interviews with social-housing occupants.

**Figure 6:** Step-by-step research impact factor and its contributions to knowledge in developing evidence-based energy policy framework, considering households' adaptive thermal comfort.

# 1. Introduction: Contribution to knowledge

## Key research subjects and Contribution to knowledge

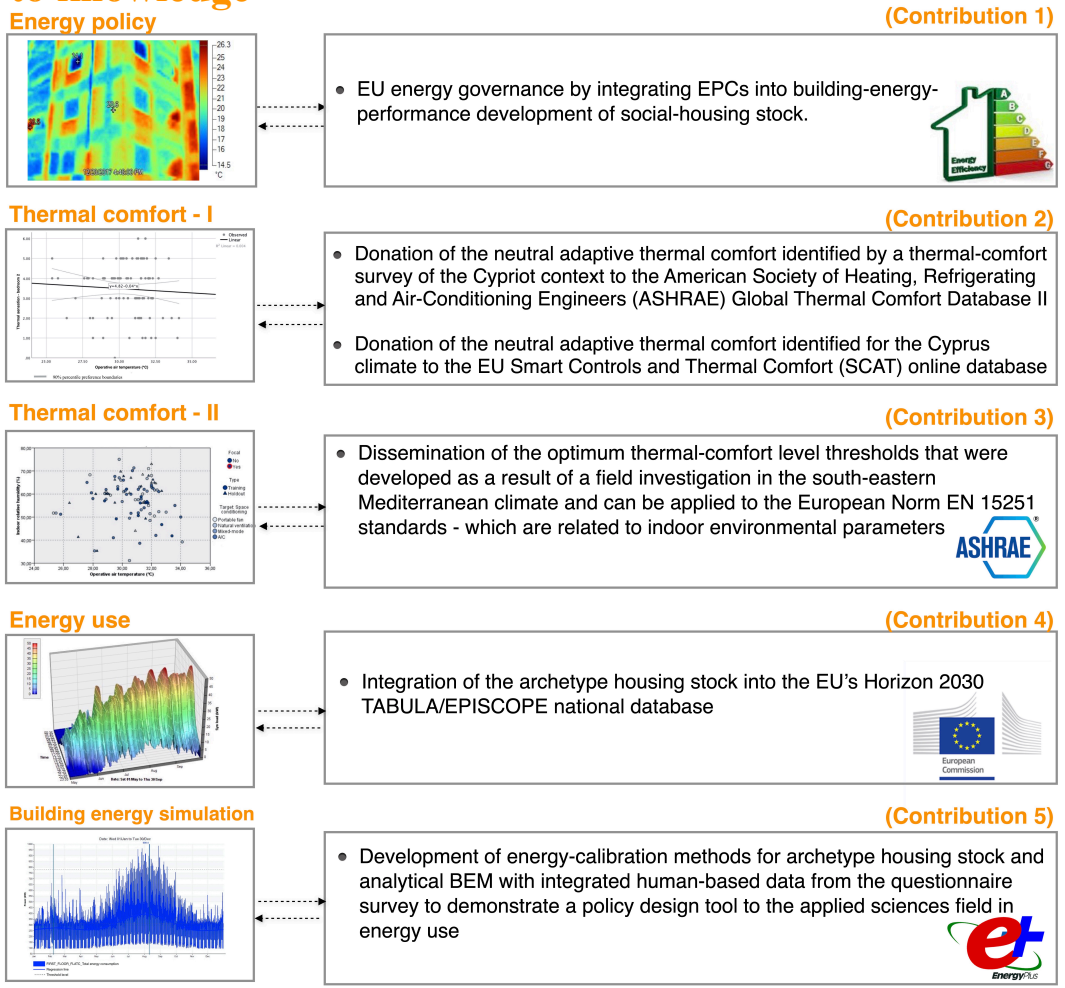
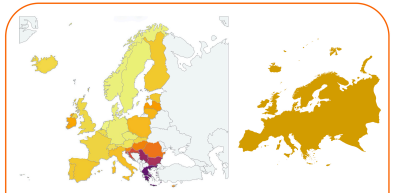



**Figure 7:** The impact of key research areas to the contribution to knowledge.

# 1. Introduction: Novelty of study and implications for energy policy design

**Impact to EU-27 energy policy framework:** Developing an evidence-based retrofitting strategies to assess robust energy-performance evaluation and certification schemes in the South-eastern Mediterranean countries

**Energy governance in Europe and Policy design**



EU and Southeastern Mediterranean basin

Archetype selection criteria

- South-eastern Mediterranean climate of Cyprus where the weather is subtropical (*Csa*) and partly semi-arid (*Bsh*)
- Post-war social housing stock was selected as archetype buildings in four different climatic zones.
- Four climatic zones:

Zone 1 - semi-mountainous
Zone 2 - coastal
Zone 3 - mountainous
Zone 4 - inland

>

**Households' socio-demographic characteristics**

Social housing estates

Residential tower blocks (RTBs)

- To improve the current methods of design by including human behaviour
- To understand the occupants' real life experiences with energy use
- To investigate the significant impact of the buildings' thermal properties on occupants' thermal comfort
- To develop appropriately tailored approaches for energy policy design

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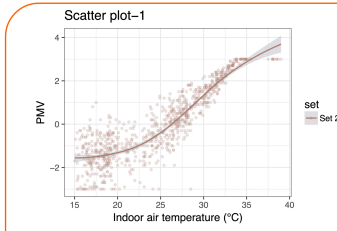
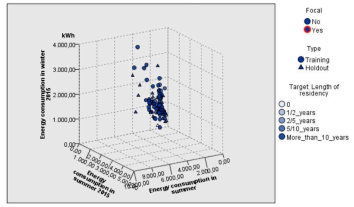
**Energy performance and Occupants' thermal comfort**




Thermal comfort



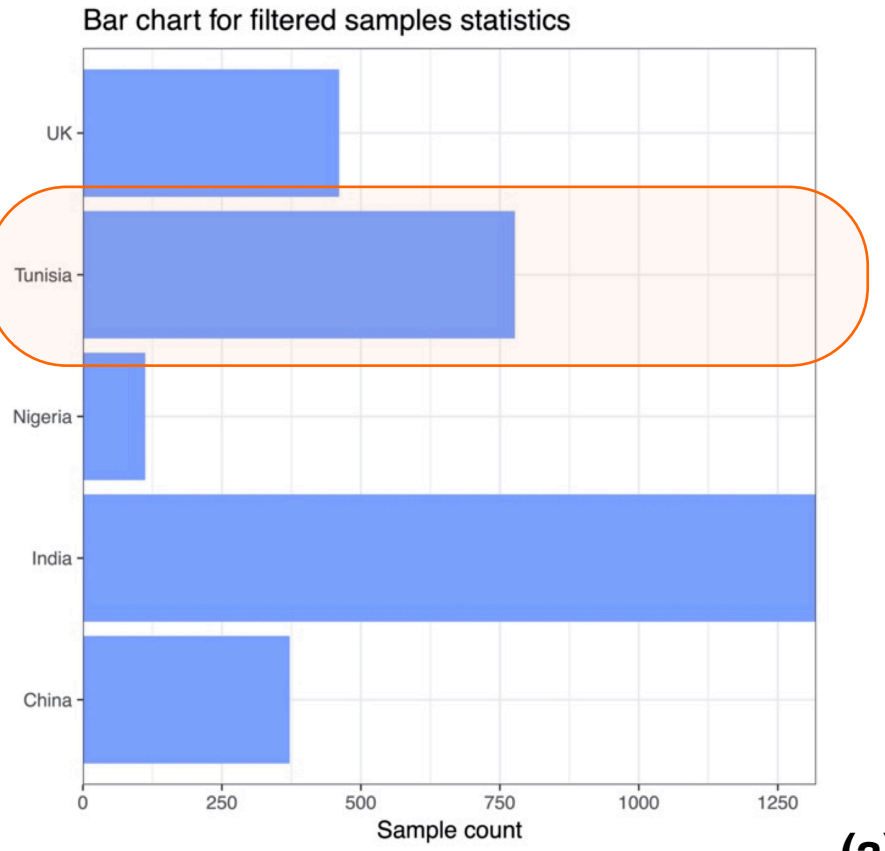
Energy forecasting

- Highlighting the importance of indoor air temperature and identification of thermal comfort levels.
- A base case model developed to inform policy making decisions in energy use.
- In-vivo data collected to improve occupants' health and well-being.
- Energy forecasting plans could be methodologically planned and put into action.

