Climate and cultural based design and market valuable technology solutions for Plus Energy Houses

Report on redefined comfort zones for each climate-cultural cluster

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1. Objectives within the CULTURAL-E project

As stated in the CULTURAL-E proposal, the overall objective of the project is to define a viable and tailorable concept of Plus Energy Houses (*PEH*). In order to fulfil the aim and perform a successful implementation, design, configuration, technology selection, and system operation, an integrated climate and cultural approach needs to be conducted. In fact, the run of the latest decades towards energy efficiency and indoor comfort conditions has generally overrun country-specific features, often resulting in buildings which do not account for climate peculiarities and socio-cultural diversities of users.

The focus of WP 5 "*Co-benefits of Plus Energy Houses*", led by partner UNIVE, is the identification of the hidden and wider benefits achieved with PEH. Strictly liked to WP2 and WP4, WP5 aims at identifying co-benefits both at household and community level. As stated in the project overview, the journey consists in a stepwise process, which includes the following goals.

- Define the nature of co-benefits coming from PEHs and their technologies (e.g. improved IEQ, reduced energy costs), and how these matches with users' expectation and local/economy needs.
- Evaluate the entity of co-benefits in PEHs compared to common practice and estimate the benefits at households' level associated with improved indoor conditions.
- Estimate the limits where an increased co-benefit is no longer justified by extra costs.
- Estimate co-benefits from PEHs at community level.
- Valuation of different PEHs co-benefits for the building occupants.

Task 5.1 "*Redefinition of comfort zone (IEQ parameters) for each climate-cultural geo-cluster*" is the front of the work, led by UNIVE and collecting the contributions from participants RMIT and EURAC. The final objective of this task is to investigate user's expectations and preferences for the indoor environment according to their preferences, climate context and cultural-social background. With a deeper focus on thermal conditions, the analysis concerns all the four main aspects of indoor environmental quality (*IEQ*), i.e. thermal, visual, acoustic and air quality. Findings from literature review, current research and databases investigation are compared with current common design practice and available building codes.

Among the specific objectives of CULTURAL-e, Task 5.1 addresses the followings (Figure 1).

- Objective 1: Define cultural peculiarities related to European climates that strongly impact building energy consumption. In the perspective of energy efficient buildings and comfortable indoor environments, designers need to take a step back from homogenization and reconsider the remarkable differences which stand among the various European climates, along with other geo-specific peculiarities. Beside this, design concept, technological solution, energy consumption and operational strategies are also strictly related to the users cultural and social attitudes. For these reasons, in close synergy with Task 2.1, Task 5.1 aims at identifying climate and cultural peculiarities, and their heterogeneity across Europe, as keys to understand and minimize building energy consumption, prioritize technology, and define solutions that are truly energy effective and accepted by users in the different EU geo-clusters.
- Objective 3: Develop climate and cultural tailored solution sets and technologies for Plus Energy Houses (PEHs). Up to now, Plus Energy Houses have been generally regarded as pioneers in technology as a result of a meticulous and relatively expensive work of design and construction. This means high capital cost from different perspectives, from the design, to the technologies and construction, and the investment rarely pays off in pure monetary cost-benefit terms. In CULTURAL-E, the vision is enlarged thanks to a preliminary investigation of built-environment-related climate and cultural differences specific to geo-clusters. By these means, clear boundaries are defined for the use of different technologies and the achievement of peculiar requirements, with solutions cost-effectively tailored to what it is really needed in each specific climate and for cultural peculiarities, avoiding wasting resources and time working on elements that are not needed or socially not accepted.
- Objective 4: Understand the variables that building users bring to buildings, and provide interventions designed to shift energy using practices. When considering a building as a whole, users are active entities who make actions towards the indoor environment, its tools and systems, driven by social practices, cultural

beliefs, habits and comfort preferences. All these aspects can strongly impact the building's behaviour and therefore its energetic performance and the achievement of PEH targets. In order to make the household the central element of the plus energy house, design choices, mechanical systems and operation strategies will be informed by users, so as to (i) prevent and mitigate unintended energy use scenarios, (ii) reduce users' frustration related to a frequent need to adjust parameters, iii) reduce chances of setting inefficient or unintended high energy using parameters; iv) improve householders' experience of the indoor environment, v) account for occupants' rules and conventions and enable an energy social change.

- Objective 8: Dissemination objectives. Plus Energy Houses design requires a new rethinking on the relationship between users and buildings, building construction and operation, households and IEQ aspects. CULTURAL-E involves the Architects' Council of Europe in order to guarantee an effective feedback loop when adapting bioclimatic design strategies to modern architecture for Plus Energy Houses.

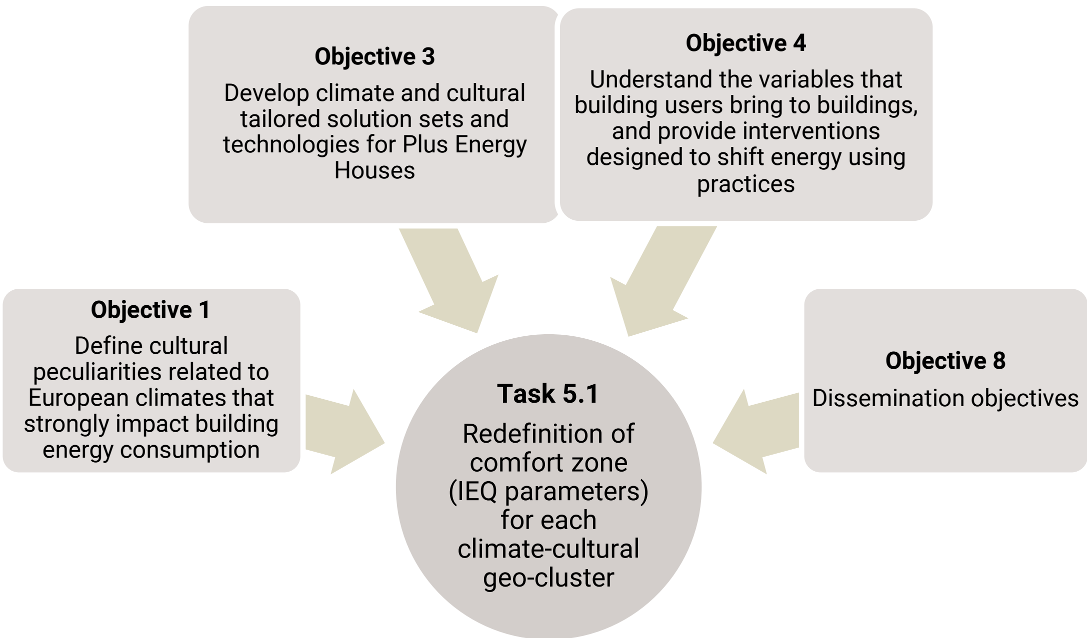


Figure 1. Task 5.1 and related overall objectives

2. Task 5.1 "Redefinition of comfort zone (IEQ parameters) for each climate-cultural geo-cluster": an overview

As introduced above, the focus of Task 5.1 is indoor environmental quality (*IEQ*) conditions for households in Plus Energy Houses. Strong relevance is given to the thermal environment, being closely related to both users' wellbeing and building's energy performance, and being strongly affected by occupants' climate background and adaptation history. However, the work concentrates on all the main four indoor comfort aspects, hence including also visual, acoustic and air quality. Households' expectations in terms of comfort are assessed according to preferences, climate context, as well as cultural and social background. Findings raised from literature analysis and data bases investigations have been collected, and will be compared and integrated with current available standards in the field, local building codes and common practices in design and construction.

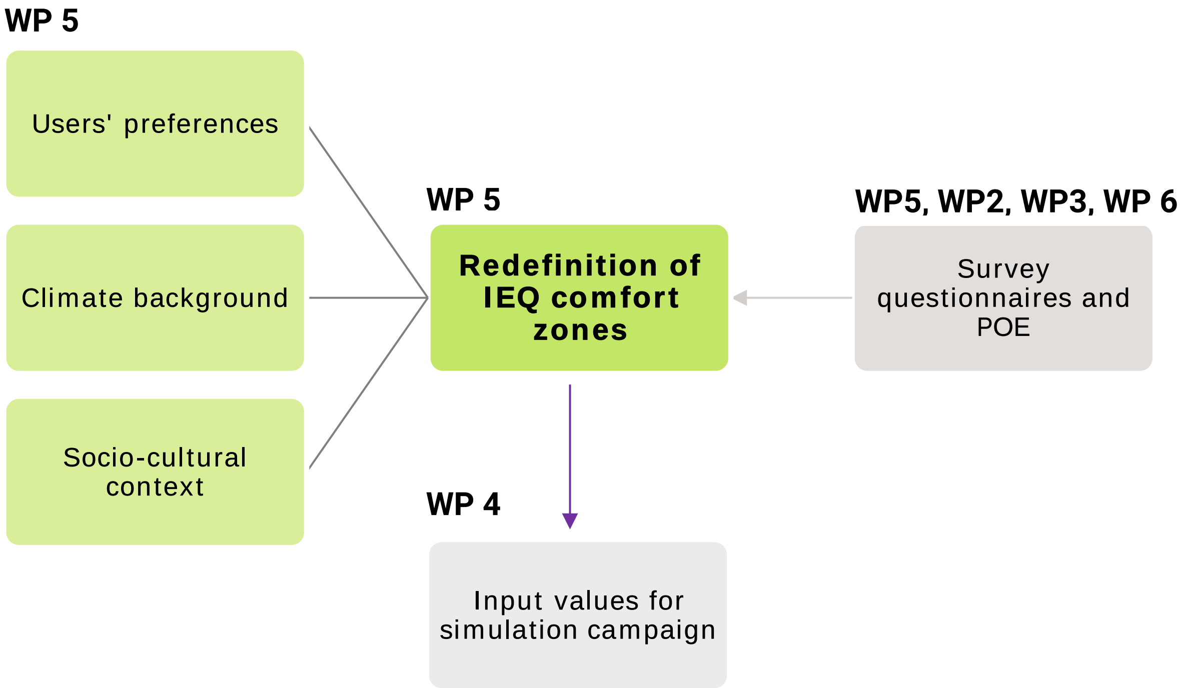


Figure 2. Task 5.1 workflow and link with other WPs

The research work (Figure 2) will lead to the redefinition of the IEQ comfort zones, beyond the narrow and homogeneous prescriptions of the current standards and accounting for users' diversities driven by the specific climate and socio-cultural features. Up to now (M8), analysis have been focused mainly on the thermal environment, to be then extended to the other comfort areas during the further developments of the work. Thermal comfort, indeed, is known in literature as the most significant contributor to overall user satisfaction in indoor environments (Frontczak & Wargocki, 2011). Final results will be validated by means of subjective survey questionnaires administered inside demo cases and other buildings, accordingly. Survey campaign will start at M12, and surveys will be elaborated jointly with WP2 and will be useful to assess the drivers which determine a variation in energy use, system operational choices and indoor parameters. to complement the post occupancy evaluations (*POE*) performed in Task 6.5, surveys will address users' traditions, habits and conventions and the role of knowledge, rules and expectations of energy services, as well as comfort expectations and preferences, health and wellbeing.

Since in a current scenario diversities are neglected and peculiarities overrun by standardization and homogenization, findings will constitute a significant contribution in the research field. Results will be strong inputs for the simulation campaign foreseen in WP4, so as to modulate the demo cases' simulations according to climate-specifications, comfort expectations and to socio-cultural attitudes of users.

3. Structure of the deliverable

Following the activities' workflow of Figure 2, this deliverable is structured as follows.

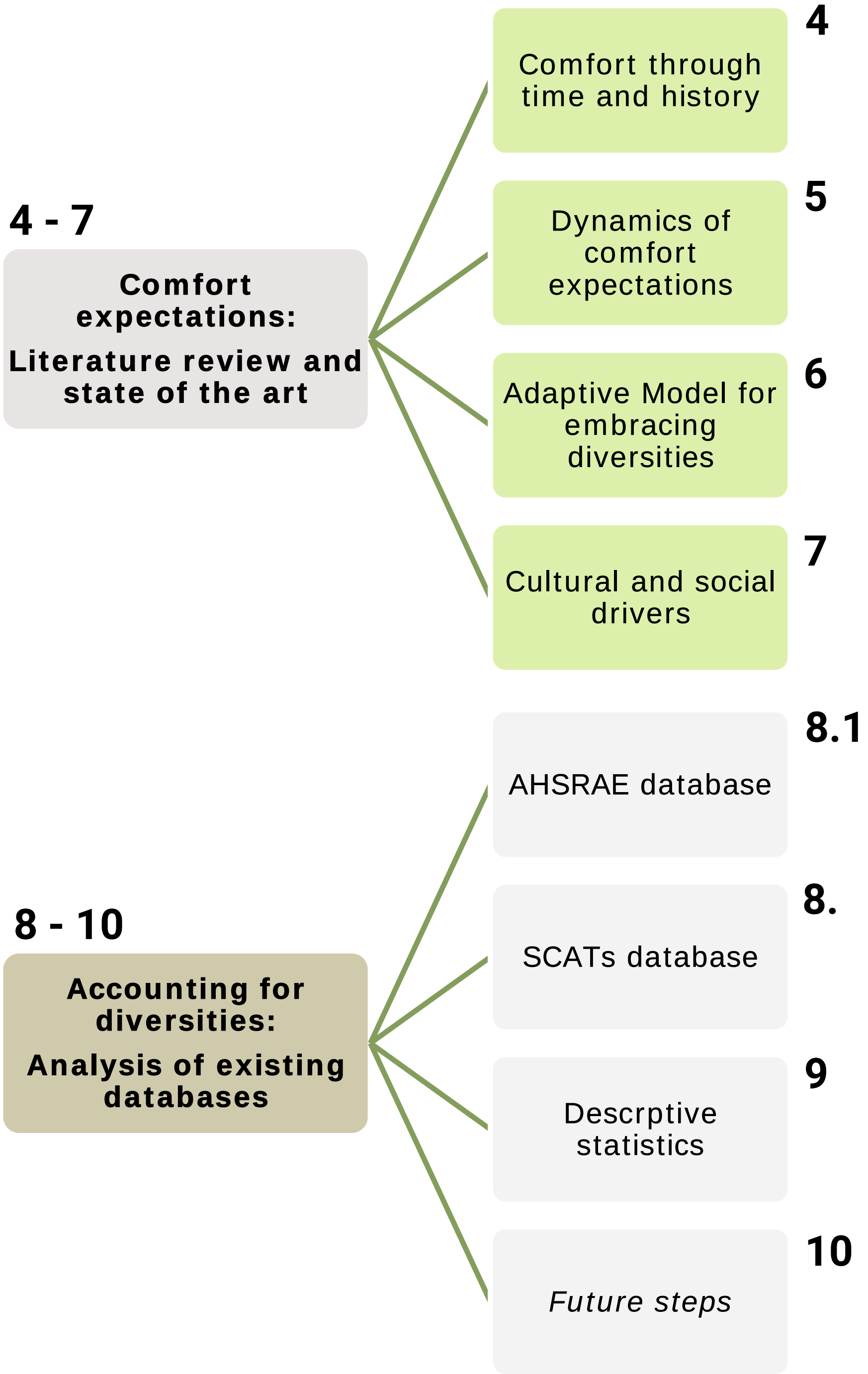


Figure 3. Structure of D5.1 deliverable

As shown in Figure 3, this deliverable comprises two macro sections: the former (paragraphs from 4 to 7) regards literature review and state of the art in the research field of the very notion of comfort and comfort expectations. The latter consists in the redefinition of comfort zones accounting for climate-cultural diversities (paragraphs from 8 to 10).

- In the first section, a literature review has been conducted in order to have a better understanding of users' comfort expectations for the indoor environment and of the mechanisms which drive their behaviours. Firstly, in chapter 4, an excursus is proposed regarding the shift in the very notion of comfort through time and history. In chapter 5, the focus is moved to the dynamics of comfort expectations for what concerns users' background and long-term history, identifying behavioural, attitudinal, physiological, and psychological mechanisms which play a fundamental role. Successively, a critical analysis of the trends of the last decades is proposed aiming at a shift in IEQ paradigms, starting from the targets that have recently guided indoor environmental standards and arriving to the identification of potential measures applicable in order to meet occupants' expectations and to embrace diversities (chapter 6). Finally, in chapter 7, an attempt of identification of social and cultural drivers influencing users' comfort expectations and household management is offered, so as to structure a framework to differentiate occupants' profiles and patterns according to their socio-cultural background.
- In the second part of the document, existing databases are analysed in order to grasp diversities in comfort expectations according to climate geo-clusters. Due to the data available and the state of the art, research mainly focuses on thermal comfort and on the use of personal controls in the indoor environment. In chapter 8 databases are presented, i.e. i) ASHRAE Global Thermal Comfort Database II and ii) SCATs Smart Controls and Thermal Comfort database. In chapter 9 the performed analyses are presented, and descriptive statistics are offered by means of plot visualization. First evaluations and comments are proposed, to be integrated in the following months with deeper statistical analyses.

Finally, in chapter 10, following steps for the upcoming months and future outlooks from WP5 are overviewed.

4. The notion of comfort through time and history

With the term *comfort* we indicate a mind state where the subject expresses their level of satisfaction with the surrounding environment. However, the topic is very complex and covered by multiple different disciplines, from engineering, architecture and building physics, to social sciences, psychology, physiology, and anthropology. In fact, evidence suggests that the notion of comfort is not one-dimensional, which would result into a very limited and narrow understanding, but it needs a more holistic approach to embrace all the different shades and natures. Due to this polyhedric nature, the very notion of comfort has evolved through time, being the answer to various changes and influences, i.e. cultural, social, technological and economic. According to Rybczynski (Rybczynski, 1986), it was only in the XIX century that the term comfort was first used related to environmental comfort concerning heat, ventilation ang light. Today, the word comfort is often associated with the thermal aspects, and as stated by ASHRAE (ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017) it is 'the condition of mind that expresses satisfaction with the thermal environment'. In a very engineering perspective, comfort zones are strictly defined basing on ideal conditions to be measured and matches with a condition of neutrality. However, the situation is far more complex, and it is influenced by contextual boundaries and other socio-cultural influences. Indoor environments can be richer experiences than merely neutrality, with their own ability of providing valuable sensory stimulations to users.

"creating a ***sensationless****, thermal Nirvana"*

With these premises, it is clear that comfort is not something to simply be measured directly. To easy the task, researchers in the field have ended up to measuring only the physical parameters that influence the body's heat exchange with the environment, by the assistance of subjective feedbacks about thermal sensation, resulting in making assumptions about users' satisfaction or dissatisfaction. In other words, as stated in Brager and de Dear (Brager & de Dear, 2003), the engineering ideal notion of comfort implies an absence of sensation, striving to create indoor environments that never vary over time or space, purposely creating a "sensationless, thermal Nirvana" (Prins, 1992). Through time and history, this mindset has eventually led to the current common notion of indoor environment: very tight and static environments, where transition and stimuli are not admitted, with very narrow ranges of microclimatic parameters to be maintained equally for all the subjects.

These arguments have been mostly developed on the thermal area of comfort, being the first in line in the comfort theories, but can be easily extended to the other comfort aspects, such as lighting, acoustics and air quality.

Going beyond this very limited concept means accounting for other variables impacting human experience, like climatic, architectural, psychological, ecological, social and cultural, which strongly influence our very own basic needs and our personal attitudes towards the indoor environments (Figure 4).

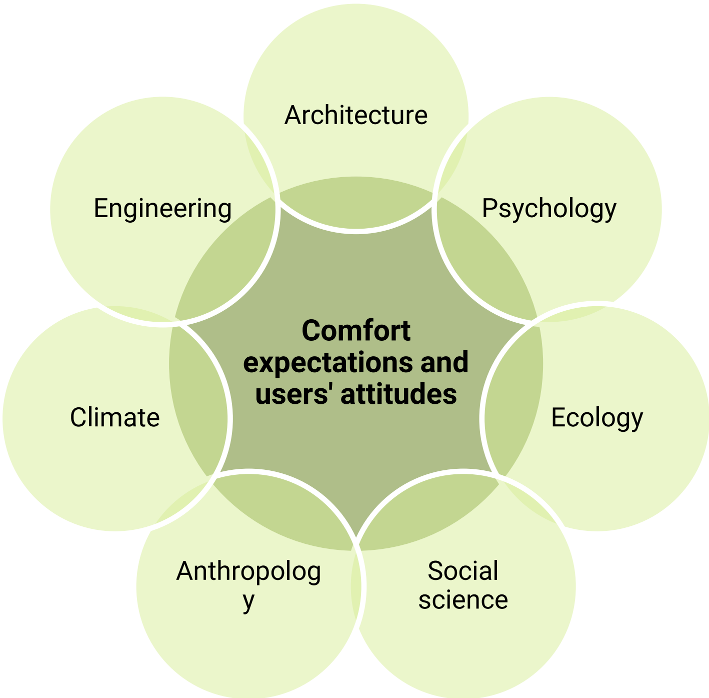


Figure 4. Features affecting comfort expectations and users' attitudes

In CULTURAL-E, the aim is to widen the common general approach to IEQ and comfort, by investigating in particular i) socio-cultural (WP2 and WP5) and ii) climatic variables (WP5).

5. The dynamics of comfort expectations: from our own background, to adaptation and change

When considering a building as a whole, its performance is influenced by some building factors as well as some factors connected with the users. For what concerns the formers, they include constructive, climate, technical and technological features; regarding the users, they imply behaviour, attitudes and dynamics, control over the environment, IEQ and health, concerning respectively the user as both an active and passive variable inside the building. As active occupants, users are not merely subjected to the indoor conditions, but act towards the environment driven by needs, necessities and preferences, and in general by the main key driver of achieving comfort. Thus, it is necessary to grasp how users interact with the indoor environment and address the diversities included in these interactions.

Thermal comfort, in particular, is considered as the most significant contributor to overall user satisfaction in indoor environments (Frontczak & Wargocki, 2011). According to thermal comfort theories, two main comfort approaches are internationally well known and accepted for assessing indoor conditions: i) the adaptive model and ii) the PMV/PPD model. The latter, developed by P.O. Fanger and based on the heat balance of the human body, has lately been often criticized since it implies a very static environment, with narrow and constant conditions, does not reflect the variability in comfort temperatures, it is regardless of the external climate diversities and does not account for adaptation mechanisms. On the opposite faction, the adaptive model is based on the outdoor running mean temperature, considers the adaptability to various environments, accounts for transient and dynamic indoor conditions and attempts to address diversities in users' interactions.

Three main thermal adaption mechanisms play a role in the thermal comfort adaptive approach (Brager & de Dear, 2003).

- Physiological acclimatization, namely changes in physiological responses, physiological set points and gains for controlling shivering, skin blood flow and sweating.
- Psychological adaptation, i.e. changes in one's perception and reaction to sensory information.
- Behaviour adjustment, that is all the conscious actions taken by the user such as altering clothing, eating cold or hot food, using fans, etc…

In the dynamics of thermal comfort and adaptation, **user's expectation** becomes a key element. Defined by Fanger himself the "7th parameter in the heat balance model of thermal comfort", **it is a complex combination of many factors like one's climate history, social understanding, cultural differences and economic level**.

According to this notion, people living in poor thermal environments for a long time may think it is their destiny, and they would judge a given poor environment as less unacceptable than those who are used to good thermal environments might think (Luo, et al., 2016a). Their background has shaped their expectations and attitudes through time and space, changing their very own personal sensation and perception of the surrounding environment.

*"buildings as **comfort capsules**, where thermal **imperceptibility** is targeted, the absence of any perceptible stimuli is demanded, aiming to an **ideal** repeatable standardized format"*

However, in the last decades, expectation has been completely neglected in the design of buildings, construction and operation. The general trend that has been insinuated and consolidated, in the run for energy efficiency, functionality and IEQ, foresees buildings as *comfort capsules*, where thermal imperceptibility is targeted, the absence of any perceptible stimuli is demanded, aiming to an *ideal* repeatable standardized format. Building design and operation have progressively taken distances from the natural environment, climate, seasons, sociology, ecosystems and cycles, which on the contrary were all well accounted for in the ancient vernacular architectures. Also known as "non-pedigreed architectures", they were *the result of human intelligence applied to uniquely human modes of life* (Rudofsky, 1964), able to embody human + nature aspects and translate them into efficiency, sustainability, functionality and comfort. **Transience, flexibility, specificity, diversity, were the key elements for these vernacular constructions.**

Given these premises, in the following paragraphs some question marks have been highlight, attempting at identifying and tracking down new trails to be covered towards the dynamics of comfort.

1.1.1 What is *ideal*?

Nowadays, in the current practice, the absence of any perceptible thermal stimuli represents the highest possible quality inside buildings, where thermal imperceptibility is the main target to be achieved. With the notion of *ideal* it is generally intended a standardized format that emphasizes **constant conditions through time, uniformity through space, targeting perceptual thermal neutrality**. A thermally neutral lifestyle is praised and created by means of very narrow ranges of indoor microclimatic parameters and a general homogenization of the built environment. This trend is what actually resides under the elaboration of the main guidelines in terms of comfort, design parameters and operativity settings, from EN ISO to ASHRAE standards, which have progressively embodied and rationalized this ideal format.

1.1.2 Has this "*ideal*" format resulted into a tangible commensurate increase of occupants' thermal satisfaction?

According to (Arens, et al., 2010), **it takes more energy to maintain a narrow indoor temperature range than a broader range**, in which the building may be allowed to float with reduced conditioning for longer periods of time. A narrow range should presumably be preferable to the building occupants to justify its increased energy cost. In this huge project conducted by the authors, three databases of occupant satisfaction in buildings were analysed to investigate the acceptability of three classes of temperature range employed in the ISO and European standards, and proposed for the ASHRAE standard. These are alternatively identified as class A, B, and C, or category I, II, and III, but their specifications are identical. The I category of comfort, either indicated with class A, was found to confer no relative satisfaction benefit to individuals or to realistic building occupancies. In addition to this, the differences in B and C class satisfaction were found small. Thus, the answer is no**, the strive for thermal neutrality has not actually led to a commensurate increase on building occupants' thermal satisfaction**.

"The standardisation of comfort, while convenient, is a dangerous thing in the face of increasing globalisation,

and threatens to ***diminish our planet's essential cultural and socio-technical diversity***"

(Shove, 2003)

1.1.3 Do people living in "*ideal*" indoor climates have higher expectations?

Thermal acceptability is a relative judgment, and results presented in (Luo, et al., 2016b) highlight how it does not necessarily occur at "neutral" thermal sensations. Findings from (Luo, et al., 2016b) (Yu, et al., 2012) suggest that **thermal comfort perception is closely related to peoples' long-term thermal history**. According to these studies, people living in higher indoor environmental quality indoor spaces become "fussy" to the thermal environment and increase their level of expectation. They do not experience any increment in thermal satisfaction, on the contrary there is an increment in users' dissatisfaction if compared to occupants in environments with much greater dynamic thermal range. This process easily leads to an excessive need for comfort and a sort of addiction to high IEQ standards.

1.1.4 Do thermal comfort expectations have symmetric dynamics?

As stated above, thermal comfort perception is closely related to long-term thermal history. Residents from different climates are likely to adapt over time to the thermal conditions in their new environment (Amin, et al., 2016) (Yu, et al., 2012). However, comfort expectations do not have symmetric dynamics. It has been demonstrated (Luo, et al., 2016b) that is easier to lift building occupants' expectations than lower them. This is also due to the fact that building users' thermal comfort is subjected to the what behavioural economists call **"the endowment effect," or "divestiture aversion": people place higher value on things merely because they currently own them or have done so in living** (Kahneman, et al., 1991). Thermal comfort satisfactions are highly negotiable socio-cultural constructs. It is expected that over time, residents from differing climates are likely to adapt to the thermal conditions in their new environment, but this process is not a two-way path. Obviously, this uplifting dynamic would generate an infinite loop, where occupants demand for increasingly higher IEQ conditions, with obvious negative effects on energy consumptions and climate issues like GHG emissions.

1.1.5 How can we meet occupants' expectations and inner diversities?

With all the premises above, it is clear that creating an environment with satisfies all users and matches all their peculiarities is a very difficult task, and it is a way distant from the concepts of ideal, standard, static, homogeneous. Moving aside from the latter trend of the last decades, which foresees indoor environments with narrow and constant microclimatic parameters, maybe it is time to take a step back and embrace a shift towards more transient environments. In this direction, the need is to rethink **indoor environments as more dynamic, to empower users more than systems, to encounter for diversities instead of striving for homogenization** (Amin, et al., 2016) (Luo, et al., 2016a) (Yu, et al., 2012). Regarding the latter, the concept of *alliesthesia* can be summoned.

An example of addiction through time: the arrival of Air Conditioning

The very notion of comfort has evolved through history, responding to various climatic, social, technological, economic and cultural influences, where technological adoption has usually run a pace far faster than cultural change. Our very attitudes about comfort, both at an individual and at a cultural scale, influence our basic need or aversion to the adoption of technologies, e.g. as in the case of mechanical heating or cooling over passive strategies. In the United States, during the 50s, air conditioning has had significant positive impacts on society, with also enormous historical and cultural effects on peoples' attitudes about comfort, the way in which we design and inhabit buildings, and even ways in which we interact as a society.
Air conditioning (*AC*) soon became the expression of cultural and social changes, including the role of family, gender, and social class. It embodied a socio-economic status, leading to an addiction and treated as an entitlement for social acceptability. It was the symbol of a material culture and economic competition.
Initially driven by cultural and social issues, AC evolved into a physiological addiction, where 'air-conditioning rapidly teaches the body to hate the heat' (Prins, 1992), and changes our own perception and expectations and our response to outdoor climate.

Mechanically VS Naturally ventilated buildings

The above considerations require a little excursus on the eternal contrast between mechanical and natural ventilation, where the adoption of mechanical systems embodied life, cultural and societal changes, as well the economic competition and industry spin, before becoming a mean for better thermal environments. In a massive study conducted by Brager and de Dear in 2001 (de Dear & Brager, 2002) the ASHARE Global Thermal Comfort database I was analysed to draw findings about users' thermal preferences in the two types of ventilated indoor spaces. For what concerns mechanically ventilated buildings, occupants revealed to had become finely adapted to the narrow and constant conditions typically provided by the mechanical system. They used to become quickly uncomfortable if conditions deviated from the narrow set points. On the contrary, occupants of naturally ventilated buildings were adapting behaviourally and psychologically to the varied indoor climates driven by external weather and season cycles.

To recap, the increase of air conditioning systems has raised from an increased economic development and from the fear of future heat waves, causing on the contrary an increase in energy consumptions. On the side of users, this has eventually led to a significant change in our perception of the thermal environment and our adaptation processes, causing a **weaker physiological acclimatization, a weaker ability of adaptation, a decreased ability to deal with heat and impaired thermoregulation mechanisms, including vasoconstriction, shivering and other mechanisms to maintain core temperature.**

“the need is to rethink indoor environments as more ***dynamic****, to* ***empower users*** *more than systems, to encounter for* ***diversities*** *instead of striving for homogenization”*

Alliesthesia

With the increasing awareness of GHG emissions due to the HVAC systems, new strategies have been implemented in buildings so as to deliver an acceptable thermal environment, e.g. displacement ventilation, mixed-mode strategies, personally controllable (task-ambient) systems, chilled beams. Among these, natural ventilation has been reconsidered, which actually is not an innovation but on the contrary it has a very long history: natural ventilation was systematically used by vernacular architecture, and by ancient Romans as testified by Marcus Vitruvius, in his *De architectura libri decem*.

In the last decades, as stated above, the trend has been to deliver static and isothermal indoor climates in buildings, to which occupants attained thermal steady-state with the minimal expenditure in terms of temperature regulatory effort.

Nowadays, the new technologies of thermal comfort are tending towards dynamic, anisothermal environments, in which to place the occupants into a moderately non-steady-state thermal condition in which their physiological and behavioural temperature regulatory mechanisms are reactivated.

According to current standards, occupants' thermal comfort expectations can be conformed to some generalization. However, *taking the science of thermal comfort beyond useful but quite simplistic statistical models will demand a more thorough understanding of the inner workings of human thermal perception* (de Dear, 2011).

The phenomenon of alliesthesia is used to differentiate thermal pleasure from thermal neutrality and acceptability (de Dear, 2011). This notion consists in the circumstances in which a given stimulus can induce either a pleasant or an unpleasant experience, depending on the subject's internal state.

With this mechanism, the behavioural responses in the body's regulatory system -e.g. hunger, thirst, or temperature regulation- are mediated. In these homeostatic systems, whenever the regulated variable within the milieu interieur is displaced from its set-point, external environmental stimuli that serve to diminish that displacement are perceived by the subject as pleasant and desirable (de Dear, 2011). Contrary to static environments, with alliesthesia any external thermal stimulus which might have prospect of restoring body core temperature would be perceived as pleasant by the occupant.

1.2 User-centric environments: empower users in the indoor environment

In a real environment, people do not only passively accept the thermal stimuli, but also actively interact with the environment through the "human–environment" feed-back cycle.

"an improvement of comfort is not only due to merely physical conditions, but the ***psychological effects themselves play a key role in the mechanisms of adaptation****"*

Personal control systems consist in different ways, from local ventilation outlets or fans, radiant or convective heaters, temperature-controlled surfaces on chairs, desks, floors, etc. These controls have the benefit of improving both comfort for users and energy saving (Zhang, et al., 2010) (Zhang, et al., 2011) and are feasible to meet individual comfort requirements which differ due to subjective individual variables, like gender, age, body mass, metabolic rate, clothing, and thermal adaptation (Karjalainen, 2012) (Indraganti & Rao, 2010) (Luo, et al., 2015). **This means that they increase the inhomogeneity of the thermal environment, expanding the temperature control range, while increasing the subjective satisfaction rate** (Bauman, et al., 1998). In the study conducted by Brager et al. (Brager, et al., 2004) in a naturally ventilated office building, it was demonstrated how occupants with more opportunities to operate windows voted thermal sensation closer to neutral than those who had less power over control.
According to (Zhou, et al., 2013), thermal comfort improvements are merely due to psychological factors, however more research is need in the field to confirm it. In this direction, the study conducted by (Luo, et al., 2016b), has shown how an improvement of comfort is not only due to merely physical conditions, but the psychological effects themselves play a key role in the mechanisms of adaptation. Some important hints can be drawn from the analysis. Subjects' perceived ability to control over thermal environment improves their thermal comfort perception, and this improvement is merely due to a psychological influence. The users' thermal discomforts can be reduced through even a very slight improvement of the thermal conditions by implemented personal controls. Thus, it is recommended that occupants are provided with sufficient opportunities to control their thermal environments.

According to literature, various strategies can be implemented in indoor environments to boost this change in the paradigm and encounter the new perspectives embracing environmental asymmetries, transient and ununiform environments, thermal stimuli, users' empowerment, thermoregulatory activation (Figure 5):

- air motion, across occupants' exposed skin surfaces through purposive natural ventilation or localized mechanical systems;
- localized heating and cooling, by actual contact to exposed body surfaces;
- thermal gradients, both in vertical and horizontal planes;
- low energy design options, compared with the brute-force, sealed facade air-conditioning monoculture that pervades in recent decades;
- exploitation of natural diurnal, synoptic, and seasonal rhythms in weather and climate, and in so doing minimizing the risk of thermal boredom in built environments;
- building configuration and users occupancy, according to subject's climate history and long-term background;
- personal comfort systems, empowering users' personal control;
- mix-mode buildings.

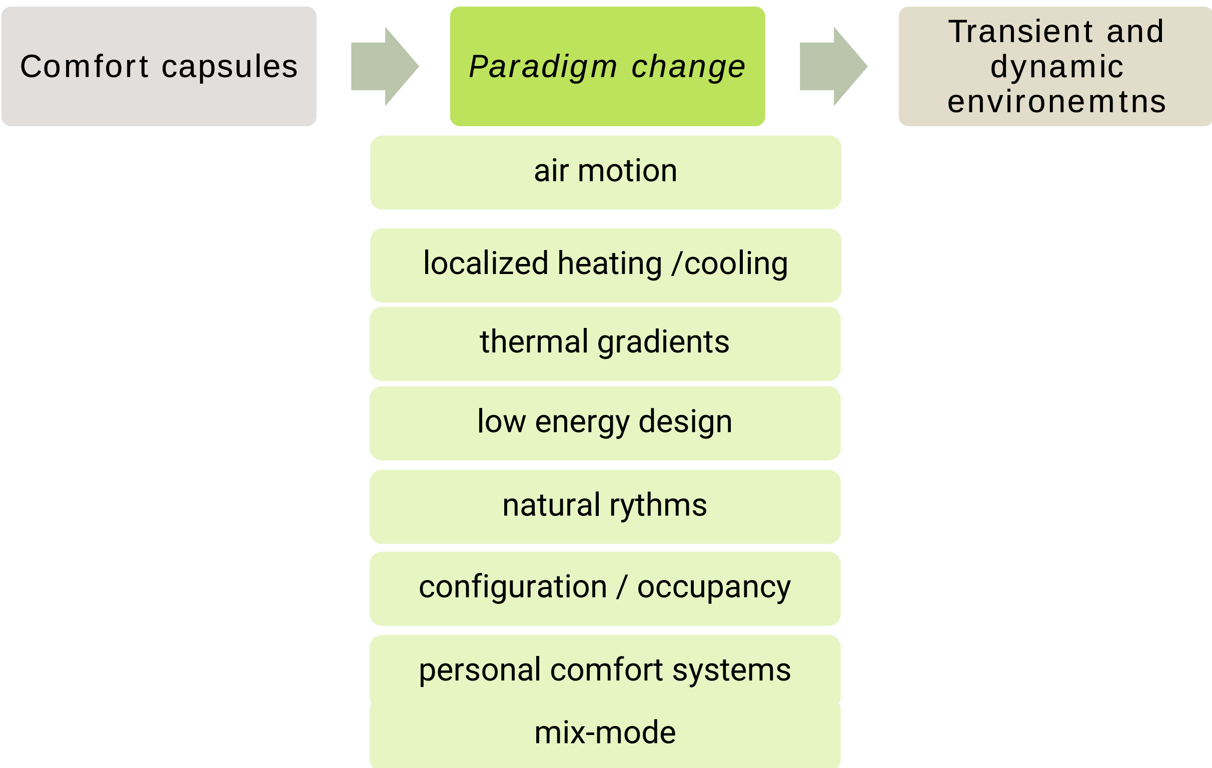


Figure 5. Strategies to boost a shift into building design, construction and operation

Demonised for long time by the culture of indoor *ideal*, standardization, and "comfort capsules", all these strategies can contribute to restoring human physiological, behavioural and psychological adaptability to thermal environments, while not taking a high price on energy consumption and costs. Moreover, they can help in taking a step forward into accounting for subjects' diversities, not striving for homogenization, but on the contrary accounting for occupants' climate and cultural peculiarities in buildings' design, construction and operability.