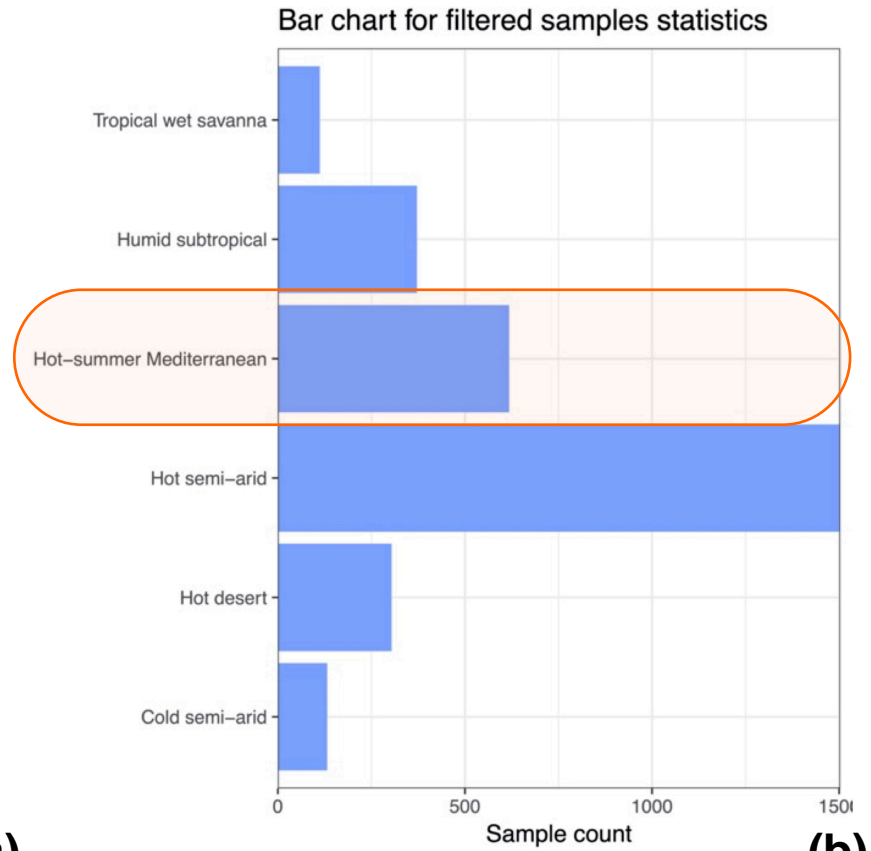
**Figure 8:** Road map to EU energy policy framework by making a contribution to knowledge.

# 2. Systematic Literature Review: ASHRAE Global Thermal Comfort Database II

## Development of the ASHRAE Global Thermal Comfort Database II: Visualisation and Query builder




(a)




(b)

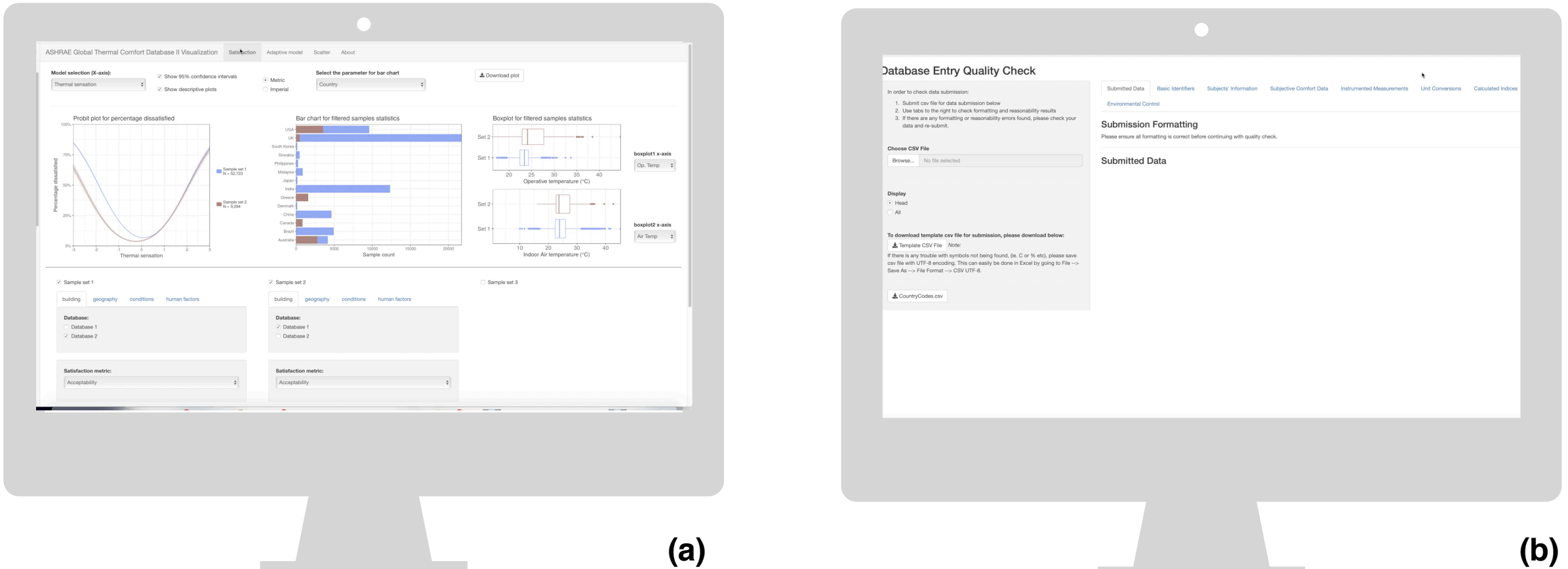
**Figure 9: (a)** Sample adaptive thermal comfort studies by country; **(b)** TSV configuration of field studies by climate type.
***Source:*** Data extracted from thermal comfort visualisation tool; available at https://cbe-berkeley.shinyapps.io/comfortdatabase (Földváry *et al.*, 2018).

Previously available pilot studies:

- Földváry, V., Bekö, G., Langer, S., Arrhenius, K., & Petráš, D. (2017). Effect of energy renovation on indoor air quality in multifamily residential buildings in Slovakia. Building and Environment, 122, 363–372. https://doi.org/10.1016/j.buildenv.2017.06.009
- Bouden, C., & Ghrab, N. (2005). An adaptive thermal comfort model for the Tunisian context: A field study results. Energy and Buildings, 37(9), 952–963. https://doi.org/10.1016/j.enbuild.2004.12.003

# 2. Systematic Literature Review: ASHRAE Global Thermal Comfort Database II

## Development of the ASHRAE Global Thermal Comfort Database II: Visualisation and Query builder




(a) (b)

**Figure 10: (a)** Query builder which was developed to demonstrate global research data for the identification of 'neutral' adaptive thermal comfort; **(b)** Donation of field study investigation data conducted by the researcher to the ASHRAE Global Thermal Comfort Database II.

***Source:*** **(a)** Data extracted from thermal comfort visualisation tool; available at https://cbe-berkeley.shinyapps.io/comfortdatabase (Földváry *et al.*, 2018); (b) Data processed in Query builder dashboard; available at https://databaseqc.shinyapps.io/submission/