6. Thermal comfort theories: the adaptive model towards embracing diversities

Standard and guidelines both at European and worldwide level do not account for climatic differences neither other diversity factors, like socio and cultural ones, limiting the actual significance and usability of the proposed criteria and requirements. This subsists for all the four mentioned comfort areas, but it is much more evident regarding the thermal environment, where users' preferences are strongly linked to such diversities.

In order to assess the quality of the thermal environment for mechanically conditioned buildings, criteria usually consist in the thermal comfort indices, i.e. Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD). Local discomfort is also considered as an integration for the evaluation, usually including vertical air temperature difference, warm/cool floor, radiant asymmetry and draught rate. Contrarily, in free-running buildings where no mechanical conditioning is present, thermal comfort is evaluated by means of operative temperature ranges, calculated as a function of the running mean outdoor temperature of preceding days. This latter method, known as Adaptive Comfort Model, has actually been the first ever attempt to include users' expectations, adaptability mechanisms and outdoor climate diversities. The PMV/PPD approach, in fact, implies a very static environment, with narrow and constant conditions, does not reflect the variability in comfort temperatures, it is regardless of the external climate diversities and does not account for adaptation mechanisms. It has been in the early 1970s that Nicol and Humphreys (Nicol & Humphreys, 1972) challenged the 'steady-state' comfort theories with the introduction of the adaptive comfort theory. According to it, building occupants are likely to adapt to their environment either by adjusting clothing, controls or location, so as that they could tolerate environmental conditions outside those recommended by 'steady-state' theories, and hence the current thermal comfort standards (McCartney & Nicol, 2002). According to Nicol and Humphreys (Nicol & Humphreys, 1973), adaptation to the thermal environment is a key factor in the interpretation of thermal comfort data from users. The mechanisms of adaptation create a self-regulating system which tends to produce a condition of thermal comfort. From the data analysed by the authors, coming from a variety of sources from England, Iraq, India and Singapore, it is shown how different individuals and groups adapted themselves to cope with the conditions they had met but, despite adaptation includes physiological changes, a major share of it was achieved by means of different social customs and in particular by different clothing.

"the response made by an individual to any particular stimulus will depend upon ***social conditions****"*

On the one hand, according to the authors, three ways that lead the flow of metabolic heat to the environment can be voluntarily adjusted (Figure 6):

- changes in metabolic rate per unit body surface area, by changing posture or activity;
- changes in clothing insulation;
- changes in the thermal environment.

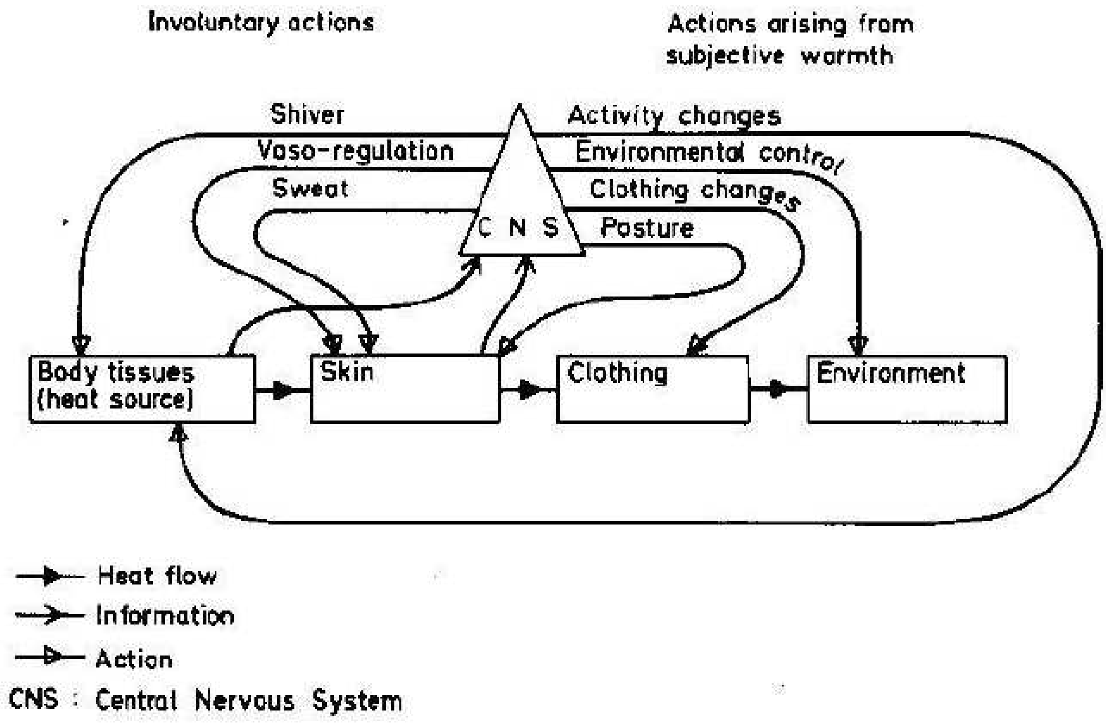


Figure 6. The thermal regulatory system (Nicol & Humphreys, 1973)

On the other hand, the response made by an individual to any particular stimulus will depend upon social conditions. In fact, the extent to which an individual can change his clothing, the number and typology of activities, and the use of environmental controls, depend on social limits, pressures and circumstances. **Social constraints consist in the limits of the obtained control**.

Thus, **a self-regulating control system works to ensure thermal comfort, and it will in any case strive towards its optimum. The problem is to provide to each individual the right circumstances in which this mechanism easily take place**. For this reason, it becomes so important to investigate these circumstances, from climatic differences, to all the socio and cultural constraints which affect occupants' capacity to self-regulate by adaptation mechanisms.

Their studies were further implemented when in 1978 Humphreys introduced the concept of optimum internal temperature, that is the temperature at which most people will report comfort inside a building and it could be related to the external temperature at that location (Humphreys, 1978) over a considerable range (Figure 7).

The development of the Adaptive Control Algorithm (ACA) for thermal comfort raised from the understanding of the complexity of an actual application of the adaptive comfort theory. By means of the ACA, designers were finally provided with a method for assessing indoor temperatures according to the principles of the adaptive comfort.

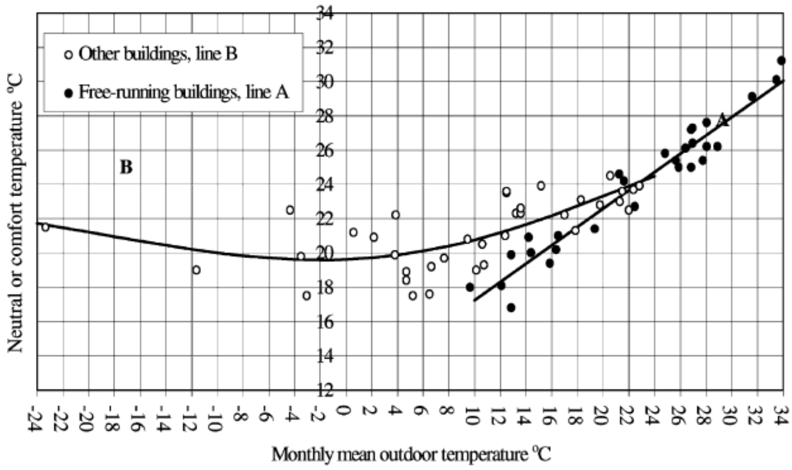


Figure 7. External temperature VS comfort temperature (Humphreys, 1978)

The Adaptive Control Algorithm and the adaptive comfort theory were also the pillars under the SCATs project, which was developed and ran from December 1997 to December 2000 and whose objective was to provide a method of reducing energy consumption in air-conditioned buildings by developing control systems that could utilise the principles of adaptive comfort theory.

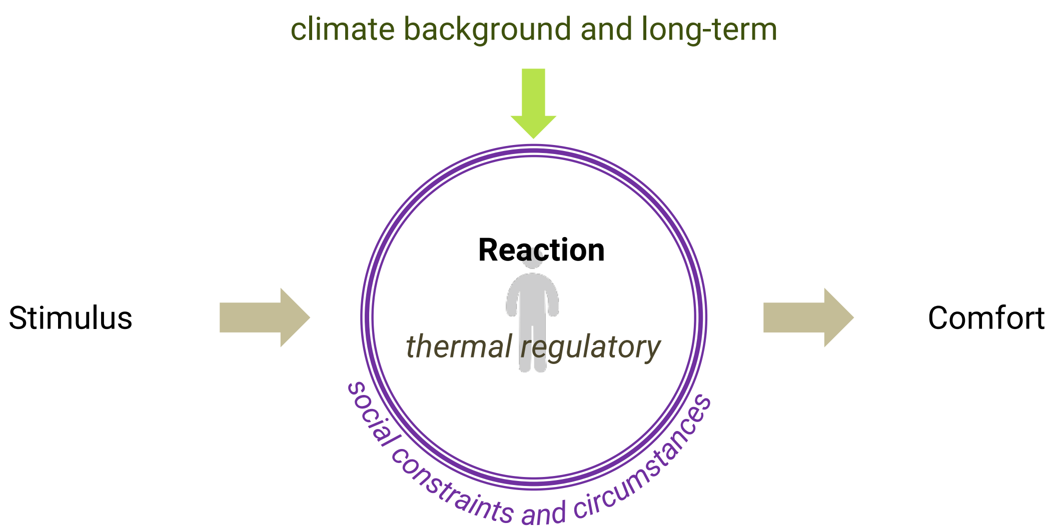


Figure 8. Mechanisms of adaptation

As stated by (Attia, et al., 2017), in relation to thermal comfort limits based on the evolution of comfort models -from the Fanger Static Method and the Adaptive Method defined in the 70s and 80s respectively, the Passivhaus (pH) (Passiv House Institute, s.d.) standards created in the 90s, the EN 15251 (CEN - European Committee of Standardization, 2007) approved in 2007, The Energy Performance of Building Directive 2010/31/EU (EPDB) (European Parliament and the Council of European Union, 2010) including the recent amendments in 2018 and 2019 in regards to Near Zero Energy Buildings (nZEB), or the last edition of ASHRAE 55 (ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017) -updated in 2017-, the global Indoor comfort standards have been extended from an original office building domain to the residential building sector, which both could be compared from a similar human occupancy activities perspective.

The EU standard EN 15251 suggests using the Fanger's Method when designing buildings including mechanical heating and/or cooling systems, but it indicates to base the building design criteria on the adaptative model for those exempted of mechanical ventilation. Also, more recently, nZEB frameworks have been adopted as part of the EU national building regulations based on the EPDB, where it is indicated to follow the EN 15251. Despite these recommendations, each organisation has developed and adapt their own thermal comfort ranges and energy performance scope within the existing EU standards, e.g. pH standard defined as summer comfort criteria to avoid exceeding 25°C during 5% of the time working, but this compromises the users' comfort expectations in the 4 climate areas targeted by the CULTURAL-E project (Mediterranean, Oceanic, Continental and Sub-arctic climates). As identified by studies conducted in these various climatic contexts -e.g. (Carlucci, et al., 2013) (Pagliano & Zangheri, 2010) (Peacock, et al., 2010) (Barbosa, et al., 2015) (Badescu, et al., 2015) (Berge & Mathisen, 2013)-, housing occupants reported frequent situations of discomfort due to overheating problems in both living and night dwelling areas, these perceptions respond to the specific climatic conditions, clothing habits and energy practices, among others, according to each socio-cultural context. In consequence, several forums and discussions have been conducted by building experts and practitioners -e.g. EU funded project Passive-on-, where it have been recommended to allow the inclusion of adaptative comfort concepts in high energy performance building designs in order to avoid overheating while, simultaneously, enabling to reach the expectations from users to interact with the building systems operation so that the users' control of the housing equipment and technologies is foreseen which might allow to avoid the occupants discomfort perceptions.

"The overfocus on energy performance in nZEBs can lead to health and comfort problems. […] adaptive thermal comfort could be helpful, to take advantage of the individual range of adaptive possibilities in a nZEB" (Attia, et al., 2017). This statement could be applicable, as well, for the PEB design, where to integrate an hybrid system where both systems, mechanical heating-cooling and free-running using natural passive ventilation strategies, could operate independently in correspondence to the specific requirements determined by the site characteristics, cultural behaviours, weather seasons and outdoor temperatures.

Furthermore, results from research studies shows that "comfort parameter settings have a higher impact on the air conditioning energy demand for a nZEB than for a traditional dwelling. It is demonstrated that by adopting extended comfort ranges, significant energy savings would be achieved in countries with temperate climates for nZEB. […] the current standards and regulations should be reviewed. […] new adaptive control algorithm should be developed to define optimized comfort temperatures in the different climate areas" (Guillen-Lambea, et al., 2017).

As early demonstrated in the studies conducted by McCartney & Nicol (McCartney & Nicol, 2002), it exists building design criteria and methods -e.g. the Adaptive Comfort method- which could allow the reduction of energy consumption in mechanically heated and cooled buildings, without compromising the perceived comfort levels by the occupants. The Adaptive Comfort method queries about the effectiveness of the fixed standard temperature ranges applied into the design process, especially in warm climates and, also, in broader climate change contexts, in particular in the current era when further norther European regions are frequently reaching hot extreme scenarios and, by consequence, air conditioning systems are being extensively integrated into new building designs. It is more and more often that current fix thermal comfort standards are not responding to the occupant expectations, however **the Adaptive Comfort method may allow designing hybrid systems in order to enable indoor comfort outcomes through natural ventilation techniques instead of the energy intensive and high-technological solutions commonly used nowadays.**

7. Cultural and social drivers affecting comfort expectations

Understanding cultural and social drivers in human adaptation is gaining a pivotal role towards energy efficiency and indoor environmental quality in buildings. In fact, the constraints of social practice, cultural habits, adaptation and social norms have a strong impact on the interaction chain human-environment, being the factors that drive occupants' behaviours. Humans appear as active energy users, taking actions towards the built environment and thus "manipulating" buildings and their performance. In order to understand everyday practices and patterns in household management a multidisciplinary approach is certainly needed in the implementation of a multi-layers analysis, so as to grasp **"what makes people consume energy in the ways they do"**. Understanding users' patterns and attitudes opens the way to a new form of modelling buildings, beyond the usual technology and economic-based approach (Wilhite & Shove, 1998).

"the simple traditional chain cause-effect gains complexity: humans' attitudes and they responses to the surroundings are not only affected by objective space conditions, but also by ***social and inner psychological factors****"*

Humans' decisions are driven by various factors, changing over time and, to some extent, unpredictable. In the relationship human-environment, the simple traditional chain cause-effect gains complexity: humans' attitudes and they responses to the surroundings are not only affected by objective space conditions, but also by social and inner psychological factors. According to Shove (Shove, 2003), occupants' actions are deeply influenced by social norms, as well as cultural and economic factors. The change of habits and dynamics often result in a standardization of consumption patterns thus, instead of focusing on individual actions and attitudes, the focus should be put on the transformation of collective conventions (Shove, 2003). According to the user-centred theories for the built environment, two different positions can be identified:

- an *environmental determinism*, which assumes that the environment causes the users' behaviour;
- a *social constructivism*, where the human attitudes are determined by the social context.

The first one, favoured for its immediate applicability, has revealed to minimize and oversimplify all the possible variables that influence the human behaviour, whereas human experience is highly influenced also by social norms, interactions and constructions. For these reasons, according to Vischer (Vischer, 2008), a user-centred theory is more located in between these two extremes: **subjects' behaviour is influenced by the environment but not determined by it, while being affected by other aspects like feelings, intentions, attitudes, expectations and social context**.

Cultural and social variables include a very wide range of aspects and topics, from a household level to a community one, with a perspective that often goes beyond the individual attitudes. According to Watson et al. (Watson, et al., 2016), group mechanisms include:

- organizational cultures, referring to organizational or institutional social order;
- management strategies, as the processes that control individual users and user groups;
- social norms and practices, referring to the tacit knowledge and related behaviour patterns of individual users.

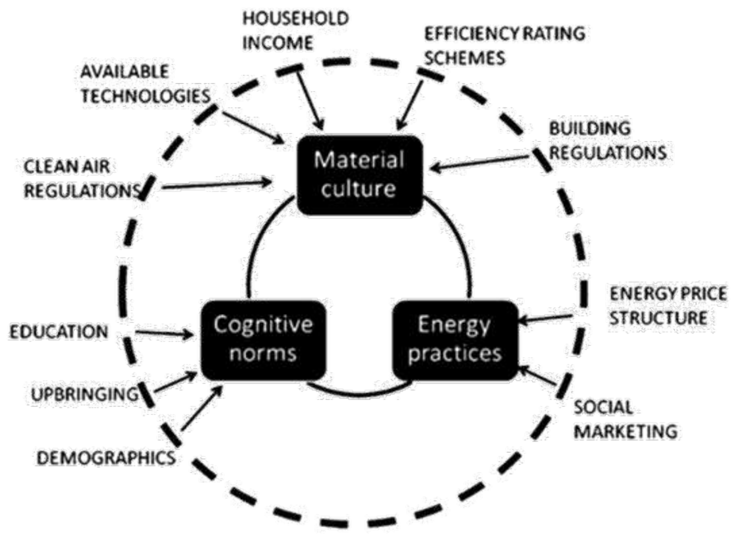


Figure 9. Energy Cultures Framework (ECF) (Stephenson, et al., 2010)

Contrary to the conventional approach where users' practices, attitudes and expectations tend to be flattened towards a generalized use of technologies and standards of comfort, using these categories can lead to cluster users according to their actual cultural and social diversities. The approach foresees a lifestyle segmentation procedure, by which subjects are investigated by means of driver factors in order to capture and map patterns in different populations.

In this direction, in the Deliverable D2.1 of CULTURAL-E "*Climate and cultural differences in energy use in domestic buildings*" the Energy Cultures Framework (*ECF*) by Stephenson et al. (Stephenson, et al., 2010), is recalled.