# 3. Methodology: Questionnaire survey design and Data acquisition

**Research data triangulation method:** Stages of development to validate questionnaire survey findings

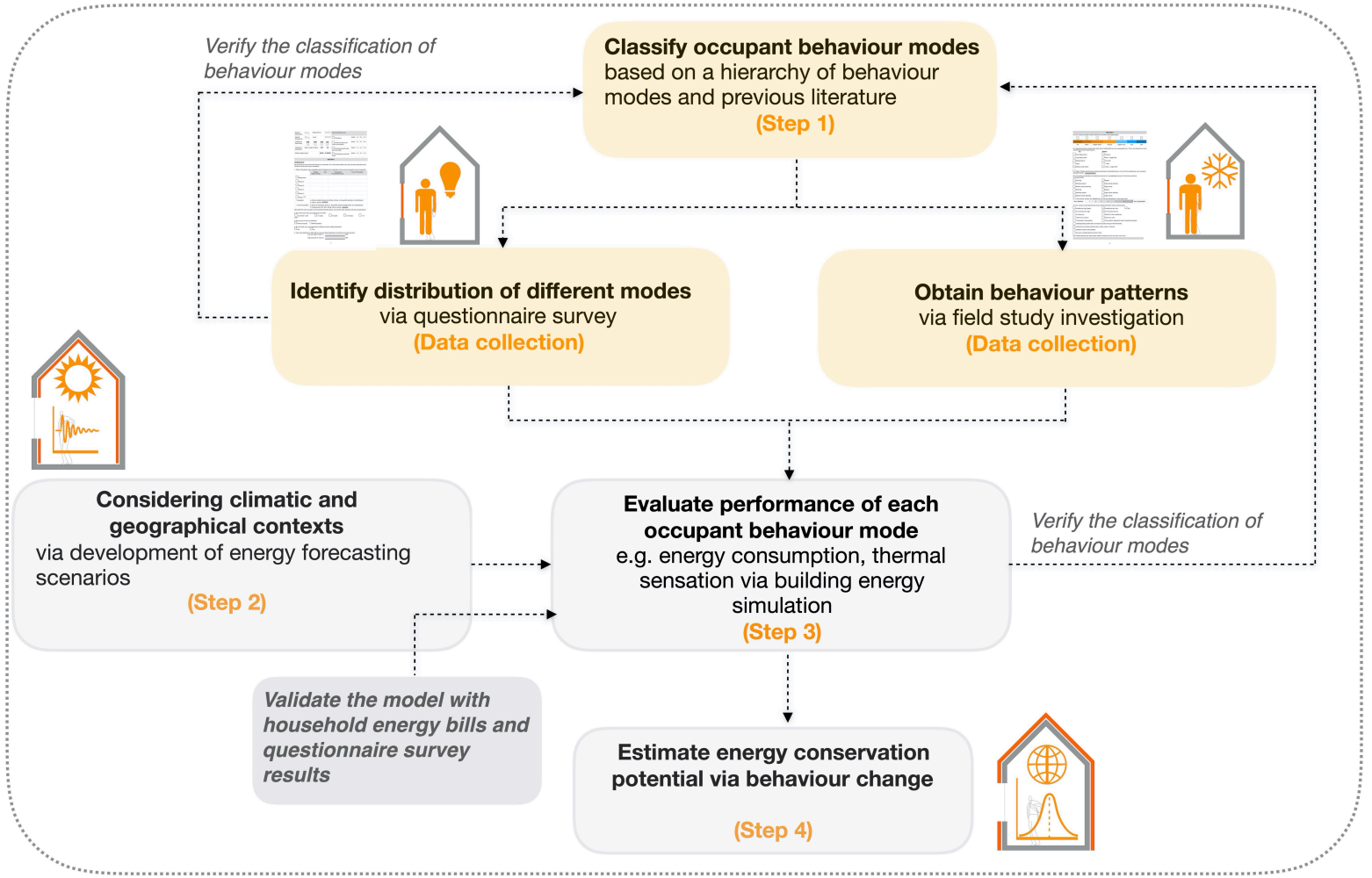



**Figure 11:** Development stages of evidence-based energy policy framework.

# 3. Methodology: Field study investigation to identify 'neutral' adaptive thermal comfort

## Conduct of the survey and field instruments: Physical measurements and Data acquisition

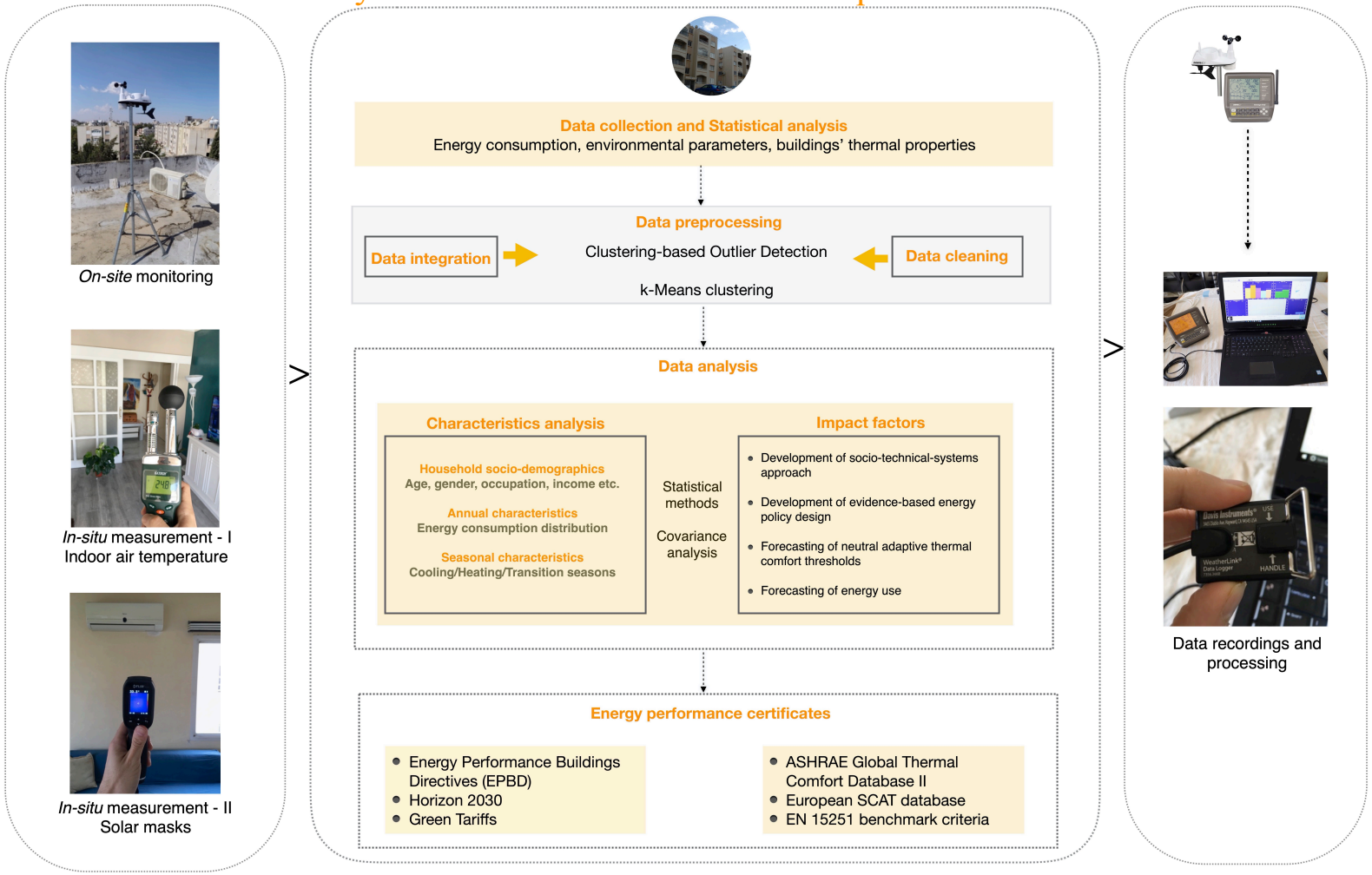



**Figure 12:** The set-up of the field study investigation and data processing.

# 4. Results and Discussions: Regression forecasting of neutral adaptive thermal comfort

## Universal design approach: Contribution to the development of the ASHRAE Global Thermal Comfort Database II

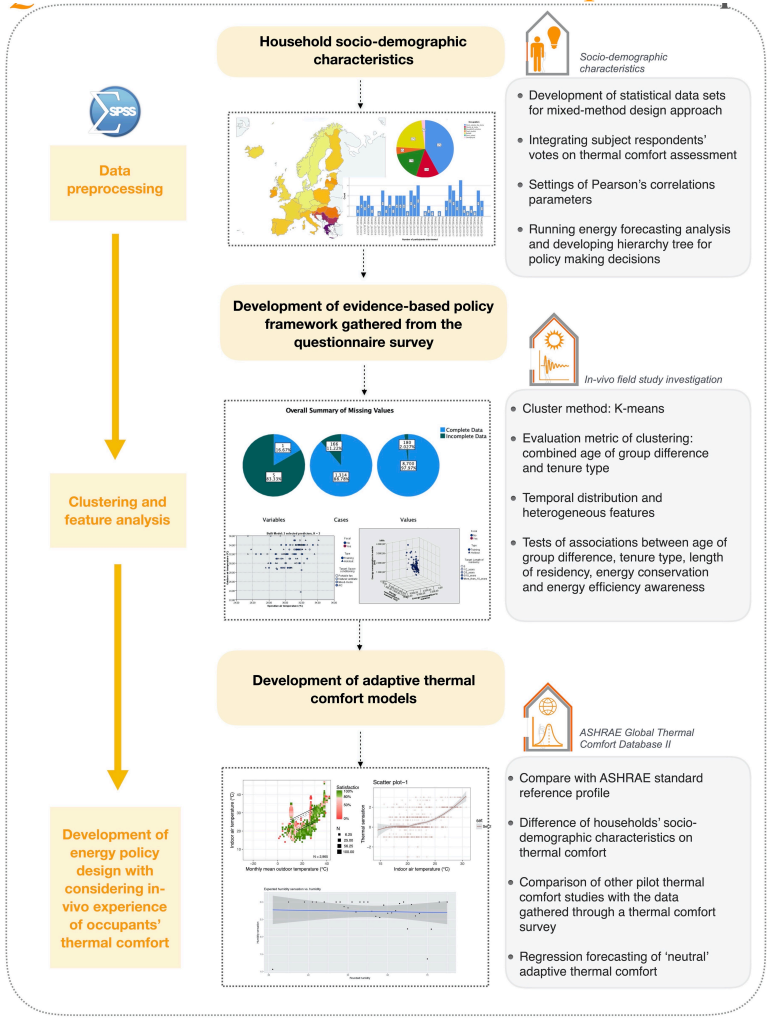



**Figure 13:** The novel methodological workflow developed for the identification of 'neutral' adaptive thermal comfort.


**Figure 14:** *In-situ* measurements recorded while **(a)** wall-mounted A/C system was in use in late afternoon; **(b)** single glazed aluminium-framed window was open in late afternoon; **(c)** double-glazed window was open in early morning (participant was interviewed in balcony); **(d)** internal doors were open in early morning (participant was interviewed in balcony, and portable fan was in use during survey); **(e)** windows were open; and **(f)** inverter A/C system was in use.