The ECF is meant as a conceptual framework for the understanding of the factors that influence energy consumption attitudes. Being "achieving comfort" one of the main causes for behaviours and energy patterns, this culture-based approach can be extended as a structure for addressing the problem of multiple interpretations of 'behaviour' by suggesting that it is influenced by the interactions between three core vectors, i.e. norms, energy practices and material culture (CULTURAL-E - Climate and cultural based design and market valuable technology solutions for Plus Energy Houses, 2020). As it can be observed, the three main concepts constitute the core of the framework but they include themselves wider systemic contextual features. The ECF is meant for clustering users according to similar interacting norms, material cultures and practices, returning a population segmentation by means of reasonably distinctive energy cultures. This categorization can then contribute to a deeper understanding of the consumer behaviour towards the environment, and thus to the identification of the most suitable and effective interventions according to user's attitudes, preferences and aspirations.
In the recent EU H2020 project "ENERGISE" (ENERGISE, 2019), this ECF is recalled. This research work aims at achieving a greater scientific understanding of the social and cultural influences on energy consumption by developing and validating options for a bottom-up transformation of energy use in households and communities across Europe. Also in this case, the basic hypothesis is that patterns in energy use arise from social settings -e.g. communities, associations, local and regional institutions- that shape household-specific practices. As stated in (ENERGISE, 2019), *ENERGISE explicitly recognises the existence of distinctive, culture-specific combinations of practices adopted and shared by particular units of social organisation (e.g. households, communities, organisations, nation-states). This implies a view of cultural change as a key ingredient of successful energy sustainability transitions*.
In the above-mentioned document, a modified version of the *ECF* of Stephenson is proposed with examples, and it is reported hereafter. The definitions in Table 1 have been used to cluster the drivers which lead to diversities in comfort expectations and energy end-use.

Table 1. Source: ENERGISE (ENERGISE, 2019). Modified version of Energy Cultures Framework (ECF) by Stephenson et al.

Element	Examples
Material conditions	Technologies, energy infrastructure, house characteristics such as insulation, energy sources and heating devices
Attitudes, perceptions and social norms	Aspirations, expected comfort levels, environmental concern, respect for tradition, social acceptability of wasteful/resource-intensive activities
Everyday practices	The temporal and spatial dynamics of practices unfolding in the home that play a role in when and how the home is heated, as well as what rooms are heated and when ,(such as cooking and washing), use of appliances, use and maintenance of technologies

As stated in (ENERGISE, 2019), according to (Spurling, et al., s.d.),**individual behaviour constitutes the visible performance of a social practice that rests upon the effective use of objects, tools and infrastructures, of knowledge and skills and of cultural conventions, expectations, and socially shared tastes and meanings'**. In other words, observable behaviour is the tip of the 'practice iceberg' (Figure 10), with the social underpinning of behaviour (practice as entity) forming the (often much larger) invisible part. Attempts to shift behaviour towards sustainability are thus likely to have only limited effects. '[…] social practices are a better target for sustainability policy than 'behaviour', 'choice' or technical innovation alone. Understanding the dynamics of practices offers us a window into transitions towards sustainability'.

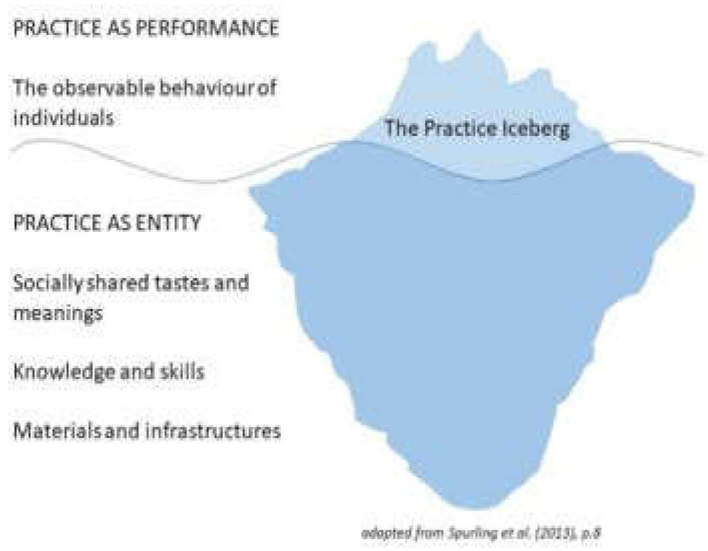


Figure 10. Source: (ENERGISE, 2019). "The Practice Iceberg"

According to the characterization in Table 1 and in line with the drivers proposed in WP2 (CULTURAL-E - Climate and cultural based design and market valuable technology solutions for Plus Energy Houses, 2020), a list of potential drivers in users' indoor comfort expectations is proposed hereafter and their connection with *IEQ* areas is highlighted (Table 2). The list of drivers is the result of a literature review -e.g. (Altman, et al., 1980) (Wilhite & Shove, 1998) (Wilhite, et al., 2000) (Hofstede, 2001) (Shove, 2005) (Brager & de Dear, 2008) (Horta, et al., 2014) (Watson, et al., 2016) (Wilhite, 2016) (Segev, 2015) (Satish, 2019) (Khovalyg, et al., 2020) (Wang, et al., 2018) (Rupp, et al., 105) (d'Ambrosio

Alfano, et al., 2017) (Grivel & Candas, 1991) (Beshir & Ramsey, 1981) (Lan, et al., 2008) (van Hoof, et al., 2017) (Taylor, et al., 1995) - and their connection with the different indoor environmental aspects is made explicit hereafter.

Material conditions

1- Industry spin, economic competition and policies. The economic level of a specific region, its policies and industry spin play a key role especially in the adoption of a certain technology. Consequently, the level of technologies available and their level of use impact the expectation of users in terms of comfort, being their adaptation background highly influenced and determined by the level of convenience they are used to. As mentioned above in the example of AC spread, in the US, by the 1950s, air-conditioning was the nation's second fastest growing industry (Brager & de Dear, 2008). It became the symbol of a growing economy, a social status, and soon changed humans' comfort expectations and their body mechanisms of un-adaptation to transient environments. A technology can be the expression of technological abundancy and of economic thrive of a nation, but silently can change peoples' level of comfort and convenience and reinforce their addiction to newly human-self-created needs. In addition to this, the spread of technologies has often political and policy consequences (Brager & de Dear, 2008), as these large populations use their voices and votes to elect representatives who will vote in matter of energy, incentives or restrictions, or other policy options that would inhibit their energy access.
2- Household size, design and construction. According to (Wilhite, et al., 2000), dwellings everywhere in the industrial world have been getting larger and larger, responding to an increasing need of specialized rooms, appliances, and the physical space needed to accommodate needs and services. This is the more evident in the recent times, when the latest COVID-19 pandemic has obliged billions of people in the world to working from home. Household characteristics, from design and construction technologies to merely taste, have during centuries always reflect cultural and societal features of a specific place in the world. In fact, thinking about the primitive vernacular architectures, these were designed to fulfil

basic needs and encounter the relationship between human and natural ecosystems, in a time where wellbeing was strictly connected with the surrounding environment and humans were still able to be resilient and adapt to variability. Thus, household characterization is a hint of the level of capacity of a specific society to cope with the natural environment, and design and construction have a role in determining comfort conditions in indoor environments. Household size and occupancy impact energy consumptions and can differ a lot basing on culture. Moreover, the importance given to design and aesthetics can also strongly impact the willingness of implementation of a system or technology.

Mentioning an example, Japan offers a view of how cultural factors can influence attitudes about comfort and the implementation of conditioning systems, technologies, and household arrangements. Japanese people prefer to condition people rather than living spaces, believing that heat and cool unoccupied spaces as a wasteful action. The traditional heating system in Japan is the *kotatsu*, a personal heater placed under the dining table, which provides a social as well as a utilitarian arrangement, and is linked to the preservation of the important social bonds of the family (Fuji & Lutzenhiser, 1992).

3- Energy access. According to (Horta, et al., 2014), predation has been for decades the predominant relational mode in Western societies. Indeed, as cultural norms and social conventions have embodied the “need” of access to services and commodities developed and made available through intensive fossil energy consumption, energy exploitation has become an imperative of economic development. However, different conditions in different European areas can lead to a differentiation in the types of energy that can be accessed and thus to a different type of technology or system adoption. The use of a system instead of one another, sometimes also promoted by legislation or policies, impact the expectations of users regarding indoor comfort parameters and subjects’ adaptation to different stimuli.

4- Economic condition. Economic scarcity and energy poverty can be a significant cause of poor salubrity and comfort inside buildings. As reported by the European Commission, energy poor households experience inadequate levels of these essential energy services, due to a combination of high energy expenditure, low household incomes, inefficient buildings and appliances, and specific household energy needs. It is estimated that more than 50 million households in the European Union are experiencing energy poverty. Adequate warmth, cooling, lighting and the energy to power appliances are essential services needed to guarantee a decent standard of living and citizens' health. Access to these energy services empowers European citizens to fulfil their potential and enhances social inclusion. Furthermore, energy poverty influences many policy areas, including health, environment and productivity. Addressing energy poverty has the potential to bring multiple benefits, including less money spent by governments on health, reduced air pollution, better comfort and wellbeing, improved household budgets, and increased economic activity. (European Commission, s.d.).

Attitudes, perceptions and social norms

5- Convenience, comfort and health. The notion of domestic comfort historically referred to attributes such as privacy, convenience, leisure and ease. In the eighteenth century, comfort was viewed just as a generalised feeling of well-being and calm contentment (Brager & de Dear, 2008). Through history, the level of expected leisure in household has changed, strictly linked with social escalation, social-status and roles. The more, health levels and importance of salubrity in indoor environments has gained greater knowledge and recognition. The level of awareness and importance given to such aspects can be a reading key for users' expectations in indoor environments.

6- Connection with natural environment and adaptation. As mentioned above, the progressive detachment to the natural ecosystems and the thrive for static, narrow and constant indoor conditions has progressively increase the gap between human adaptation mechanisms and natural seasonal cycles. Humans have slowly lost their intimate relationship with nature, and its importance in terms of necessity, delight, affection, sacredness (Brager & de Dear, 2008). This has come to the extent of an actual change in our physiology, comfort needs and thermoregulation mechanisms (Luo, et al., 2016b) (Yu, et al., 2012). The surviving relationship of a specific culture with the natural environment could be the meter for potentially estimating the amount of the loss in human physiological adaptation and resilience.

7- Living standard and socio-economic status. People are interested in having access to services and not in energy consumptions per se (Wilhite, et al., 2000). Services, obtained technologies, leisure and comfort are the face of a living standard and the expression of a person's achieved socio-economic status (Satish, 2019). As expressed in (Kahneman, et al., 1991), people are eventually led by "the endowment effect" or "divestiture aversion", and place higher value on things merely because they currently own them or have done so in living, striving for maintaining the achieved leisure and status.

8- Education level. According to Educational Theories (Chatterton, 2011), when it comes to policy implementation, behaviour plays a crucial role. In (Frederiks, et al., 2015), the authors have highlighted the difference between what households admit to what they actually do. For instance, there is an attitude-action gap, a value-action gap, a knowledge-action gap and an intention-action gap. Beside energy and environmental issues, education level also plays a fundamental role in the understanding of the proper use of a technology and a system and, a correct use, can certainly lead to a better wellbeing, health and comfort in the indoor environment.

9- Appearance, sensation and physical features. The social acceptability of sensations, odours, and physical appearance has changed through history, time and space. Just as a very blatant example, Elizabethan England as one set of cultural circumstances in which body odours were valued, compared to the contemporary times, where they are considered a social liability (Fitch, 1970). Attitudes about body odour and the social acceptability of perspiration are the expression of historical and cultural differences in what Fitch calls the 'habitat of the senses'. Different cultures and society can still maintain a certain different level of importance regarding sensations and appearance, and this results in the different level of comfort and leisure to be maintained in indoor environments to achieve such appearance baseline.

10-Age and gender. According to literature, different studies have pointed out the diversities in comfort expectations between users of different age and between males and females. For what concerns age, current thermal comfort models seem to be not sufficiently accurate to be used for elder people, since age plays an effect on the physiology of the human body and adults' adaptation or options of personal control among older people may be limited in comparison with young adults. Aged persons show impaired thermoregulatory control and may require a more intense thermal stimulus to elicit the appropriate behavioural responses in the home. It is also possible that such stimuli will result in a greater heat flow, elevating the risk of dysthermia in the aged (Taylor, et al., 1995). In (Indraganti & Rao, 2010) a significant but poor correlation was observed between age and thermal sensation and overall comfort and thermal non-acceptance was lower in older subjects. Moreover, energy access and energy poverty, connected with financial limitations, are more likely to happen with elder people, and this may lead to suboptimal living conditions and may lead to morbidity and mortality (van Hoof & Hensen, 2006) (van Hoof, et al., 2017). On the other side, children have themselves a different physiological, psychological and behavioural response to stimuli than adults. For example, in (Yun, et al., 2014) it has been shown that children were more sensitive to changes in their metabolism than adults, and their preferred temperature was lower than that predicted by the PMV model and the Adaptive Model from the standards. The results in (Teli, et al., 2012) suggest that children have a different thermal perception than adults. According to the authors, pupils' perceived overall comfort is not always related to their thermal state, i.e. some may feel hot but state that they are feeling comfortable. Children appear to have a higher metabolic rate per kg body weight and seem to experience, due to their daily schedule, a variation of activity levels and a strong relationship with the outdoor climate different to adult office activities. In addition, kids take limited adaptive action with regards to clothing during the day, but this highly depends on the socio-cultural norms and school regulations.

On the side of gender implications, the review conducted in (Karjalainen, 2012) shows that a growing number of studies have found significant differences in thermal comfort between the genders. More than half of the laboratory and field studies have found that females express more dissatisfaction than males in the same thermal environments and females seem to be more sensitive than males to a deviation from an optimal temperature and express more dissatisfaction, especially in cooler conditions.

11- Disabilities and activity level. People with disabilities have a different perception and use of the surrounding environment. In fact, they could have an impaired physiological response, as well as some limitations for what concerns behavioural and adaptation mechanisms. This can have a strong impact on all the comfort areas, depending on the type and level of disability. For example, for what concerns thermal comfort, people with physical disabilities have a different activity level and metabolic rate, do have less opportunity of adaptation by movement or clothing, and, if space and appliances are not properly designed, they can also experience difficulties in the management of systems and operation. According to (Parsons, 2002), people with disabilities have different thermal requirements due to mobility, postural and anthropometric differences as well as effects on thermoregulatory responses caused by the disability itself (blood flow, sweating, shivering, etc.) or methods to cope with the disability such as the use of drugs. Moreover, it seems that many people with physical disabilities were affected both physically and mentally when they are in a state of thermal discomfort (Hill, et al., 2000). Also in this, as for elder occupants, financial limitations can also be the cause suboptimal living conditions.

12- Family and societal structure. Basing on the cultural cognition thesis (*CCT*) by Douglas (Douglas, 1982), perceptions of societal risks are based on the values characteristic of the groups with which people identify by (Douglas & Wildavsky, 1982). According to the CCT framework, preferences and societal organization is performed by means of two cross-cutting axes: *hierarchy-egalitarianism* and *individualism-communitarianism*. In a hierarchical perspective, rights, duties and goods should be distributed differentially and on the basis of defined, stable social characteristics such as gender, wealth or ethnicity. On the contrary, an egalitarian worldview foresees that the distribution should be performed equally in the society. In addition to this, people with a ‘communitarian’ or collectivistic belief assert that societal interests should come before individual ones and that society should be responsible for securing the conditions necessary for individuals to thrive. Contrary to this, an individualistic worldview believe does not account for a collective interference or assistance. Given this, collectivism has a crucial role into shaping pro-environmental worldviews and values (Segev, 2015). Same mechanisms can be translated into the smaller scale of a household environment: according to Triandis (Triandis, 1995), collectivism includes interdependence among people, ingroup harmony and consensus and prioritizing group goals over the goals of the individual. The behaviour of collectivists is often driven by social norms and the willingness to share resources, activities and occasions with other family members, and this clearly can unload the energy consumptions burden if compared to an individualistic management, where each family member acts by his own and with its very objectives.

According to Hofstede (Hofstede, 2001) (Hofstede, 1991) this analysis can be performed by means of four dimensions, which are *i) power distance, ii) uncertainty avoidance, iii) individualism as opposed to collectivism, and iv) masculinity as opposed to femininity*. Definitions hereafter are cited from the Hofstede’s book review by Arrindell (Arrindell, 2003). Power distance is the extent to which the members of a society accept that power in institutions and organizations is distributed unequally. Uncertainty avoidance accounts for the degree to which the members of a society feel uncomfortable with uncertainty and ambiguity, leading them to support beliefs that promise certainty and to maintain institutions that protect conformity. Individualism stands for a preference for a loosely knit social framework in which individuals are supposed to take care of themselves and their immediate families only, as opposed to collectivism, which stands for a preference for a tightly knit social framework in which individuals can expect their relatives, clan, or other in-group to look after them, in exchange for unquestioning loyalty. Masculinity stands for a society in which social gender roles are clearly distinct: men are supposed to be assertive, tough, and focused on material success; women are supposed to be more modest, tender, and concerned with the quality of life. Femininity stands for a society in which social gender roles overlap and both genders are supposed to be modest, tender, and concerned with the quality of life. In this perspective, observing family and societal structures among different cultures according to these aspects can give deeper hints on the process by which environmental-related and pro-environmental behaviours are shaped, and thus provides a more realistic model for predicting conservation behaviour, energy end use patterns, and the levels of convenience and leisure preferred at a household level. In fact, the choice of a hierarchy-egalitarianism or an individualism-communitarianism approach shapes the management and organization of household activities, timing and spaces, thus having a direct effect on indoor conditions and usability patterns.

13- Media and marketing. The spread of a particular technology or the adoption of a policy can be boosted by media ad advertising techniques. For example, as for the air conditioning arise, this was promoted as the solution to social dilemmas and as a necessity for the ideal home. In particular, the advertisements played on the renewed domestic role of women and the family, the importance of convenience and leisure, and changing attitudes about comfort and nature (Brager & de Dear, 2003). Aside from industry spin and natural time turnovers, usually media and marketing have helped transitions and characterizations, leading the way to the consolidated images of family in our belief, with implications on the role of women and the family in the society, the importance of convenience and leisure, appearance codes, space and time management, addiction to a technology as an entitlement as a living standard, and to the final extent also changing attitudes about comfort and the environment.

Everyday practices

14- Activities and meanings. Contemporary societies have re-shaped the “normal” routine of the everyday life: an active life versus a more sedentary and relaxed routine can have different reverberations in the way users perceive the spaces they live in and the meaning subjects give to the scape they are surrounded by. Occasions and activities are changing through time and belong to the very essence of each specific culture. The pace at which people live their everyday life changes the pace at which they live buildings and homes, changing their relationship with the organization of spaces and with their expectations of convenience of a certain indoor environment, in correlation with the functionality and purpose of a specific space (Altman, et al., 1980).

15-Life-working balance and biorhythms. Everyday life and activities are strictly connected to the family and societal structure, and can be declined into different aspects. Starting from *working-life balance*, yet in 1997 Erickson (Erickson, 1997)conducted a cross-cultural ethnographic survey about the "scheduling" aspect of convenience. The author spotted that being "busy", in contemporary society, was an important indicator of a successful life, and this has led during the years to a change in working schedules and in space organization to accomplish those schedules. This was confirmed in another anthropological study conducted in the "Silicon Valley" in California (Knowlton, 1999), where people used an inordinate amount of time in "making their busy lives manageable". To the purpose, people during the years have started to equip their homes so as to manage work, also during night shifts and to stop their fear of missing out. That was the starting of a new era, which is by now a fundamental point in our society, where people started to manage schedules among family members, to organize home-office space, to re-arrange domestic spaces and life. It was a first clear signal of an upcoming change in the concept of home, in our very notion of convenience, leisure and comfort, in the reshaping of family bonds, and all this led to significant increases in household energy consumptions. Conventions started to evolve, comfortably but energy-intensive ways of life become normal and embedded in society (Wilhite, et al., 2000).

16-Time-space management. This shift in work-life balance has obviously led also to the definition of societal patterns, in particular in the ones known by Altman and Rapoport (Altman, et al., 1980) as *i) organization of space* -i.e. purposes, activities, values-, *ii) organization of meaning* -i.e. social status, social identity, income, appropriate behaviour, cognitive schemata organization-, *iii) organization of communication* -social interactions, movement patterns, privacy needs-, *iv) organization of time* -i.e. time flow, future/past, rhythms of human activities-. Many of these aspects can be grouped into *occasions* -i.e. who does what, with whom, when and in what context, and where (Altman, et al., 1980). The spatiotemporal framework of occasions and activities was changing, changing homes' design, size and arrangement. From now people are struggling for privacy and convenience also into their own family mechanisms, and this has marked even thicker the line among different cultures, where individualism is opposed to collectivism, masculinity is opposed to femininity and a generations turnover is changing the conventions stratified into societies. The different arrangements in terms of space, meaning, communication and time are deeply nested in the different societies, translated into our own idea of home, and are embedded in their design: this has obviously caused implications in the end use energy demand and in the management of wellbeing and functionality in indoor environments.

The proposed approach is a first attempt to identify main potential drivers affecting users' comfort expectations and attitudes towards the environment, trying to fill the gap that still exists in the research field of IEQ and energy demand. Obviously, the subject is not an immediate task, since it requires the joint effort of different disciplines and knowledge, from architecture, engineering and building physics, to social sciences, physiology, etc... In the following months of work of WP5 this first attempt of identifying main drivers will be deepened and validated. The aim is to propose a framework of drivers useful to analyse and characterize different users' profiles and patterns according to their main socio-cultural features and background.

Table 2. Potential drivers affecting users' comfort expectations and behaviours in indoor environments

	MATERIAL CONDITIONS				ATTITUDES, PERCEPTIONS AND SOCIAL NORMS									EVERYDAY PRACTICES		
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
ENVIRONMENTAL ASPECT	**Industry spin, economic competition and policies**	**Household size, design and construction**	**Energy access**	**Economic condition**	**Convenience, comfort and health**	**Connection with natural environment and adaptation**	**Living standard and socio-economic status**	**Education level**	**Appearance, sensation and physical features**	**Age and gender**	**Disabilities and activity level**	**Family and societal structure**	**Media and marketing**	**Activities and meanings**	**Life-working balance and biorhythms**	**Time-space management**
Air Quality environment	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓			
Hygro-thermal environment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Visual environment	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓
Acoustic environment	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓		✓	✓
Human nature environment	✓	✓		✓	✓	✓	✓	✓				✓	✓		✓	✓

8. Assessing diversities from data: analysis of existing databases

In order to identify existing differences in comfort expectations (Figure 11), the literature analysis has been integrated with the investigation of existing databases concerning users' feedbacks in indoor environments. With this aim, two main repositories in the field have been selected, namely the i) *ASHRAE Global Thermal Comfort Database II* and the ii) *Smart Controls and Thermal comfort (SCATs)* database.

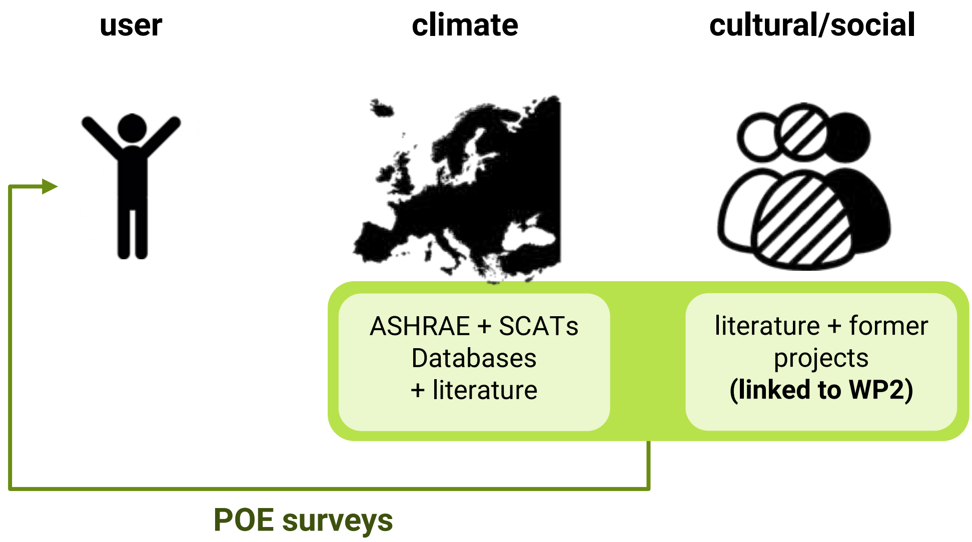


Figure 11. Task 5.1 workflow

8.1. ASHRAE Global Thermal Comfort Database II (Földváry Ličina, et al., 2018)

The ASHRAE Global Thermal Comfort Database II project was launched in 2014 under the leadership of the Center for the Built Environment of the University of California at Berkeley's and The University of Sydney's Indoor Environmental Quality Laboratory. The scope of the initiative was to collect the raw data coming from field studies focusing merely on thermal comfort, conducted worldwide during the last two decades. The outcome is an online, open-source database, which includes approximately 81 846 sets of objective indoor climatic observations with accompanying "right-here / right-now" subjective responses given by the building occupants who were exposed to them. The database can be consulted through a web-based interface which allows to filter data by means of multiple criteria (Figure 14), e.g. building typology, occupancy type, subjects' demographic variables, subjective thermal comfort states, indoor thermal environmental criteria, calculated comfort indices, environmental control criteria and outdoor meteorological information. As it can be observed from Figure 13 and Figure 14, data include different countries around the world and refer to various climates. According to (Földváry Ličina, et al., 2018), all datasets from individual studies underwent a stringent quality assurance process before being included. However, due to the intrinsic nature of this database, being a collection of different studies conducted at different levels by different research teams, data have actually revealed to be highly heterogeneous and to some extent inconsistent.

For what concerns raw data referring to Europe, this consists of the largest sample size in the set with 31 392 observations. Distribution is described in Table 3.

Table 3. Adapted from: (Földváry Ličina, et al., 2018). Sample size distribution according to the data's experimental location in the ASHRAE Global Thermal Comfort Database II

		Cooling strategy				
		Air conditioning	Mixed mode	Mechanically ventilated	Natural ventilation	Undefined
Europe n = 31 392	Classroom	8	0	170	3 034	0
	Multifamily housing	0	0	0	1 242	0
	Office	11 408	2 191	1 386	11 944	0

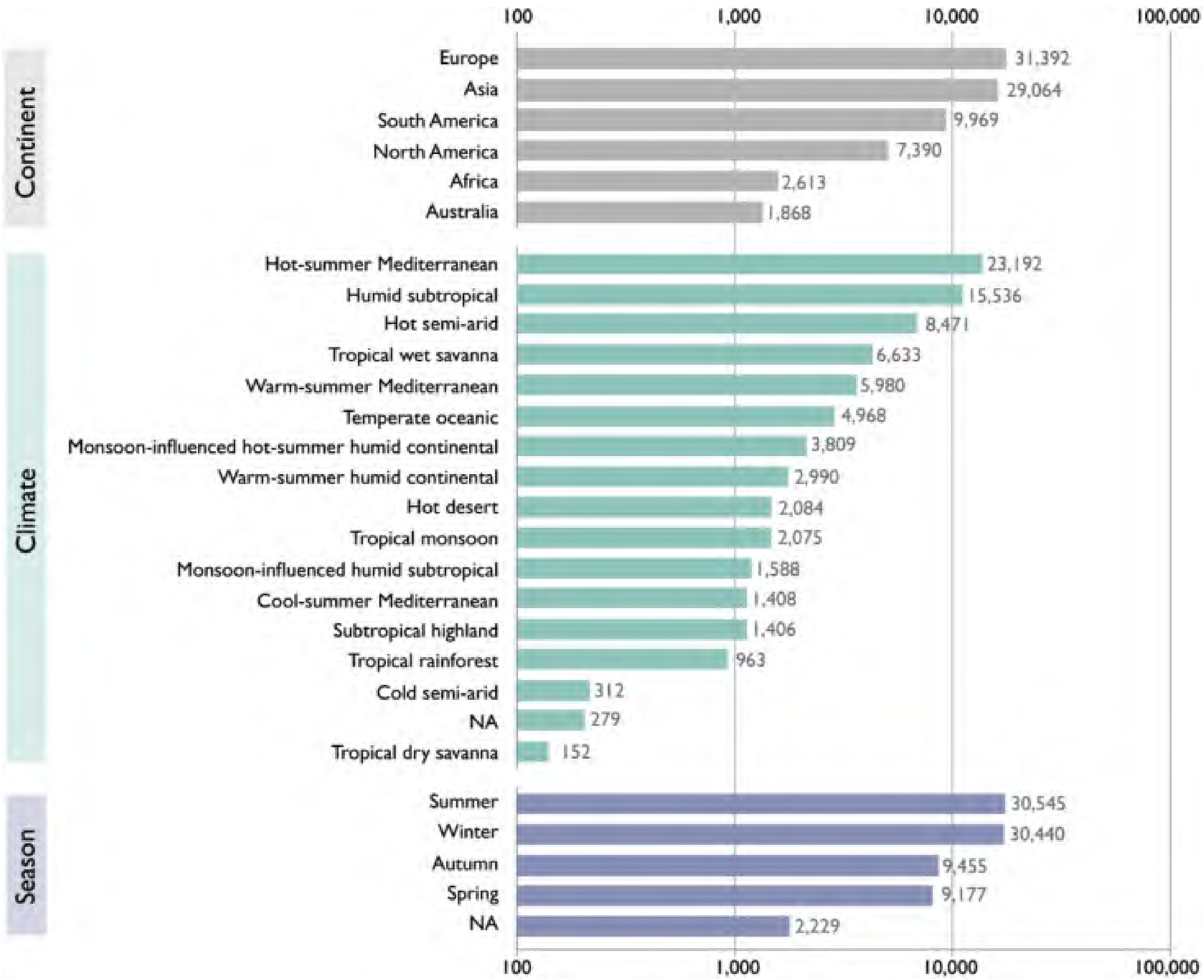


Figure 12. Source: (Földváry Ličina, et al., 2018). Distribution of thermal comfort data by continent in the ASHRAE Global Thermal Comfort Database II

Figure 13. Source: (Földváry Ličina, et al., 2018). Location of the field studies contained in the ASHRAE Global Thermal Comfort Database II

Variable	Description
Basic Identifiers	
Publication (Citation)	Published paper describing the project from where the data was collected
Data contributor	Principal Investigator of the study
Year	Year when the field study was conducted
Season	Spring, Summer, Autumn, Winter
Climate	Köppen climate classification
City	City where the study was done
Country	Country where the study was done
Building type	Classroom, Multifamily housing, Office, Senior Center, others
Cooling strategy	Air Conditioned, Mechanically Ventilated, Mixed Mode, Naturally Ventilated
Subjects' Personal Information	
Age	Age of the participants
Sex	Male, Female, Undefined
Subject's Weight	Participating subject's weight (kg)
Subject's Height	Participating subject's height (cm
Subjective Thermal Comfort Information	
Thermal sensation	ASHRAE thermal sensation vote, from −3 (cold) to +3 (hot)
Thermal acceptability	0-unacceptable, 1-acceptable
Thermal preference	cooler, no changes, warmer
Air movement acceptability	0-unacceptable, 1-acceptable
Air movement preference	less, no change, more
Thermal comfort	From 1-very uncomfortable to 6-very comfortable
Clo	Intrinsic clothing ensemble insulation of the subject (clo)
Met	Average metabolic rate of the subject (Met)
activity_10	Metabolic activity in the last 10 min (Met)
activity_20	Metabolic activity between 20 and 10 min ago (Met)
activity_30	Metabolic activity between 30 and 20 min ago (Met)
activity_60	Metabolic activity between 60 and 30 min ago (Met)
Humidity sensation	3-very dry, 2-dry, 1-slightly dry, 0-just right, -1slightly humid, -2-humid, -3-very humid
Instrumental Thermal Comfort Measurements	
Air temperature	Air temperature measured in the occupied zone (°C, °F)
Ta_h	Air temperature at 1.1 m above the floor (°C, °F)
Ta_m	Air temperature at 0.6 m above the floor (°C, °F)
Ta_l	Air temperature at 0.1 m above the floor (°C, °F)
Operative temperature	Calculated operative temperature in the occupied zone (°C, °F)
Radiant temperature	Radiant temperature measured in the occupied zone (°C, °F)
Globe temperature	Globe temperature measured in the occupied zone (°C, °F)
Tg_h	Globe temperature at 1.1 m above the floor (°C, °F)
Tg_m	Globe temperature at 0.6 m above the floor (°C, °F)
Tg_l	Globe temperature at 0.1 m above the floor (°C, °F)
Relative humidity	Relative humidity (%)
Air velocity	Air speed (m/s, fpm)
Velocity_h	Air speed at 1.1 m above the floor (m/s, fpm)
Velocity_m	Air speed at 0.6 m above the floor (m/s, fpm)
Velocity_l	Air speed at 0.1 m above the floor (m/s, fpm)
Calculated Indices	
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
SET	Standard Effective Temperature (°C, °F)
Environmental Control	
Blind (curtain)	State of blinds or curtains if known (0-open, 1-closed); otherwise NA-non applicable
Fan	Fan mode if known (0-off, 1-on); otherwise NA-non applicable
Window	State of window if known (0-open, 1-closed); otherwise NA-non applicable
Door	State of doors if known (0-open, 1-closed); otherwise NA-non applicable
Heater	Heater mode if known (0-off, 1-on); otherwise NA-non applicable
Outdoor monthly air temperature	Outdoor monthly average temperature when the field study was done (°C, °F)

Figure 14. Adapted from: (Földváry Ličina, et al., 2018). Variable coding conventions in the ASHRAE Global Thermal Comfort Database II

As stated in (Földváry Ličina, et al., 2018), main information was labelled as follows.

- Basic identifiers, such as building code, geographical location, year of the measurements, and heating/cooling strategy.
- Personal information about the subjects participating in the field studies, such as sex, age, height, and weight.
- Subjective thermal comfort questionnaire, such as sensation, acceptability, and preference, as well as self-assessed metabolic rate (met) and clothing intrinsic thermal insulation level (clo).
- Instrumental measurements indoor climate, including various types of temperatures, air velocity, relative humidity.
- Comfort indices, including Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), and Standard Effective Temperature (SET) calculated uniformly throughout the entire database using a calculator that was fully compliant with the ISO Standard 7730 (CEN - European Commitee of Standardization, 2005) sourcecode in the case of PMV and PPD calculations, and ASHRAE/ANSI Standard 55 (ANSI/ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017)sourcecode in the case of the 2-node SET index. Compliance of the calculator was checked by applying it to the validation datasets supplied in appendices to the two standards.
- Indoor environmental controls available (blinds, fan, operable window, door, heater).
- Outdoor meteorological information, such as monthly average temperatures. Some original data submissions contained relevant meteorological data. For cases without those data, fields meteorological data were updated based on archival weather data sourced from weather station websites based on the available information about location and the time of the measurements.

Despite the huge effort by the project towards creating a homogeneous database, by using a standardized spreadsheet format for collecting information from the different studies, due to the intrinsic nature of this repository, data have been revealed difficult to be gathered into a consistent and complete sample for conducting analysis in WP5. The main reasons are that: i) field studies were conducted at different times in a very extended time range, adding a time-dependent variable to the analysis; ii) different

studies do not have all the same data available, both in terms of subjective and objective evaluations, making difficult the conduction of consistent analysis and statistics.
In order to create the first database for WP5 investigations, raw data from the web-based platform have been firstly filtered according to the following targets:

- Location: Europe
- Building typology: all typologies
- Year: all years
- Cooling strategy: all typologies

Despite our investigation regards PEHs, and thus residential facilities, the choice of including all the typologies in the dataset has been due to the necessity of a consistent sample size for the following analysis. In fact, being the aim of our research to identify occupants' comfort preferences according to climate/country specific variables, we have not considered the building typology as a main discriminant feature. However, to obtain consistent data, the metabolic rate of respondents has been filtered to 0.8 ≤ MET ≤ 1.3, as the activity level that can be found in residential buildings according to standards (ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017).
The final sample size consisted of 24 962 observations, ascribable to 5 climates:

- Hot-summer Mediterranean [Temperate, Csa]
- Warm-summer Mediterranean [Temperate, Csb]
- Warm-summer Humid Continental [Continental, Dfb]
- Mild Temperate [Temperate, Cwa]
- Temperate Oceanic [Temperate, Cfb]

For data analysis scope, also connected with the users' clothing level, data were divided into two season-specific groups, i) spring-summer and ii) autumn-winter, with a size of respectively 13 080 and 11 882 observations.