# 4. Results and Discussions: Regression forecasting of neutral adaptive thermal comfort

## *On-site* monitoring of environmental conditions to develop benchmarking criterion

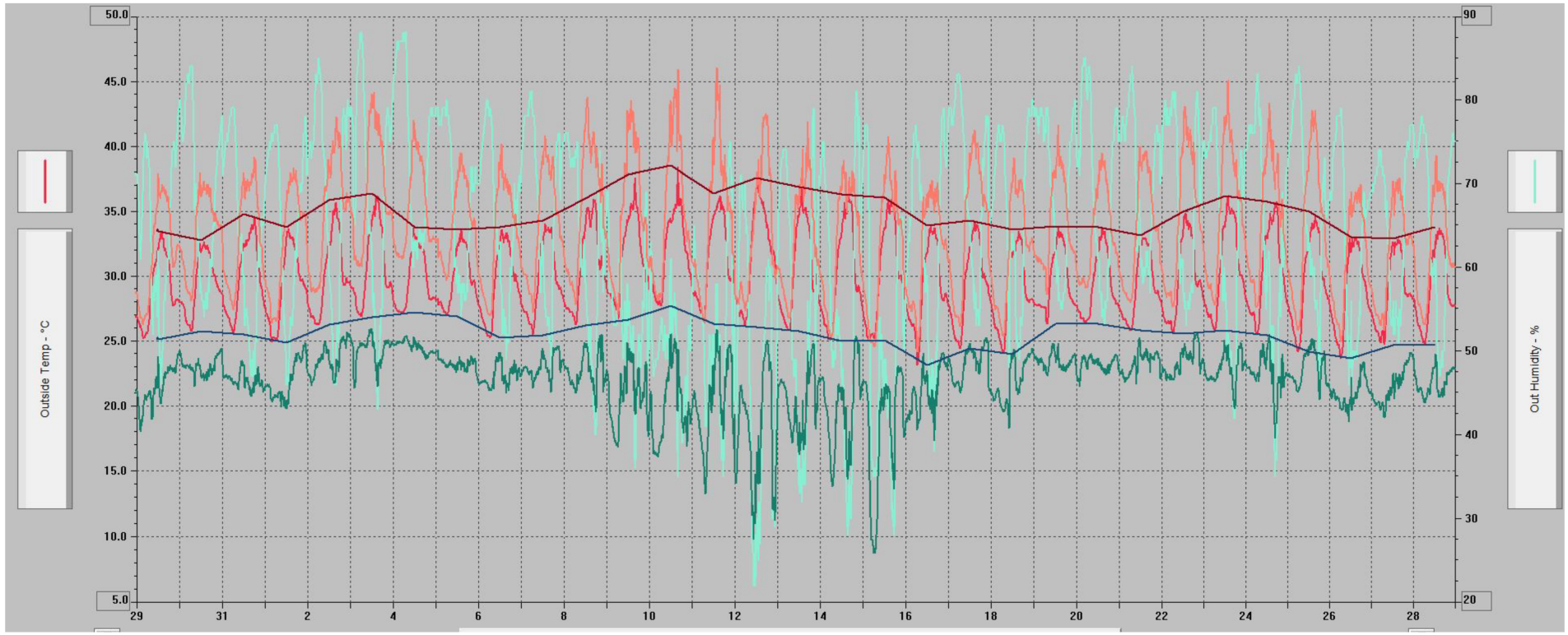



**Figure 15:** *On-site* environmental monitoring readings between July 29 and August 29, 2018.

# 4. Results and Discussions: Regression forecasting of neutral adaptive thermal comfort

## Adaptive Thermal Comfort: Households' socio-demographic characteristics and its impact on adaptive thermal comfort

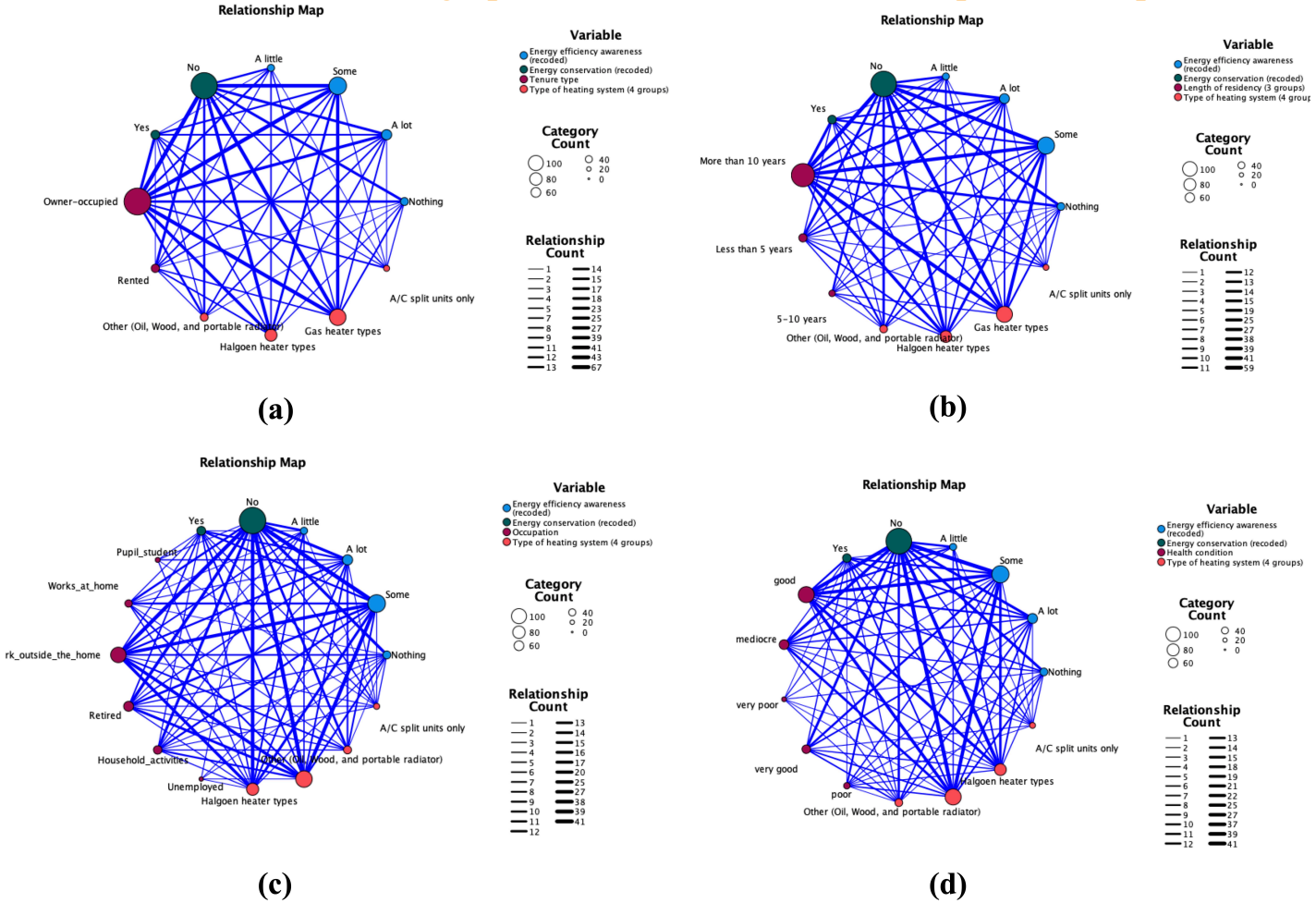
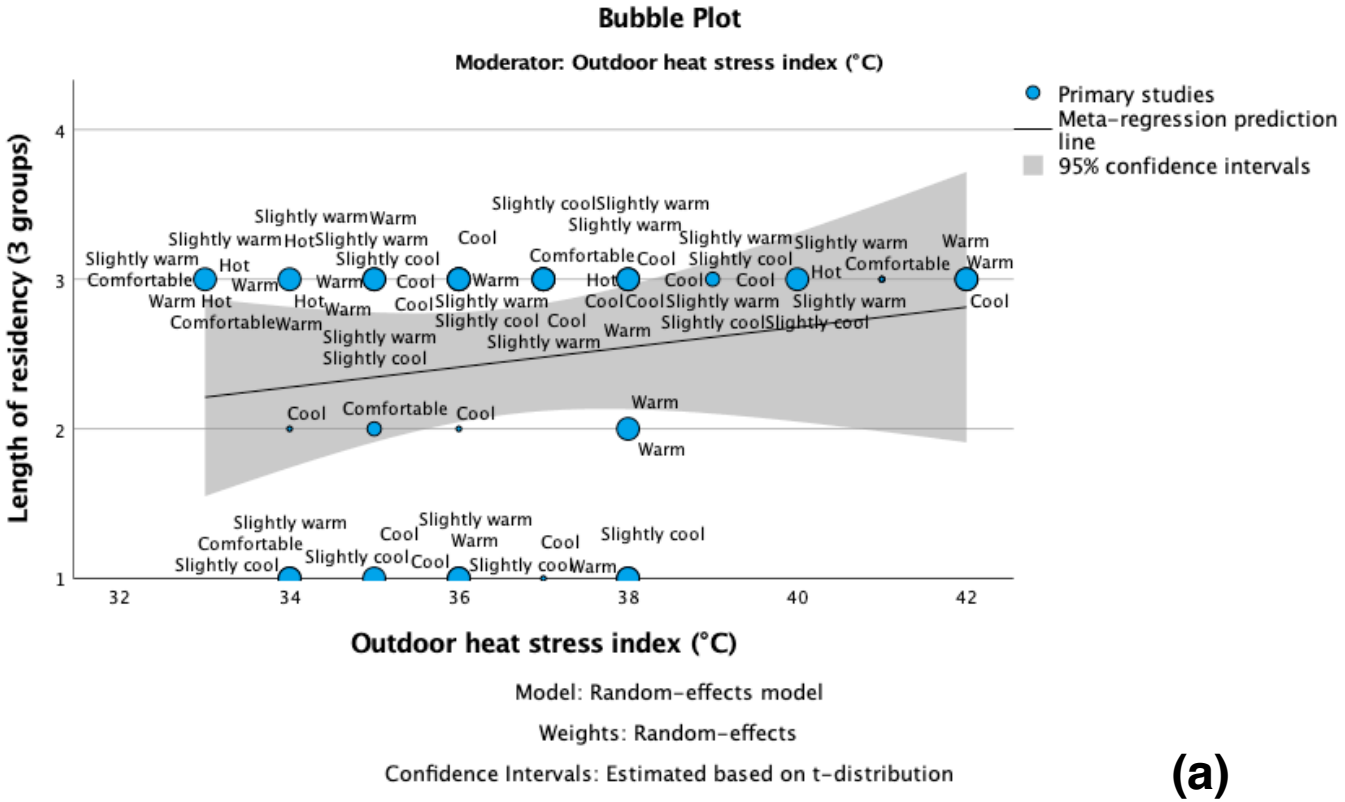


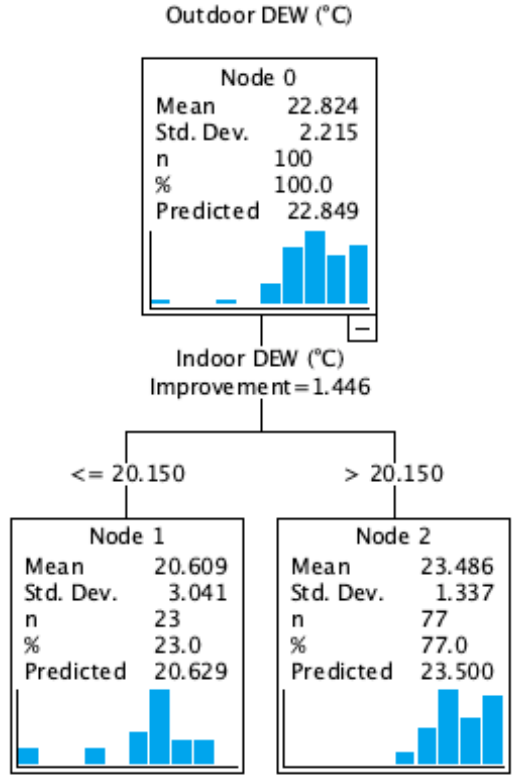

**Figure 16:** Selected socio-demographic characteristics of respondents: **(a)** tenancy status; **(b)** length of residency; **(c)** employment status; **(d)** health condition; **(e)** energy conservation; and **(f)** energy-saving awareness.

# 4. Results and Discussions: Regression forecasting of neutral adaptive thermal comfort

## Adaptive Thermal Comfort: Households' thermal sensation votes versus environmental monitoring parameters - Part 1




(a)

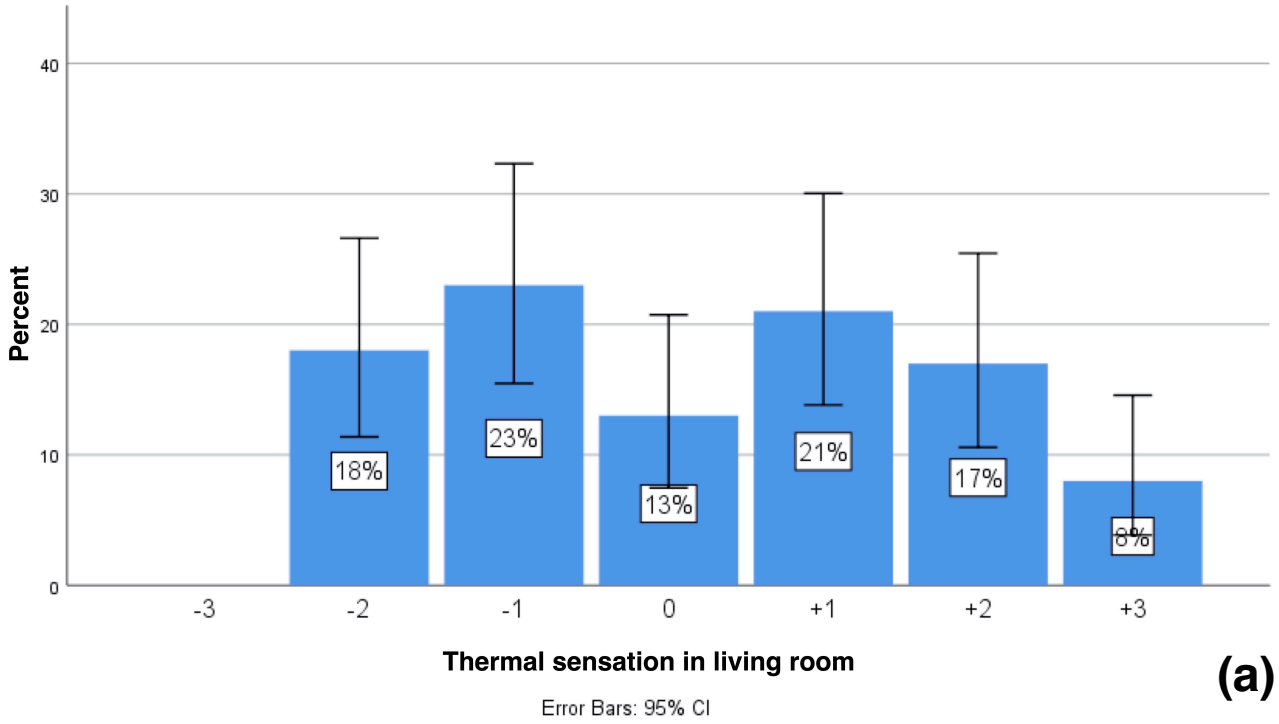



(b)