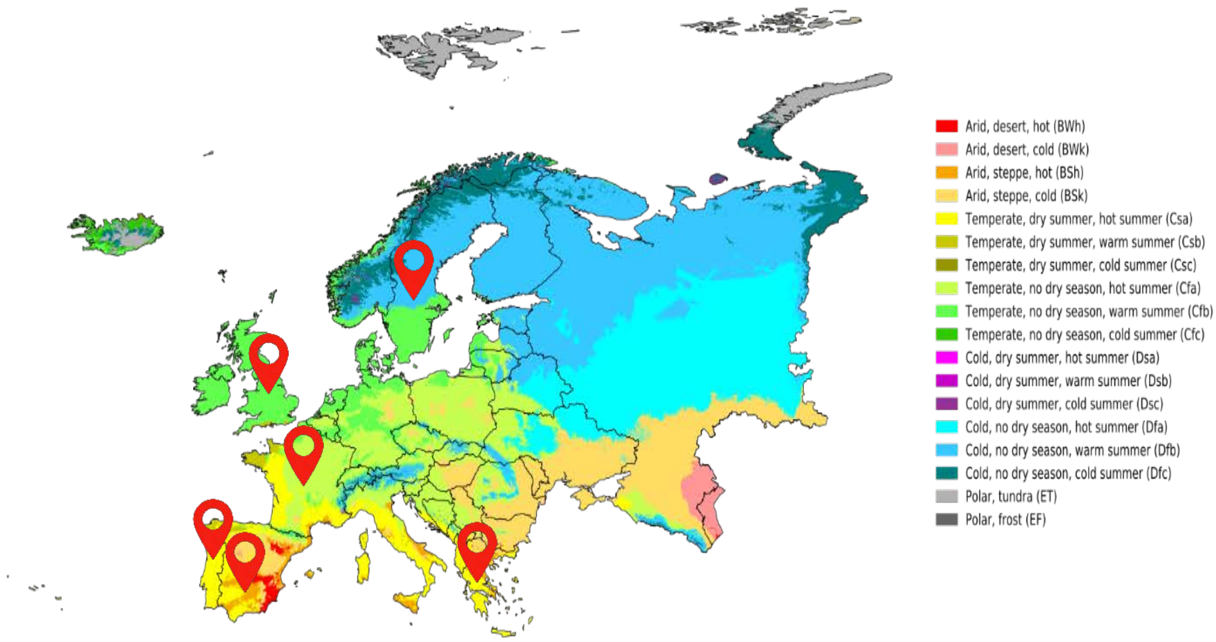
8.2. Smart Controls and Thermal comfort (*SCATs*) database (McCartney & Nicol, 2002)

In addition to the ASHRAE database recommended in the CULTURAL-E project proposal, another database has been identified as considered of importance for the research work. The SCATs project was developed and ran from December 1997 to December 2000 with the goal of providing a method of reducing energy consumption in air-conditioned buildings by developing control systems that could utilise the principles of adaptive comfort theory. Oxford Brookes University acted as project coordinator and led a consortium of academic and industrial researchers from the UK, France, Sweden, Greece and Portugal. The project was designed around the adaptive comfort theory (Paragraph 6) and one of the main results has been the creating of a consistent database about thermal comfort field studies across Europe, then used to develop the Adaptation Control Algorithm. Actually, one great feature of this database is that, contrarily to the ASHRAE one, it contains information not only about the thermal environment, but it extends also to other comfort areas and investigates users' adaptation attitudes towards the environment.

For what concerns the monitoring of environmental parameters, the database includes the following observations:

- air temperature (°C)
- globe temperature (°C)
- relative humidity (%)
- air velocity (m s^{-1})
- CO2 concentration (ppm)
- illuminance at working plane (lux) and
- background noise level (dB(A) and dB(lin))

The survey campaign was conducted in the five countries across Europe represented by the SCATs consortium, i.e. France, Greece, Portugal, Sweden and UK as highlighted in Figure 15.



Source: Beck et al.: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018)

Figure 15. Köppen-Geiger climate classification map for Europe (2071-2100)

Five buildings were studied in each country and there was a variety of servicing type, building construction, size and use. The buildings selected are shown in Figure 16. Two types of questionnaire were used in the field studies: transverse and longitudinal.

Country	Building	Location	Function	Weight	NV/AC	Occupants
France	F1	Lyon	University teaching	HW	NV	35
	F2	Lyon	University administration	HW	MV	36
	F3	Lyon	Energy advice	MW	AC	30
	F4	Lyon	Military	LW	MV	200
	F5	Lyon	Office	MW	NV	150
Greece	G1	Athens	University	MW	AC	59
	G2	Athens	Architects	MW	MM	40
	G3	Athens	University	HW	NV	100
	G4	Athens	Architects	HW	NV	4
	G5	Athens	Architects	MW	AC	12
Portugal	P1	Porto	Innovation centre	LW	PP	70
	P2	Porto	Office	MW	NV	200
	P3	Porto	Office	HW	NV	24
	P4	Porto	Utility	MW	PP	214
	P5	Afragida	Energy advice	HW	NV	50
Sweden	S1	Goteborg	University	HW	PP	100
	S2	Malmo	Office	MW	AC	130
	S3	Goteborg	Engineering	MW	AC	200
	S4	Goteborg	Engineering	MW	AC	150
	S5	Halmstad	Trade centre	LW	AC	100
UK	U1	London	Publishing	LW	MM	250
	U2	London	Local authority	LW	AC	400
	U3	London	Local authority	LW	NV	308
	U4	London	Local authority	LW	AC	na[a]
	U5	London	Data managers	LW	AC	120
	U6	London	Local authority	HW	NV	350

Figure 16. Source: (McCartney & Nicol, 2002). Buildings used in field studies in SCATs database

Aside from microclimatic monitored data, the database offers interesting hints about users' activities and controls inside the environment, which for CULTURAL-E have been considered interesting for spotting dynamics and attitudes of subjects in different countries. Elaborated questions are specified from Figure 17 to Figure 21.

For the following items, please indicate **how important it is to you** to have *personal* control over them (i.e. you can *physically make* adjustments yourself). Please answer regardless of whether or not you have the control available in your building.

	Very Important	Important	No Preference	Unimportant
Open or close a window	[ ]	[ ]	[ ]	[ ]
Adjust curtains or blinds	[ ]	[ ]	[ ]	[ ]
Open or close an internal door	[ ]	[ ]	[ ]	[ ]
Open or close an external door	[ ]	[ ]	[ ]	[ ]
Adjust a thermostat	[ ]	[ ]	[ ]	[ ]
Adjust a local heater/ radiator	[ ]	[ ]	[ ]	[ ]
Turn lighting on or off (your desk only)	[ ]	[ ]	[ ]	[ ]
Turn office lighting on or off	[ ]	[ ]	[ ]	[ ]
Adjust office lighting level (dimmer switch)	[ ]	[ ]	[ ]	[ ]
Adjust office air-conditioning	[ ]	[ ]	[ ]	[ ]
Adjust a local fan/ air outlet	[ ]	[ ]	[ ]	[ ]

For the following items, please indicate whether or not you actually have personal control over their adjustment.

Figure 17. Source: SCATs transverse database. Personal control importance

			If YES, how often do you actually make adjustments?			
	No	Yes	Often	Sometimes	Seldom	Never
Open or close a window	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Adjust curtains or blinds	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Open or close an internal door	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Open or close an external door	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Adjust a thermostat	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Adjust a local heater/ radiator	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Turn lighting on or off (your desk only)	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Turn office lighting on or off	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Adjust office lighting level (dimmer switch)	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Adjust office air-conditioning	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Adjust a local fan/ air outlet	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Figure 18. Source: SCATs transverse database. Use and frequency of use of personal controls

For the controls that you are able to personally adjust, does altering them bring effective relief to any discomfort?

	Always	Often	Sometimes	Seldom	Never
Opening or closing a window	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting blind or curtains	[ ]	[ ]	[ ]	[ ]	[ ]
Opening or closing an internal door	[ ]	[ ]	[ ]	[ ]	[ ]
Opening or closing an external door	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting a thermostat	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting a local heater/ radiator	[ ]	[ ]	[ ]	[ ]	[ ]
Turning desk lighting on or off	[ ]	[ ]	[ ]	[ ]	[ ]
Turning office lighting on or off	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting level of office lighting	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting office air-conditioning	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting local fans/ air outlets	[ ]	[ ]	[ ]	[ ]	[ ]

Figure 19. Source: SCATs transverse database. Relief given by personal controls

For the controls that you are able to personally adjust, how *quickly* does a change bring effective comfort?

	Instantly	Within An Hour	Within Half a Day	Within A Day	Never
Opening or closing a window	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting blind or curtains	[ ]	[ ]	[ ]	[ ]	[ ]
Opening or closing an internal door	[ ]	[ ]	[ ]	[ ]	[ ]
Opening or closing an external door	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting a thermostat	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting a local heater/ radiator	[ ]	[ ]	[ ]	[ ]	[ ]
Turning desk lighting on or off	[ ]	[ ]	[ ]	[ ]	[ ]
Turning office lighting on or off	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting level of office lighting	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting office air-conditioning	[ ]	[ ]	[ ]	[ ]	[ ]
Adjusting local fans/ air outlets	[ ]	[ ]	[ ]	[ ]	[ ]

Figure 20. Source: SCATs transverse database. Relief velocity by each personal control

Listed below are a number of factors which may or may not affect the working environment. Please indicate on the scale how important you consider these factors to be in establishing a good working environment.

	Not at all Important						**Very Important**
A friendly atmosphere	1	2	3	4	5	6	7
A job you enjoy	1	2	3	4	5	6	7
A comfortable room temperature	1	2	3	4	5	6	7
Adequate fresh air	1	2	3	4	5	6	7
Freedom from draughts	1	2	3	4	5	6	7
An acceptable humidity level	1	2	3	4	5	6	7
Good artificial lighting conditions	1	2	3	4	5	6	7
A view from a window	1	2	3	4	5	6	7
Adequate daylight	1	2	3	4	5	6	7
Freedom from glare	1	2	3	4	5	6	7
An acceptable background noise level	1	2	3	4	5	6	7
A good office layout and decor	1	2	3	4	5	6	7
A clean office	1	2	3	4	5	6	7
Adequate privacy	1	2	3	4	5	6	7
Personal control over environmental conditions	1	2	3	4	5	6	7

Figure 21. Source: SCATs transverse database. Importance of environmental aspects

With respect to the analysis to be performed and consistency of data, in WP5 data collected from the transverse survey were used. According to (McCartney & Nicol, 2002), the transverse questionnaire was administered once a month, generally over the course of a whole day. To avoid bias, subjects were questioned in a different order each month. Simultaneous environmental measurements were taken using the new instrumentation. The advantage of transverse surveys is that a large sample of a building's population can be surveyed on the same day providing a good cross-section of responses but, on the contrary, it is important to notice that answers are specific in time.

The database, despite being a way more restricted as sample size than the ASHRAE one, has revealed to be homogeneous and more consistent, being created with field studies designed and conducted inside the same project and in the same time range. The first raw dataset consisted of 4 655 observations. The following filtering criteria were applied as for the former database:

- Building typology: all typologies
- Year: all years
- Cooling strategy: all typologies

Also in this case, we have not considered the building typology as a main discriminant feature but the metabolic rate of respondents has been filtered to $0.8 \leq MET \leq 1.3$ (ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017). The final dataset for WP5 analysis consists of 1 270 and 1 586 observations for the spring-summer and autumn-winter time respectively.

9. ASHRAE and SCATs databases: performed analysis

The choice of the analysis to be performed with the databases has been made with respect to the data characterization of each dataset and information available. The workflow for this investigation has been elaborated as a stepwise approach, as explained below.

Figure 22. Workflow for data analysis

1. Initial databases: data from ASHRAE and SCATs databases have been collected.
2. Filtered datasets: by means of the criteria explained above, data have been filtered according to the aims of the analysis.
3. Descriptive statistics: data have been analysed by means of basic descriptive statistics and plot visualization (sample size, mean, median, quartiles).
4. Statistical models and inference: in order to obtain strong evidence and allow generalization, statistical models are developed with input variables and implemented.
5. Generalization: findings are collected and translated into significant outputs, as a valuable contribution in the research field and useful for other WPs' activities.

According to the data available, the following descriptives have been performed.

Table 4. Nomenclature and units

Nomenclature and units			
SET	Standard Effective Temperature [°C]	*Tair*	Indoor Air Temperature [°C]
Tmrt	Mean Radiant Temperature [°C]	*Top*	Operative Temperature [°C]
RH	Relative Humidity [%]	*Vair*	Air Velocity [m s^{-1}]
TSV	Thermal Sensation Vote [-]	*HSV*	Humidity Sensation Vote [-]
ASV	Air Movement Sensation Vote [-]	*CLO*	Clothing Level [-]

Table 5. Performed analysis for each database

Performed descriptive			ASHRAE Global Thermal Comfort Database II	Smart Controls and Thermal comfort
Thermal Comfort	SET vs TSV	spring-summer	✓	✓
		autumn-winter	✓	✓
	Tair vs TSV	spring-summer	✓	✓
		autumn-winter	✓	✓
	Tmrt vs TSV	spring-summer		✓
		autumn-winter		✓
	Top vs TSV	spring-summer	✓	✓
		autumn-winter	✓	✓
	RH vs HSV	spring-summer	✓	✓
		autumn-winter	✓	✓
	Vair vs ASV	spring-summer		✓
		autumn-winter		✓
	CLO vs Tair	spring-summer	✓	✓
		autumn-winter	✓	✓
	CLO vs RH	spring-summer	✓	✓
		autumn-winter	✓	✓
	CLO vs Vair	spring-summer	✓	✓
		autumn-winter	✓	✓
Environmental control	Importance			✓
	Use			✓
	Frequency of use			✓
	Relief estimation			✓
	Relief velocity			✓
	Other environmental aspects			✓

Table 6. Evaluation scales

Evaluation Scales		
Parameter	*ASHRAE Global Thermal Comfort Database II*	*Smart Controls and Thermal comfort*
TSV	from -3 (cold) to +3 (hot), being 0 the neutrality	from 1 (cold) to 7 (hot), being 4 the neutrality
HSV	from -3 (very dry) to +3 (very humid), being 0 the neutrality	from 1 (very humid) to 7 (very dry), being 4 the neutrality
ASV		from 1 (very low) to 7 (very high), being 4 the neutrality
Importance		from 1 (very important) to 4 (unimportant)
Use		0 (No) – 1 (Yes)
Frequency of use		from 1 (often) to 4 (never)
Relief estimation		from 1 (always) to 5 (never)
Relief velocity		from 1 (instantly) to 5 (never)
Other environmental aspects		from 1 (not at all important) to 7 (very important)

Data and plots are presented in **APPENDIX A** and

APPENDIX B, for ASHRAE Global Thermal Comfort Database II and Smart Controls and Thermal Comfort (SCATs) database respectively.

At this stage of the work first considerations can be drawn only by means of data plots. First assumptions are indicated hereafter, but they certainly need the integration by solid statistical models so as to validate and consolidate findings. This further statistical stage has already been undertaken and will be conducted in the next months of WP5.

The findings presented hereafter certainly need to be further discussed and deeply considered in the perspective of WP5 expected outcomes, especially for what concerns the outputs to be delivered for the development of WP4's simulation campaign and for the implementation of demo cases, for what concerns indoor spaces requirements, system management, operational choices, implementation of solution technologies and users' interfaces, according to subjects' preferences and attitudes derived from their grasped background and adaptation mechanisms.

9.1 ASHRAE database: spring-summer period (APPENDIX A)

Standard Effective Temperature VS Thermal Sensation Vote (Figure 23)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ TSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 22 °C ≤ SET≤ 25 °C
- Warm-summer Mediterranean: 25 °C ≤ SET≤ 28 °C
- Warm-summer Humid Continental: 22 °C ≤ SET≤ 24 °C
- Mild Temperate: 24 °C ≤ SET≤ 25 °C
- Temperate Oceanic: 24 °C ≤ SET≤ 27 °C

Indoor Air Temperature VS Thermal Sensation Vote (Figure 24)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ TSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 22 °C ≤ Tair ≤ 24 °C
- Warm-summer Mediterranean: 22 °C ≤ Tair ≤ 25 °C
- Warm-summer Humid Continental: 21 °C ≤ Tair ≤ 22 °C
- Mild Temperate: 26 °C ≤ Tair ≤ 27 °C
- Temperate Oceanic: 22 °C ≤ Tair ≤ 25 °C

Operative Temperature VS Thermal Sensation Vote (Figure 25)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ TSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 20 °C ≤ Top ≤ 24 °C
- Warm-summer Mediterranean: NA
- Warm-summer Humid Continental: 21 °C ≤ Top ≤ 24 °C
- Mild Temperate: NA
- Temperate Oceanic: NA

Relative Humidity VS Humidity Sensation Vote (Figure 26)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ HSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 25 % ≤ RH ≤ 55 %
- Warm-summer Mediterranean: 25 % ≤ RH ≤ 60 %
- Warm-summer Humid Continental: 30 % ≤ RH ≤ 70 %
- Mild Temperate: 40 % ≤ RH ≤ 60 %
- Temperate Oceanic: 25 % ≤ RH ≤ 60 %

Indoor Air Temperature VS Clothing Level (Figure 27)

With reference to the ranges of Indoor Air Temperature previously observed (i.e. ranges referring to -0.5 ≤ TSV ≤ +0.5), clothing levels (clo) are distributed as follows.

- Hot-summer Mediterranean: 0.66 ≥ clo ≥ 0.63
- Warm-summer Mediterranean: 0.91 ≥ clo ≥ 0.64
- Warm-summer Humid Continental: 0.67 ≥ clo ≥ 0.64
- Mild Temperate: 0.58 ≥ clo ≥ 0.42
- Temperate Oceanic: 0.77 ≥ clo ≥ 0.45

Relative Humidity VS Clothing Level (Figure 28)

With reference to the ranges of Relative Humidity previously observed (i.e. ranges referring to -0.5 ≤ HSV ≤ +0.5), clothing levels (clo) are distributed as follows.

- Hot-summer Mediterranean: 0.65 ≥ clo ≥ 0.60
- Warm-summer Mediterranean: 0.82 ≥ clo ≥ 0.68
- Warm-summer Humid Continental: 0.63 ≥ clo ≥ 0.41
- Mild Temperate: 0.57 ≥ clo ≥ 0.35
- Temperate Oceanic: 0.63 ≥ clo ≥ 0.51

Air Velocity VS Clothing Level (Figure 29)

Being not possible to assess sensation votes regarding Air Velocity, clothing levels (clo) assessed considering all Vair ranges between 0.0 and 0.5 m s^{-1}.

- Hot-summer Mediterranean: 0.64 ≥ clo ≥ 0.45
- Warm-summer Mediterranean: 0.75 ≥ clo ≥ 0.6
- Warm-summer Humid Continental: 0.65 ≥ clo ≥ 0.45
- Mild Temperate: 0.49 ≥ clo ≥ 0.37

- Temperate Oceanic: 0.76 ≥ clo ≥ 0.53

9.2 ASHRAE database: autumn-winter period (APPENDIX A)

Standard Effective Temperature VS Thermal Sensation Vote (Figure 30)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ TSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 23 °C ≤ SET≤ 28 °C
- Warm-summer Mediterranean: 25 °C ≤ SET≤ 28 °C
- Warm-summer Humid Continental: NA
- Mild Temperate: 24 °C ≤ SET≤ 26 °C
- Temperate Oceanic: 21 °C ≤ SET≤ 27 °C

Indoor Air Temperature VS Thermal Sensation Vote (Figure 31)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ TSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 21 °C ≤ Tair ≤ 24 °C
- Warm-summer Mediterranean: 21 °C ≤ Tair ≤ 25 °C
- Warm-summer Humid Continental: NA
- Mild Temperate: 23 °C ≤ Tair ≤ 26 °C
- Temperate Oceanic: 21 °C ≤ Tair ≤ 23 °C

Operative Temperature VS Thermal Sensation Vote (Figure 32)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ TSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 26 °C ≤ Top ≤ 29 °C
- Warm-summer Mediterranean: 22 °C ≤ Top ≤ 26 °C
- Warm-summer Humid Continental: NA
- Mild Temperate: NA
- Temperate Oceanic: : 20 °C ≤ Top ≤ 24 °C

Relative Humidity VS Humidity Sensation Vote (Figure 33)

Observing the majority of observations in the sample for each climate which mean ranges -0.5 ≤ HSV ≤ +0.5, the following hypothesis can be drawn.