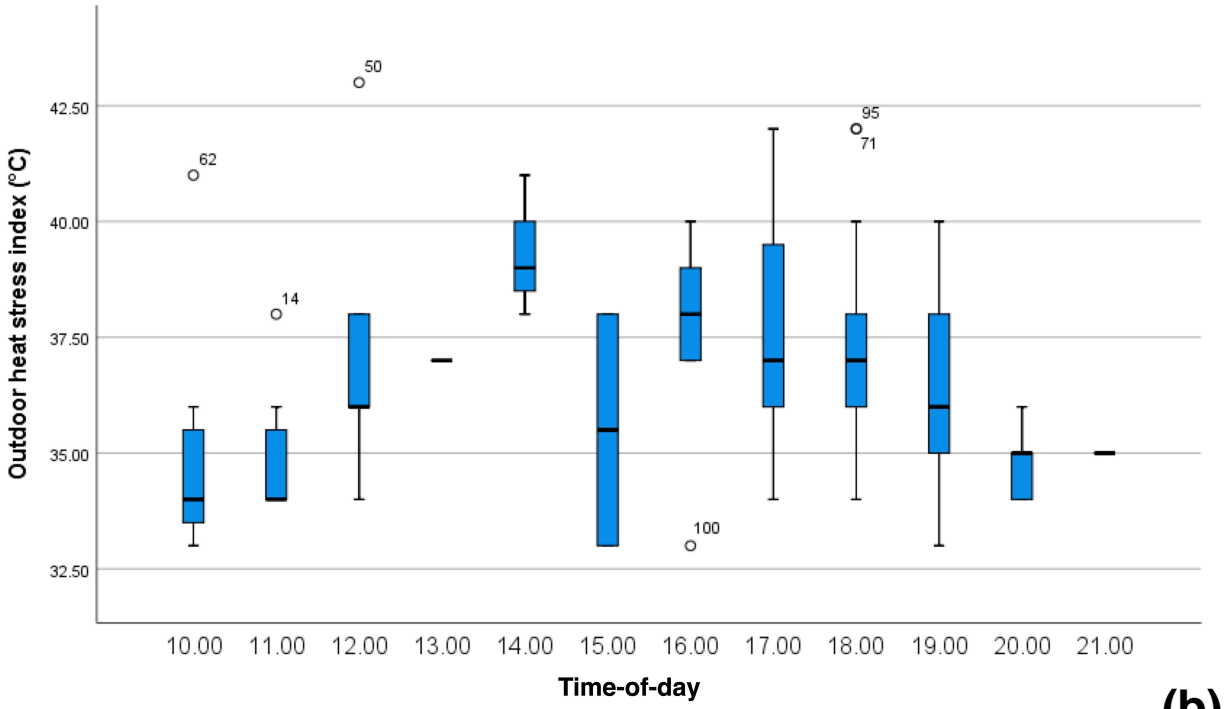
**Figure 17: (a)** Meta analysis between households' length of residency and outdoor heat stress; **(b)** TSV configuration of field studies by environmental monitoring.

# 4. Results and Discussions: Regression forecasting of neutral adaptive thermal comfort

## Adaptive Thermal Comfort: Households' thermal sensation votes versus environmental monitoring parameters - Part 2




(a)

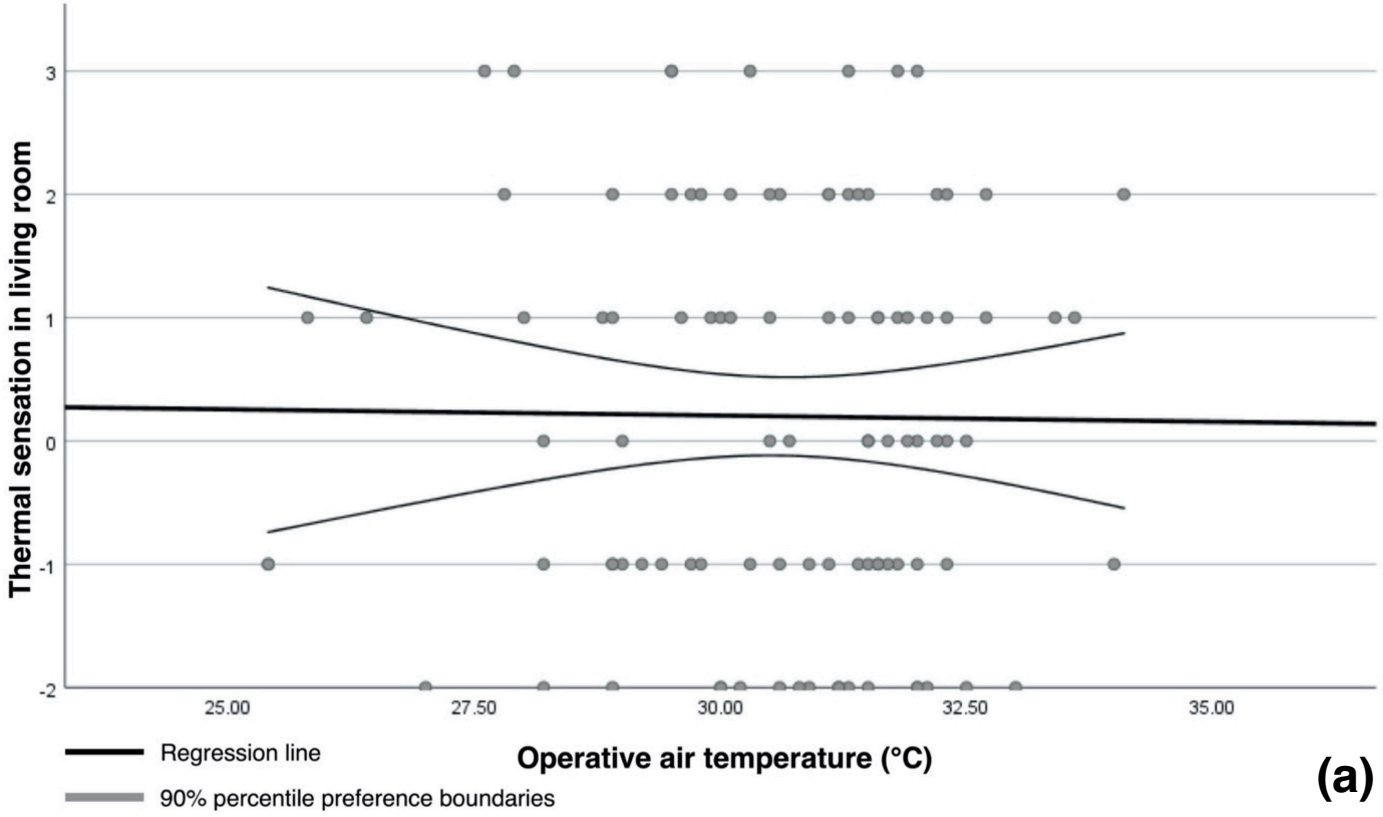



(b)

**Figure 18: (a)** Configuration of households' thermal sensation votes; **(b)** Outdoor heat stress factor by considering time-of-day factor.