- Hot-summer Mediterranean: 25 % ≤ RH ≤ 50 %
- Warm-summer Mediterranean: 25 % ≤ RH ≤ 65 %
- Warm-summer Humid Continental: 50 % ≤ RH ≤ 65 %
- Mild Temperate: NA
- Temperate Oceanic: 20 % ≤ RH ≤ 60 %

Indoor Air Temperature VS Clothing Level (Figure 34)

With reference to the ranges of Indoor Air Temperature previously observed (i.e. ranges referring to -0.5 ≤ TSV ≤ +0.5), clothing levels (clo) are distributed as follows.

- Hot-summer Mediterranean: 0.93 ≥ clo ≥ 0.90
- Warm-summer Mediterranean: 1.02 ≥ clo ≥ 0.72
- Warm-summer Humid Continental: NA
- Mild Temperate: 0.78 ≥ clo ≥ 0.71
- Temperate Oceanic: 0.73 ≥ clo ≥ 0.66

Relative Humidity VS Clothing Level (Figure 35)

With reference to the ranges of Relative Humidity previously observed (i.e. ranges referring to -0.5 ≤ HSV ≤ +0.5), clothing levels (clo) are distributed as follows.

- Hot-summer Mediterranean: 0.91 ≥ clo ≥ 0.67
- Warm-summer Mediterranean: 1.01 ≥ clo ≥ 0.78
- Warm-summer Humid Continental: NA
- Mild Temperate: NA
- Temperate Oceanic: 0.87 ≥ clo ≥ 0.62

Air Velocity VS Clothing Level (Figure 36)

Being not possible to assess sensation votes regarding Air Velocity, clothing levels (clo) assessed considering all Vair ranges between 0.0 and 0.5 m s^{-1}.

- Hot-summer Mediterranean: 0.90 ≥ clo ≥ 0.40

- Warm-summer Mediterranean: 0.87 ≥ clo ≥ 0.76
- Warm-summer Humid Continental: NA
- Mild Temperate: 0.68 ≥ clo ≥ 0.60
- Temperate Oceanic: 0.71 ≥ clo ≥ 0.64

9.3 SCATs database: spring-summer period (APPENDIX B)

Concerning the analysis of this specific database, it is important in the first place to recall that the surveys of this project were conducted mainly in offices. Thus, findings must be in the second phase weighted and discussed in the perspective of residential buildings.

Standard Effective Temperature VS Thermal Sensation Vote (Figure 37)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 26 °C ≤ SET≤ 28 °C
- Greece: 26 °C ≤ SET≤ 30 °C
- Portugal: 25 °C ≤ SET≤ 29 °C
- Sweden: 24 °C ≤ SET≤ 27 °C
- UK: 24 °C ≤ SET≤ 29 °C

Indoor Air Temperature VS Thermal Sensation Vote (Figure 38)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 24 °C ≤ Tair ≤ 27 °C
- Greece: 24 °C ≤ Tair ≤ 28 °C
- Portugal: 21 °C ≤ Tair ≤ 27 °C
- Sweden: 22 °C ≤ Tair ≤ 25 °C
- UK: 22 °C ≤ Tair ≤ 28 °C

Operative Temperature VS Thermal Sensation Vote (Figure 39)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 25 °C ≤ Top ≤ 28 °C
- Greece: 24 °C ≤ Top ≤ 29 °C
- Portugal: 21 °C ≤ Top ≤ 28 °C
- Sweden: 22 °C ≤ Top ≤ 24 °C
- UK: 23 °C ≤ Top ≤ 27 °C

Mean Radiant Temperature VS Thermal Sensation Vote (Figure 40)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 25 °C ≤ Tmrt ≤ 28 °C
- Greece: 24 °C ≤ Tmrt ≤ 30 °C
- Portugal: 23 °C ≤ Tmrt ≤ 28 °C
- Sweden: 22 °C ≤ Tmrt ≤ 25 °C
- UK: 23 °C ≤ Tmrt ≤ 28 °C

Relative Humidity VS Humidity Sensation Vote (Figure 41)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ HSV ≤ 5, the following hypothesis can be drawn.

- France: 25 % ≤ RH ≤ 55 %
- Greece: 25 % ≤ RH ≤ 50 %
- Portugal: 25 % ≤ RH ≤ 65 %
- Sweden: 25 % ≤ RH ≤ 55 %
- UK: 25 % ≤ RH ≤ 60 %

Air Velocity VS Air Movement Sensation Vote (Figure 42)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ ASV ≤ 5, the following hypothesis can be drawn.

- France: 0.0 m s^{-1} ≤ Vair ≤ 0.1 m s^{-1}
- Greece: 0.0 m s^{-1} ≤ Vair ≤ 0.2 m s^{-1}
- Portugal: 0.0 m s^{-1} ≤ Vair ≤ 0.1 m s^{-1}
- Sweden: 0.0 m s^{-1} ≤ Vair ≤ 0.1 m s^{-1}
- UK: 0.0 m s^{-1} ≤ Vair ≤ 0.4 m s^{-1}

Indoor Air Temperature VS Clothing Level[1] (Figure 43)

With reference to the ranges of Indoor Air Temperature previously observed (i.e. ranges referring to 3 ≤ TSV ≤ 5), clothing levels (clo) are distributed as follows.

- France: 0.81 ≥ clo ≥ 0.56
- Greece: 0.79 ≥ clo ≥ 0.67
- Portugal: 0.98 ≥ clo ≥ 0.64
- Sweden: 0.84 ≥ clo ≥ 0.66
- UK: 0.80 ≥ clo ≥ 0.65

Relative Humidity VS Clothing Level (Figure 44)

With reference to the ranges of Relative Humidity previously observed (i.e. ranges referring to 3 ≤ HSV ≤ 5), clothing levels (clo) are distributed as follows.

- France: 0.71 ≥ clo ≥ 0.61
- Greece: 0.81 ≥ clo ≥ 0.68
- Portugal: 0.84 ≥ clo ≥ 0.68
- Sweden: 0.84 ≥ clo ≥ 0.67
- UK: 0.71 ≥ clo ≥ 0.62

Air Velocity VS Clothing Level (Figure 45)

With reference to the ranges of Air Velocity previously observed (i.e. ranges referring to 3 ≤ ASV ≤ 5), clothing levels (clo) are distributed as follows.

- France: 0.72 ≥ clo ≥ 0.58
- Greece: 0.80 ≥ clo ≥ 0.72
- Portugal: 0.70 ≥ clo ≥ 0.80
- Sweden: 0.78 ≥ clo ≥ 0.75
- UK: 0.74 ≥ clo ≥ 0.64

[1] Being the surveys conducted mainly in office buildings, it is important to consider that in these facilities, contrary to households, a dress-code is often required.

9.4 SCATs database: autumn-winter (APPENDIX B)

Standard Effective Temperature VS Thermal Sensation Vote (Figure 46)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 25 °C ≤ SET≤ 29 °C
- Greece: 26 °C ≤ SET≤ 29 °C
- Portugal: 24 °C ≤ SET≤ 30 °C
- Sweden: 24 °C ≤ SET≤ 27 °C
- UK: 24 °C ≤ SET≤ 29 °C

Indoor Air Temperature VS Thermal Sensation Vote (Figure 47)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 22 °C ≤ Tair ≤ 27 °C
- Greece: 24 °C ≤ Tair ≤ 28 °C
- Portugal: 20 °C ≤ Tair ≤ 26 °C
- Sweden: 22 °C ≤ Tair ≤ 24 °C
- UK: 22 °C ≤ Tair ≤ 27 °C

Operative Temperature VS Thermal Sensation Vote (Figure 48)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 23 °C ≤ Top ≤ 27 °C
- Greece: 24 °C ≤ Top ≤ 28 °C
- Portugal: 22 °C ≤ Top ≤ 26 °C
- Sweden: 22 °C ≤ Top ≤ 24 °C
- UK: 23 °C ≤ Top ≤ 26 °C

Mean Radiant Temperature VS Thermal Sensation Vote (Figure 49)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ TSV ≤ 5, the following hypothesis can be drawn.

- France: 23 °C ≤ Tmrt ≤ 28 °C
- Greece: 25 °C ≤ Tmrt ≤ 30 °C
- Portugal: 22 °C ≤ Tmrt ≤ 28 °C
- Sweden: 22 °C ≤ Tmrt ≤ 25 °C
- UK: 23 °C ≤ Tmrt ≤ 26 °C

Relative Humidity VS Humidity Sensation Vote (Figure 50)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ HSV ≤ 5, the following hypothesis can be drawn.

- France: 20 % ≤ RH ≤ 55 %
- Greece: 25 % ≤ RH ≤ 65 %
- Portugal: 25 % ≤ RH ≤ 55 %
- Sweden: 20 % ≤ RH ≤ 50 %
- UK: 25 % ≤ RH ≤ 55 %

Air Velocity VS Air Movement Sensation Vote (Figure 51)

Observing the majority of observations in the sample for each climate which mean ranges 3 ≤ ASV ≤ 5, the following hypothesis can be drawn.

- France: 0.0 m s^{-1} ≤ Vair ≤ 0.1 m s^{-1}
- Greece: 0.0 m s^{-1} ≤ Vair ≤ 0.1 m s^{-1}
- Portugal: 0.0 m s^{-1} ≤ Vair ≤ 0.2 m s^{-1}
- Sweden: 0.0 m s^{-1} ≤ Vair ≤ 0.1 m s^{-1}
- UK: 0.0 m s^{-1} ≤ Vair ≤ 0.3 m s^{-1}

Indoor Air Temperature VS Clothing Level (Figure 52)

With reference to the ranges of Indoor Air Temperature previously observed (i.e. ranges referring to 3 ≤ TSV ≤ 5), clothing levels (clo) are distributed as follows.

- France: 0.98 ≥ clo ≥ 0.74

- Greece: 0.80≥ clo ≥ 0.65
- Portugal: 1.05 ≥ clo ≥ 0.72
- Sweden: 0.87 ≥ clo ≥ 0.79
- UK: 0.85≥ clo ≥ 0.73

Relative Humidity VS Clothing Level (Figure 53)

With reference to the ranges of Relative Humidity previously observed (i.e. ranges referring to 3 ≤ HSV ≤ 5), clothing levels (clo) are distributed as follows.

- France: 0.92 ≥ clo ≥ 0.60
- Greece: 0.81 ≥ clo ≥ 0.65
- Portugal: 1.00 ≥ clo ≥ 0.78
- Sweden: 0.93 ≥ clo ≥ 0.77
- UK: 0.90 ≥ clo ≥ 0.74

Air Velocity VS Clothing Level (Figure 54)

With reference to the ranges of Air Velocity previously observed (i.e. ranges referring to 3 ≤ ASV ≤ 5), clothing levels (clo) are distributed as follows.

- France: 0.87 ≥ clo ≥ 0.75
- Greece: 0.72 ≥ clo ≥ 0.70
- Portugal: 0.92 ≥ clo ≥ 0.77
- Sweden: 0.87 ≥ clo ≥ 0.83
- UK: 0.77 ≥ clo ≥ 0.82

9.5 SCATs database: personal controls (APPENDIX B)

Observing the boxplots from the database analysis, an attempt is made to elaborate first considerations on the use of personal controls in indoor environmental and users' preferences and attitudes towards the surrounding building elements.

N.B. Data for Greece are not available in the background questionnaire, thus are not reported.

Also in this case, it is important to consider that surveys were administered mainly in office buildings, thus findings could include some bias due to the different subjects' attitudinal mechanisms which take place in a shared indoor environment, with respect to private households where occupants are more free to perform actions according to their behaviour and sensations.

Q: For the following items, please indicate how important it is to you to have personal control over them (i.e. you can physically make adjustments yourself). Please answer regardless of whether or not you have the control available in your building.

According to data in Figure 55, following assumptions can be drawn.

- France: users in indoor environments seem to rate with higher importance the operability of windows, curtains or blinds, internal door between different spaces, and lights management. Less importance is addressed to the operability of external doors and of local heaters or radiators.
- Portugal: it generally appears that users' do not highly rate the importance of having a personal control over the listed items. The greatest votes are given to windows, use of curtains or blinds, task-specific lights. No significant importance is addressed to thermostats, neither local heaters nor local fans.
- Sweden: occupants address high importance rates to the operability of curtains and blinds and to lights management. Windows operability, contrary to the other countries, collect scattered votes. Use of dimmers, thermostats, local heaters or fans is not highly rated.
- UK: users generally give high rates to all personal controls, except for doors operability, general lights management and dimmers.

Q: For the following items, please indicate whether or not you actually have personal control over their adjustment.

According to data in Figure 56, it can be observed that all four surveyed countries seem to have control on windows operability, curtains and blinds, internal doors and general ambient lights. For what concerns other controls:

- France: occupants do not have great control on thermostats, local heaters or radiators, local fan or air outlets, neither task lights nor dimmers, and significantly not on air conditioning in general.
- Portugal: users do not have controls especially on thermostats, air conditioning, local fan or air outlets, task lights.
- Sweden: a significant majority of occupants do not have control on thermostats, local heaters, local fans and air conditioning in general.
- UK: users do not have great control on thermostats and air conditioning, as well as desk lights and light dimmers.

According to data visualization, it appears that users in general have control on natural ventilation through windows operability and on solar shading by means of curtains and blinds. However, for what concerns personal controls for thermal comfort and visual wellbeing, the situation is not well defined with a small potential of personal management for users.

Q: If YES, how often do you actually make adjustments?

Observing Figure 57, it can be noticed as follows.

- France: users generally seldom act over local heaters and radiators, general lights and dimmers, air conditioning and local fan or air outlets.
- Portugal: users in general do not often personally make adjustments with regards to all the listed personal controls. Usually they act more frequently on windows and curtains, internal doors, general lights and thermostats, although data distribution is pretty scattered among the votes.
- Sweden: contrary to other countries, users do no act often on windows. Users generally make adjustments over curtains and blinds, internal doors, general

lights and dimmers. For what concerns the other personal controls, they are not managed frequently and the range of distribution of votes is pretty wide.

- UK: users seem to act almost frequently on all the personal control but air conditioning, local fan or air outlets, and lights dimmer.

These answers can be strongly influenced by the fact that, in an office environment, the users are exposed to a shared environment, where its actions are affected also by the presence of other subjects with potentially different sensations and preferences. This can produce some hints also about the value that in each country is given to the presence of other people and their needs, and about the attitudes of users with different socio-cultural backgrounds.

Q: For the controls that you are able to personally adjust, does altering them bring effective relief to any discomfort?

According to data in Figure 58, it appears that the operability of windows and of curtain and blinds is the personal adjustments which is able to bring the most effective relief to discomfort for all the for countries. Further assumptions can be made hereafter.

- France: little effect is given by external door, thermostats and local heaters, air conditioning and local fans, lights dimmer.
- Portugal: little relief is produced by the adjustments of thermostats and local heaters. Data have a very wide range of votes for what concerns air conditioning and local fan or air outlets.
- Sweden: all the listed personal control seems to have a proper relief to discomfort.
- UK: a medium relief is evaluated for almost all the personal controls, expect doors operability and general lights management.

Q: For the controls that you are able to personally adjust, how quickly does a change bring effective comfort?

Also in this case, as it is shown in Figure 59, ventilation and sun shading reached by means of windows operability and by the proper use of curtain and blinds is the personal adjustments which gives the fastest relief in all the surveyed countries.

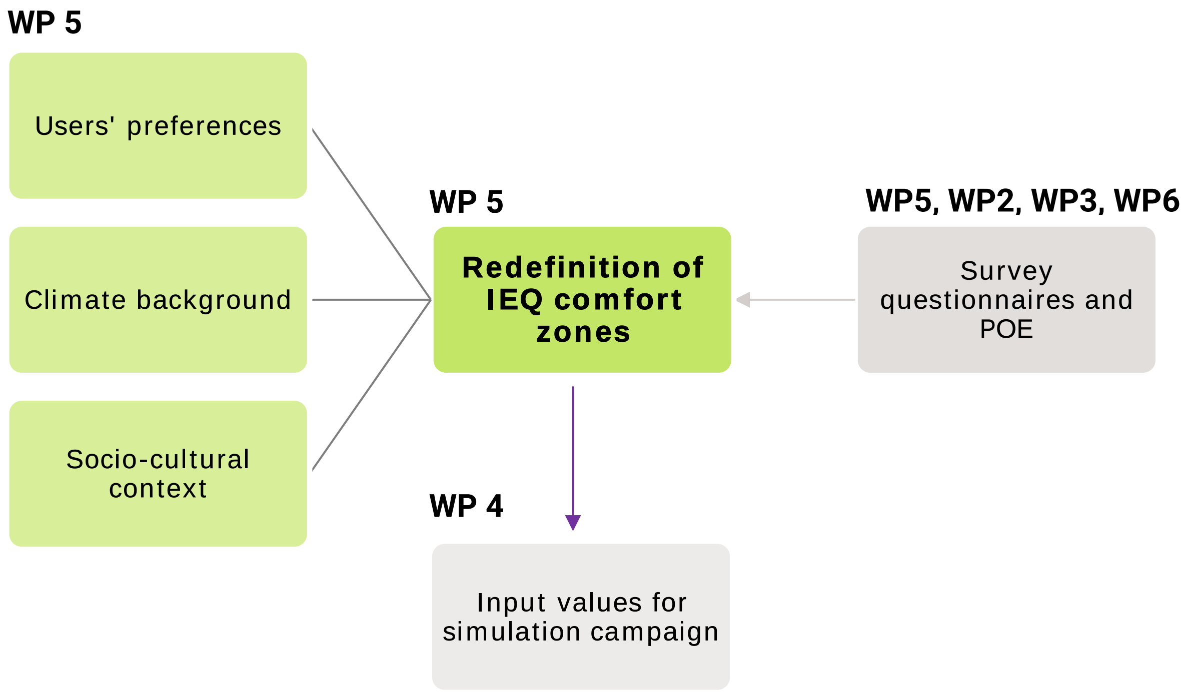
- France: a quick relief is also produced in terms of visual environments by means of lights adjustments. Other personal controls collect dispersed and not very significant votes.
- Portugal: data from users, for what concerns almost all the personal control, have a very wide range in distribution, not allowing the identification of the most significant interventions.
- Sweden: almost all the personal controls seem to have a quick relief effect towards discomfort issues.
- UK: almost all the personal controls seem to have a quick relief effect towards discomfort issues, expect for doors operability and indoor general lights management.

Q: Listed below are a number of factors which may or may not affect the working environment. Please indicate on the scale how important you consider these factors to be in establishing a good working environment.

Looking at Figure 60 and Figure 61, it is possible to drawn more general considerations about the importance given to different environmental aspects in indoor spaces. Again, these answers are related to office environments, but they have yet been considered for potential further considerations about users' preferences and attitudes. Almost all the listed aspects appear to be important for all the surveyed countries, especially for what concerns temperature values, the intake of fresh air -in particular for Sweden and UK-, daylight, the avoidance of glare and noise issues.