# 4. Results and Discussions: Regression forecasting of neutral adaptive thermal comfort

## Adaptive Thermal Comfort: Households' thermal sensation votes versus environmental monitoring parameters - Part 3



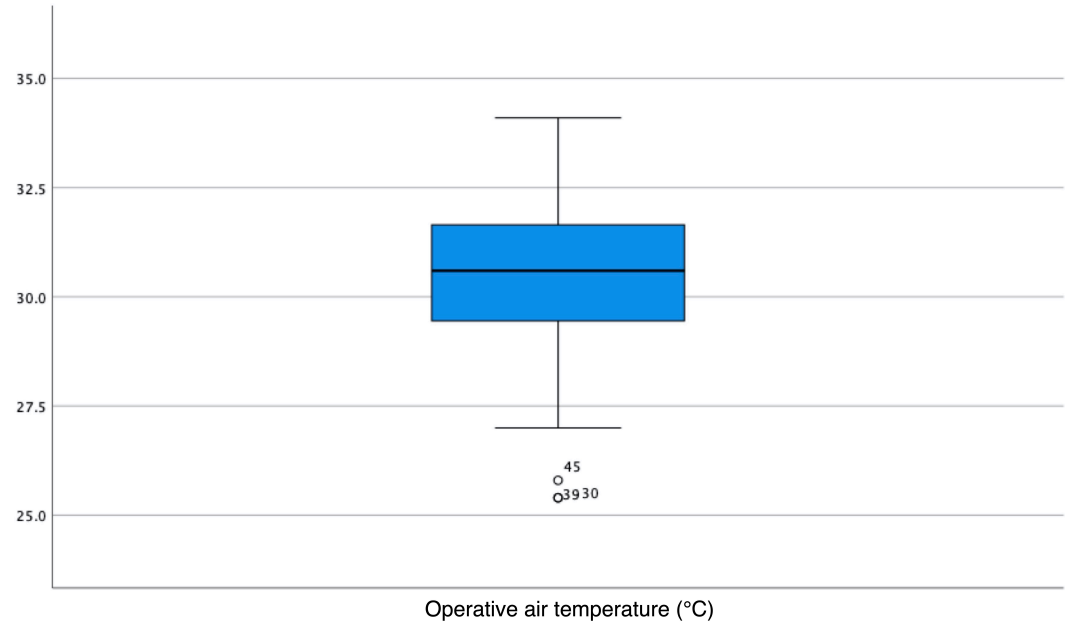
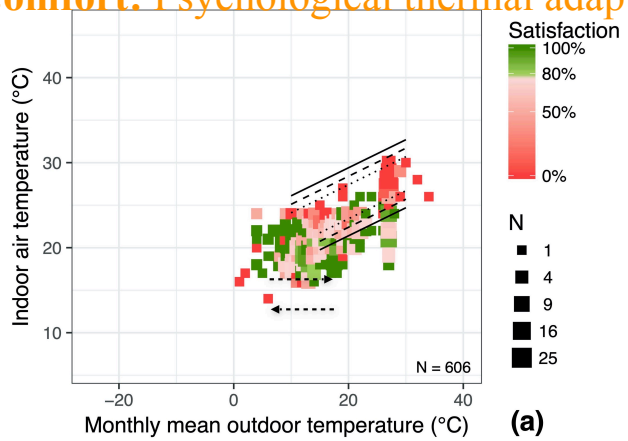
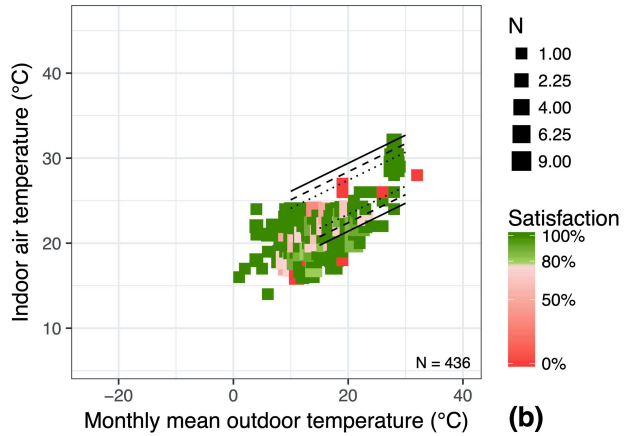



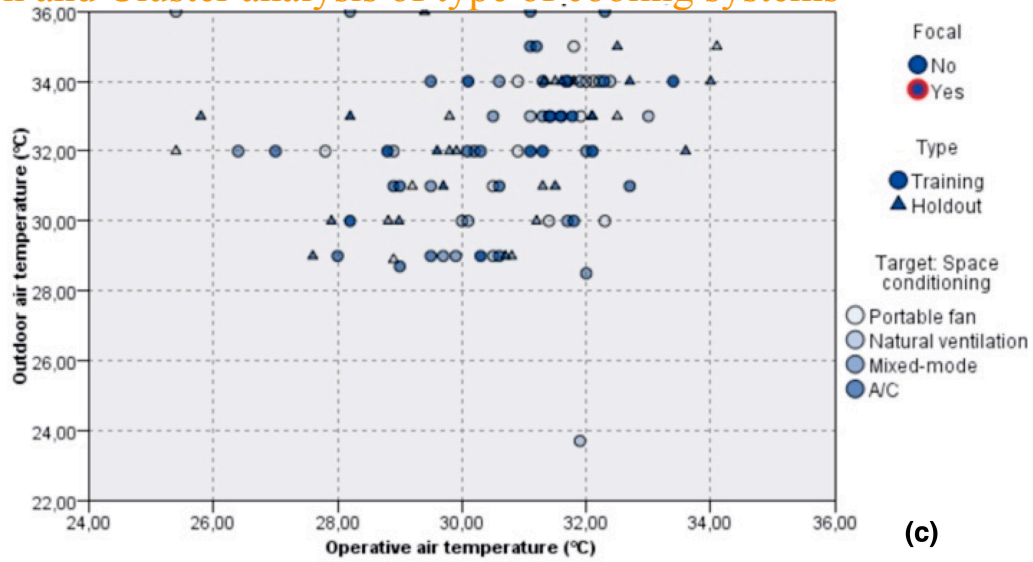

**Figure 19: (a)** Households' thermal sensation votes by considering operative air temperature; **(b)** On-site monitored operative air temperature.

# 4. Results and Discussions: Regression forecasting of neutral adaptive thermal comfort

## Adaptive Thermal Comfort: Psychological thermal adaptation and Cluster analysis of type of cooling systems




**Thermal Comfort**

**Benchmarking criterion to the ASHRAE Global Thermal Comfort Database II**

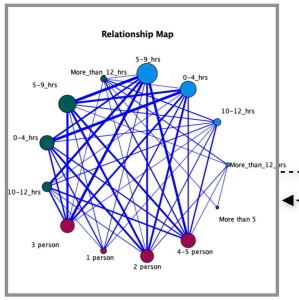
- 80% of the study respondents were slightly comfortable in a temperature ranging from 28,5 °C to 31,5 °C.
- A moderate correlation was found between the occupants' thermal sensation and the indoor air temperature ($r = 0{,}215$, $p < 0{,}05$).
- A negative moderate correlation was found between the occupants' thermal sensation and the outdoor air temperature ($r = -0{,}325$, $p < 0.01$).

**Figure 20:** Scatter-plot distribution of thermal sensation by **(a)** building typology and **(b)**; climate type; **(c)** cluster analysis of outdoor air temperature and operative air temperatures (OTs) for different types of space conditioning.

***Sources: (a)-(b)*** Graphs were extracted from an open-access thermal-comfort visualisation tool that utilised the satisfaction metric (i.e., Acceptability [TSV±2]), which is available at https://cbe-berkeley.shinyapps.io/comfortdatabase/

# 5. Conclusions: Regression forecasting of neutral adaptive thermal comfort

**Energy policy - I**

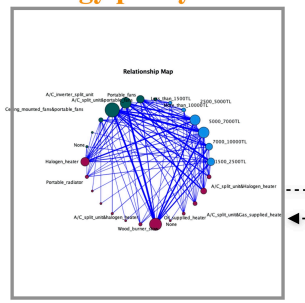



**Developing an evidence-based energy-policy framework to assess robust energy-performance evaluation and certification schemes in the South-eastern Mediterranean countries**

- Socio-technical associations between building energy use and occupants' thermal comfort were examined.
- Age bands were significantly related to the health conditions, and this relationship was strong ($\chi^2 = 73{,}739$, $p < 0{,}001$, Cramer's $V = 0{,}496$).
- Household occupations were also significantly associated with age with a moderate-strong relationship ($\chi^2 = 44{,}810$, $p < 0{,}001$, Cramer's $V = 0{,}399$).

**(Contribution 1)**

**Energy policy - II**

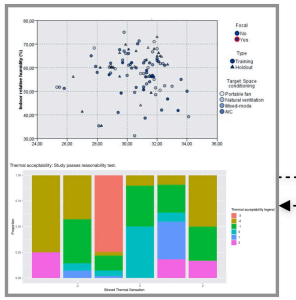



**Significance of occupancy patterns and habitual household adaptive behaviour on home-energy performance of post-war social-housing estate in the South-eastern Mediterranean climate**

- Human-based inclusive approach for residential buildings was developed.
- Weekday cooling consumption patterns were significantly and strongly related to weekend heating consumption patterns on weekend ($\chi^2 = 54{,}590$, $p < 0{,}001$, Cramer's $V = 0{,}522$).
- Energy-efficiency measures are recommended at the local and nationwide levels.

**(Contribution 2)**

**Thermal comfort**



**Regression forecasting of 'neutral' adaptive thermal: A field study investigation in the South-eastern Mediterranean climate of Cyprus**

- A novel framework combining assessment methodology with existing benchmark criterion of thermal comfort was developed.
- A moderate-strong relationship between orientation and reasons for thermal discomfort ($\chi^2 = 49{,}327$, $p < 0{,}001$, Cramer's $V = 0{,}405$) was found.
- The 'neutral' temperature was 28.5 °C, and the upper limit of the comfort range in warm indoor air temperature conditions was 31.5 °C.

**(Contribution 3)**

**Figure 21:** Research outputs contribute to the ASHRAE Global Thermal Comfort Database II.

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# 6. Outputs: Publications and Contribution to global research databases (Repositories)

## Donation to the American Society of Heating, Refrigerating and Air-Conditioning Engineers

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Regression forecasting of 'neutral' adaptive thermal comfort: A field study investigation in the south-eastern Mediterranean climate of Cyprus

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ABSTRACT

Numerous field studies have found that occupants' thermal comfort varies with local climate conditions. However, there is no generally recommended acceptable comfort range for multifamily residential buildings, nor are there specific adaptive thermal comfort prediction methods, particularly in South-eastern Mediterranean countries. We investigated an *in-vivo* experience of social householders' thermal sensation votes to predict individual aspects of adaptive thermal comfort and influences on its validity in purpose built residential tower blocks of a post-war social housing estate in Famagusta, Cyprus. We conducted field studies, which included *on-site* questionnaire surveys, environmental monitoring and *in-situ* physical measurements, on 36 base-case representative archetype buildings over 288 flats where the weather is subtropical (Csa) and partly semi-arid (Bsh). 118 flats were successfully recruited. A moderate correlation was found between the occupants' thermal sensation and the indoor air temperature ($r = 0.215$, $p < 0.05$), while a negative moderate correlation was found with the outdoor air temperature ($r = -0.325$, $p < 0.01$). The occupants' thermal sensation vote indicated that the 'neutral' temperature was 28.5 °C, and the upper limit of the comfort range in warm indoor air temperature conditions was 31.5 °C. This suggests that, in hot and dry climates in which thermally uncomfortable indoor environments occur, particularly in summer, occupants appear to tolerate a warmer condition than at other high and medium altitudes. The outcome of this study contributes to the development of the ASHRAE Global Thermal Comfort Database II where there is not any data available for the Cypriot context.

(a)

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September 13th, 2021

Prof. Dr. Haşim Altan
Department of Architecture, Faculty of Design
Director of Research Centre (ARUCAD)
Arkin University of Creative Art and Design
Girne, Cyprus

Dear Hasim,

This letter confirms the donation of a field measurement dataset to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Global Thermal Comfort Database II. This is an important outcome of the methodological framework developed to contribute to the adaptive thermal comfort studies as part of the PhD study undertaken by Mr. Bertug Ozarisoy at the Graduate School, School of Architecture, Computing & Engineering (ACE), University of East London (UEL), London, United Kingdom.

I received the associated dataset from the PhD thesis entitled 'Assessing the Domestic Energy Use and Thermal Comfort of Occupants in a Post-war Social Housing Development Estate in Famagusta, Northern Cyprus' on 10th May 2021. The dataset has been processed via the project web tool for quality assurance before being published in the open access ASHRAE Global Thermal Comfort Database II. The database is the result of a project led by an international team of experts to collate field measurements of thermal comfort for public use.

The dataset of this PhD thesis is a valuable contribution to the ASHRAE Global Thermal Comfort Database II. The field study in the South-eastern Mediterranean climate of Cyprus is a unique context and a noteworthy addition to this public resource.

Sincerely,

Thomas Parkinson, PhD
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University of California, Berkeley
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**Ozarisoy, B.**, & Altan, H. (2021). Regression forecasting of 'neutral' adaptive thermal comfort: A field study investigation in the south-eastern Mediterranean climate of Cyprus. *Building and Environment*, *202*. https://doi.org/10.1016/j.buildenv.2021.108013

**Ozarisoy, B.** 2022. Assessing the Domestic Energy Use and Thermal Comfort of Occupants in a Post-war Social Housing Development Estate in Famagusta, Northern Cyprus. PhD Thesis, University of East London, School of Architecture, Computing & Engineering, https://doi.org/10.15123/uel.8q713

# 6. Outputs: Publications

**Ozarisoy, B.** (2022). Energy effectiveness of passive cooling design strategies to reduce the impact of long-term heatwaves on occupants' thermal comfort in Europe: Climate change and mitigation. *Journal of Cleaner Production*. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2021.129675

**Ozarisoy, B.,** & Altan, H. (2022). Significance of occupancy patterns and habitual household adaptive behaviour on home-energy performance of post-war social-housing estate in the South-eastern Mediterranean climate: Energy policy design. *Energy*, *244*. https://doi.org/10.1016/j.energy.2021.122904

**Ozarisoy, B.,** & Altan, H. (2022). Bridging the energy performance gap of social housing stock in south-eastern Mediterranean Europe: Climate change and mitigation. *Energy and Buildings*, *258*. https://doi.org/10.1016/j.enbuild.2021.111687

Altan, H., & **Ozarisoy, B.** (2022). An Analysis of the Development of Modular Building Design Elements to Improve Thermal Performance of a Representative High Rise Residential Estate in the Coastline City of Famagusta, Cyprus. *Sustainability*, *14*(7), 4065. https://doi.org/10.3390/su14074065

**Ozarisoy, B.,** & Altan, H. (2021). A novel methodological framework for the optimisation of post-war social housing developments in the South-eastern Mediterranean climate: Policy design and life-cycle cost impact analysis of retrofitting strategies. *Solar Energy*, *225*, 517–560. https://doi.org/10.1016/j.solener.2021.07.008

**Ozarisoy, B.,** & Altan, H. (2021). Systematic literature review of bioclimatic design elements: Theories, methodologies and cases in the South-eastern Mediterranean climate. *Energy and Buildings*. Elsevier Ltd. https://doi.org/10.1016/j.enbuild.2021.111281

**Ozarisoy, B.,** & Altan, H. (2021). Regression forecasting of 'neutral' adaptive thermal comfort: A field study investigation in the south-eastern Mediterranean climate of Cyprus. *Building and Environment*, *202*. https://doi.org/10.1016/j.buildenv.2021.108013

**Ozarisoy, B.,** & Altan, H. (2021). Developing an evidence-based energy-policy framework to assess robust energy-performance evaluation and certification schemes in the South-eastern Mediterranean countries. *Energy for Sustainable Development*, *64*, 65–102. https://doi.org/10.1016/j.esd.2021.08.001

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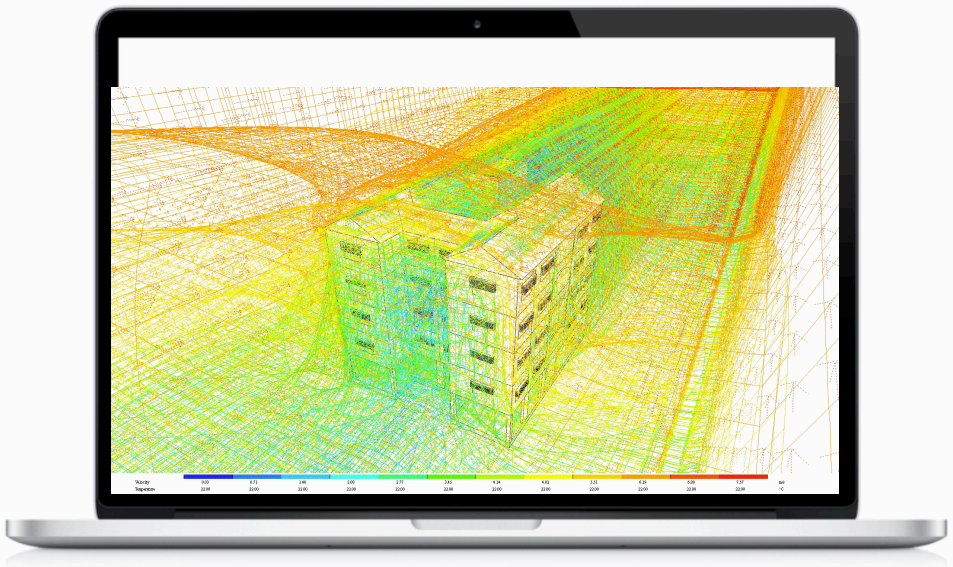
# Contact & Networking opportunities



For further discussions and possible networking opportunities
Please do not hesitate to contact with us

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*Special Thanks to*
Prof. Verity Brown
Pro-vice chancellor Impact & Innovation
University of East London

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