10. State of progress and future steps in Task 5.1

Hereafter is recalled Figure 2 which briefly visualized the steps and workflow of Task 5.1.



The following activities have been conducted so far and results have been described in this deliverable:

- Literature review and state of the art on the evolution of the very notion of comfort through time and history.
- Literature analysis on the dynamics of comfort expectations, considering users background and adaptation mechanisms.
- Analysis of thermal comfort theories focusing on the elaboration of adaptive comfort model.
- Analysis and identification of a framework of cultural and social drivers affecting comfort expectations.
- Literature review of comfort diversities according to different climate geo-clusters.

- Identification of significant comfort databases for addressing diversities in comfort expectations and users' attitudes towards the environment.
- Analysis of ASHRAE and SCATs databases by means of descriptive statistics and visualization plots.
- Elaboration of preliminary assumptions for re-define IEQ comfort zones, according to different climate geo-clusters factors.

In the upcoming months, following activities are planned to be started within the project time frame, and are expected to continue being developed after the project completion. In addition, dissemination of the results of these activities, including conference presentations and submissions for specialized publications, is foreseen.

a. Cultural and social drivers affecting comfort expectations: continuing the work proposed in chapter 7, the drivers will be validated and consolidated. A final *framework* will be elaborated to understand users' comfort profiles and environmental attitudes with respect to the impact of their social and cultural features. In this way users can be profiled by means of structured selected drivers. The work will be conducted in synergy with WP2 and integrated and validated by means of survey questionnaires to be administered in the demo cases and similar other buildings in different EU countries.
b. Analysis of existing databases: from the work presented in chapter 8 and chapter 9, further analysis will be performed. The objective is, starting from the data available, to elaborate a *statistical model* which implements probit/logit regression to grasp the correlation between users' thermal sensation and comfort expectation (as output variable) with other significant variables (input variables). The objective is to highlight both the variables which play a significant role towards subjects' comfort expectations, focusing mainly on country/climate specific input variables. In a following phase, the validated model could be used as a predictive model for users' comfort expectations, building a new indicator for comfort which takes into account occupants' climate background.
c. Survey questionnaires and Post Occupancy Evaluations: in synergy with WP2, a survey *questionnaire* will be elaborated in order to address and integrate

preliminary results from Task 5.1. Surveys will focus both on users' comfort expectations and attitudes towards the environment, trying to grasp also additional information on socio-cultural and climate drivers affecting subjects in indoor spaces. Findings will be useful for simulation campaign of WP4 and for the choice of solution technologies, operational strategies and users' interface in WP3.

d. Redefinition of IEQ comfort zones: putting together findings from previous points, *IEQ* comfort zones and ranges will be defined, according to climate-specific influencing factors. Results, together with further considerations on occupants' attitudes and socio-cultural patterns, will be significant outputs for the implementation of WP4 simulation campaign and for the implementation of demo cases, for what concerns *indoor spaces requirements, but also regarding system management, operational choices, implementation of solution technologies and users' interfaces,* according to subjects' preferences and attitudes derived from their grasped background and adaptation mechanisms.

APPENDIX A

ASHRAE Global Thermal Comfort Database II

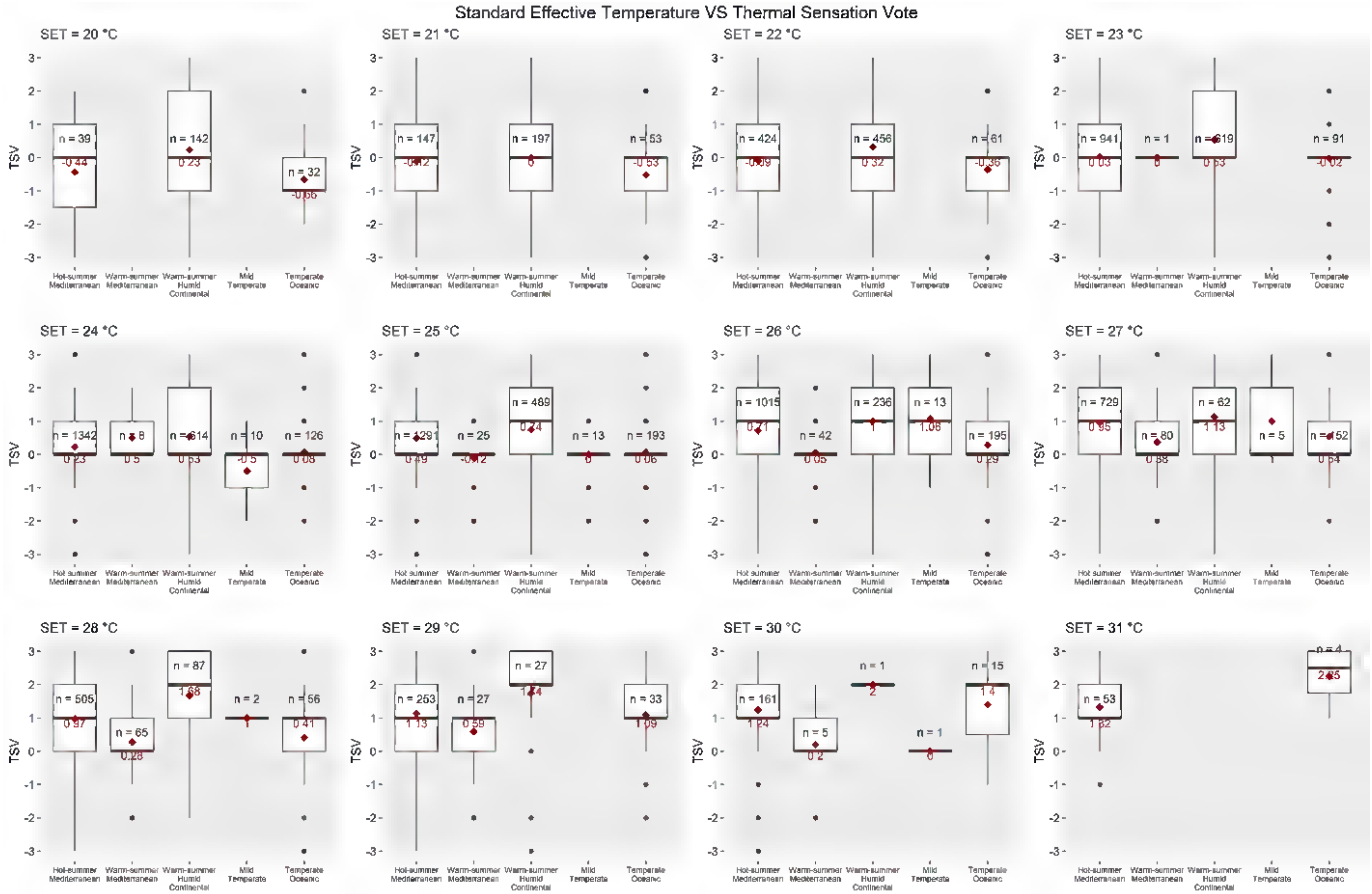


Figure 23. ASHRAE Global Thermal Comfort Database II. Spring-summer period. Standard Effective Temperature VS Thermal Sensation Vote

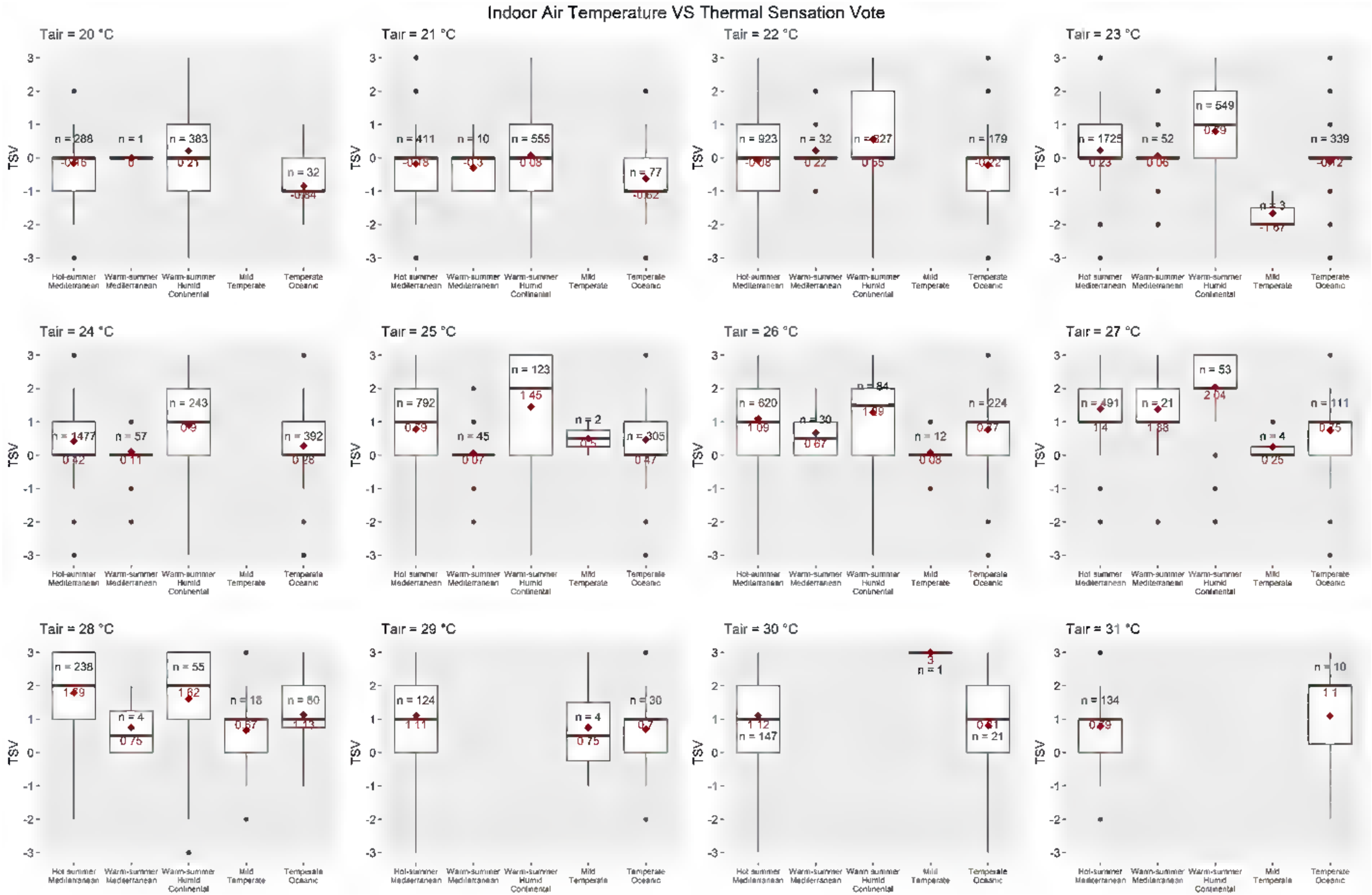


Figure 24. ASHRAE Global Thermal Comfort Database II. Spring-summer period. Indoor Air Temperature VS Thermal Sensation Vote

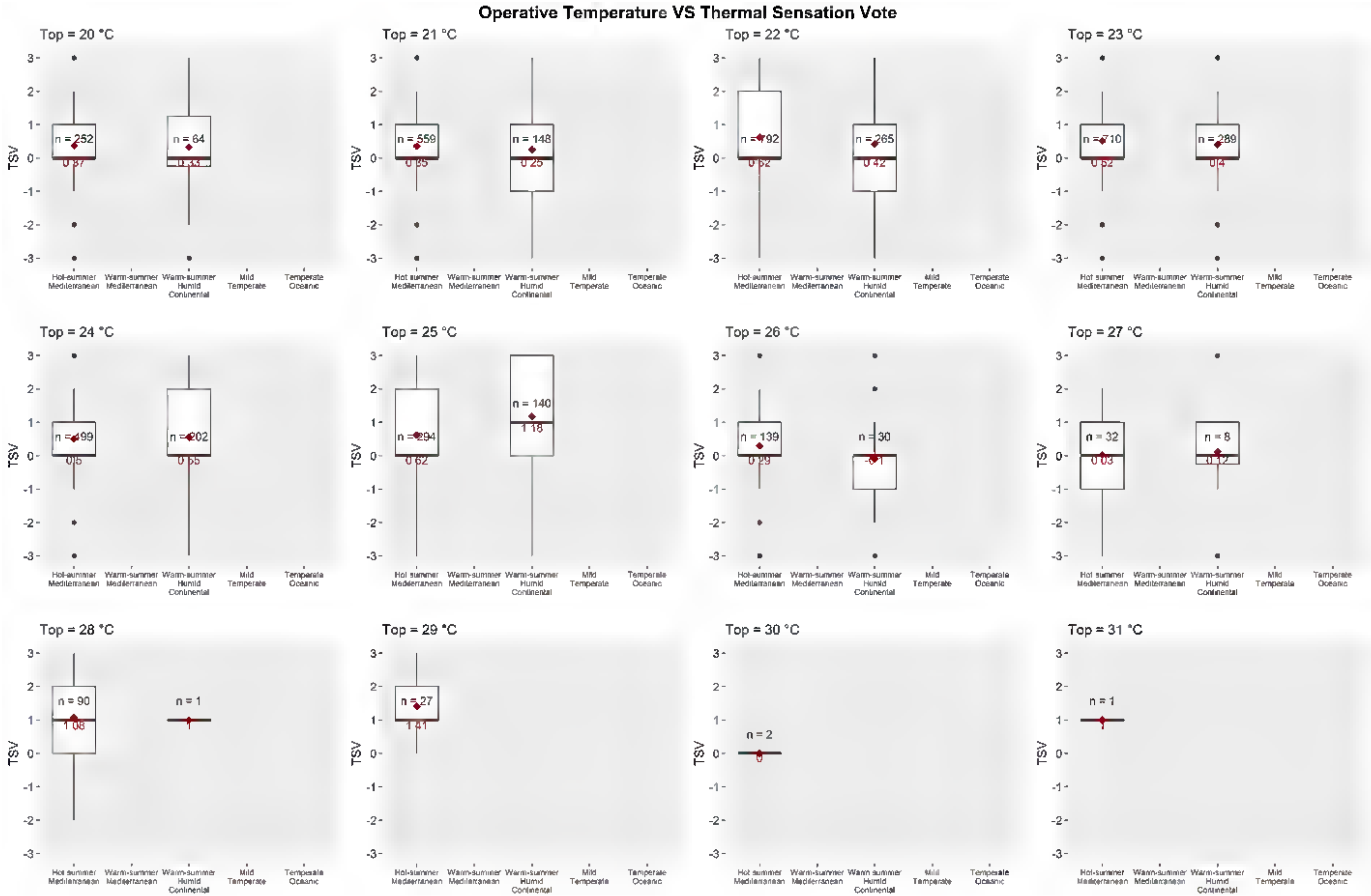


Figure 25. ASHRAE Global Thermal Comfort Database II. Spring-summer period. Operative Temperature VS Thermal Sensation Vote

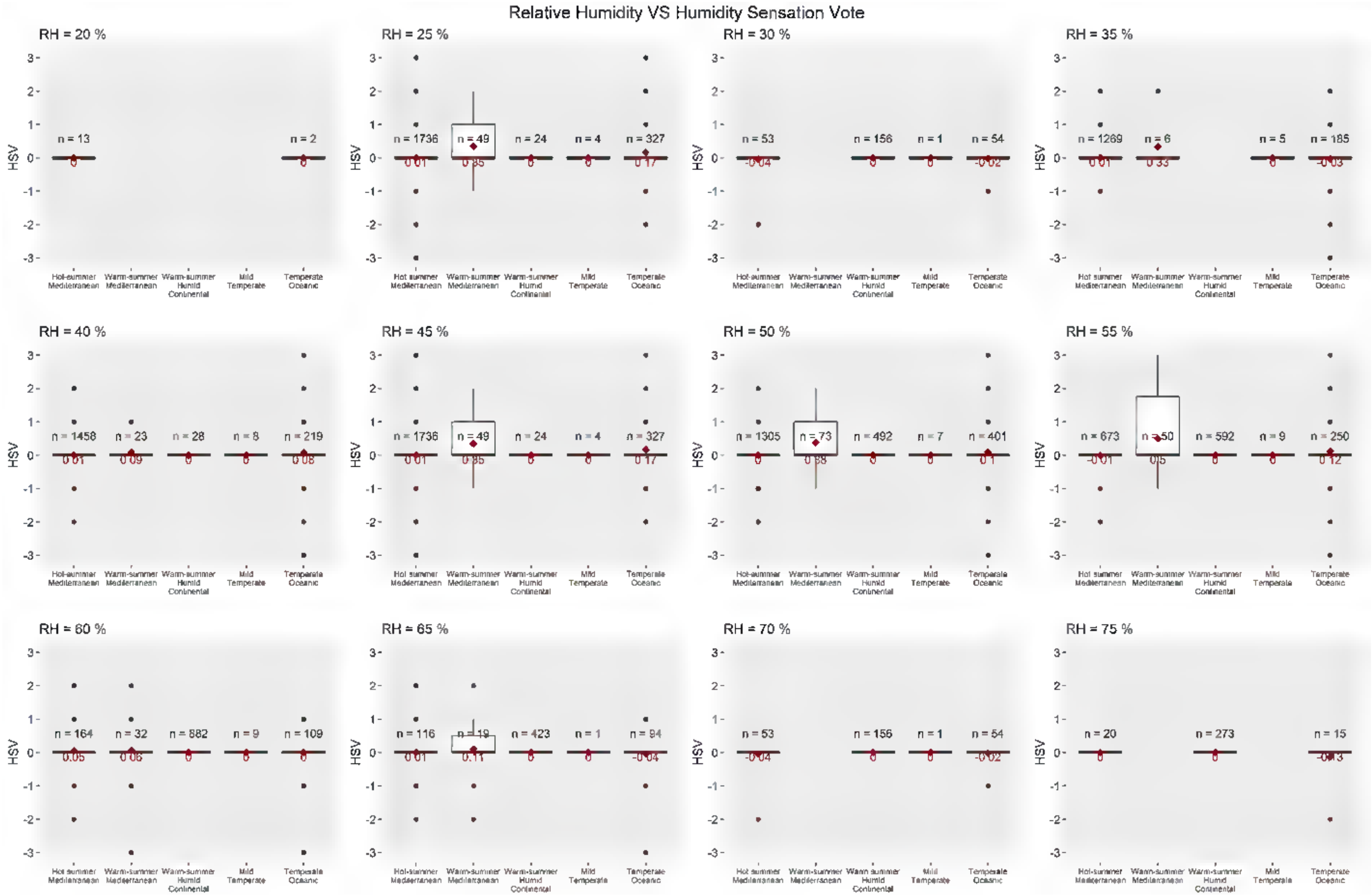


Figure 26. ASHRAE Global Thermal Comfort Database II. Spring-summer period. Relative Humidity VS Humidity Sensation Vote

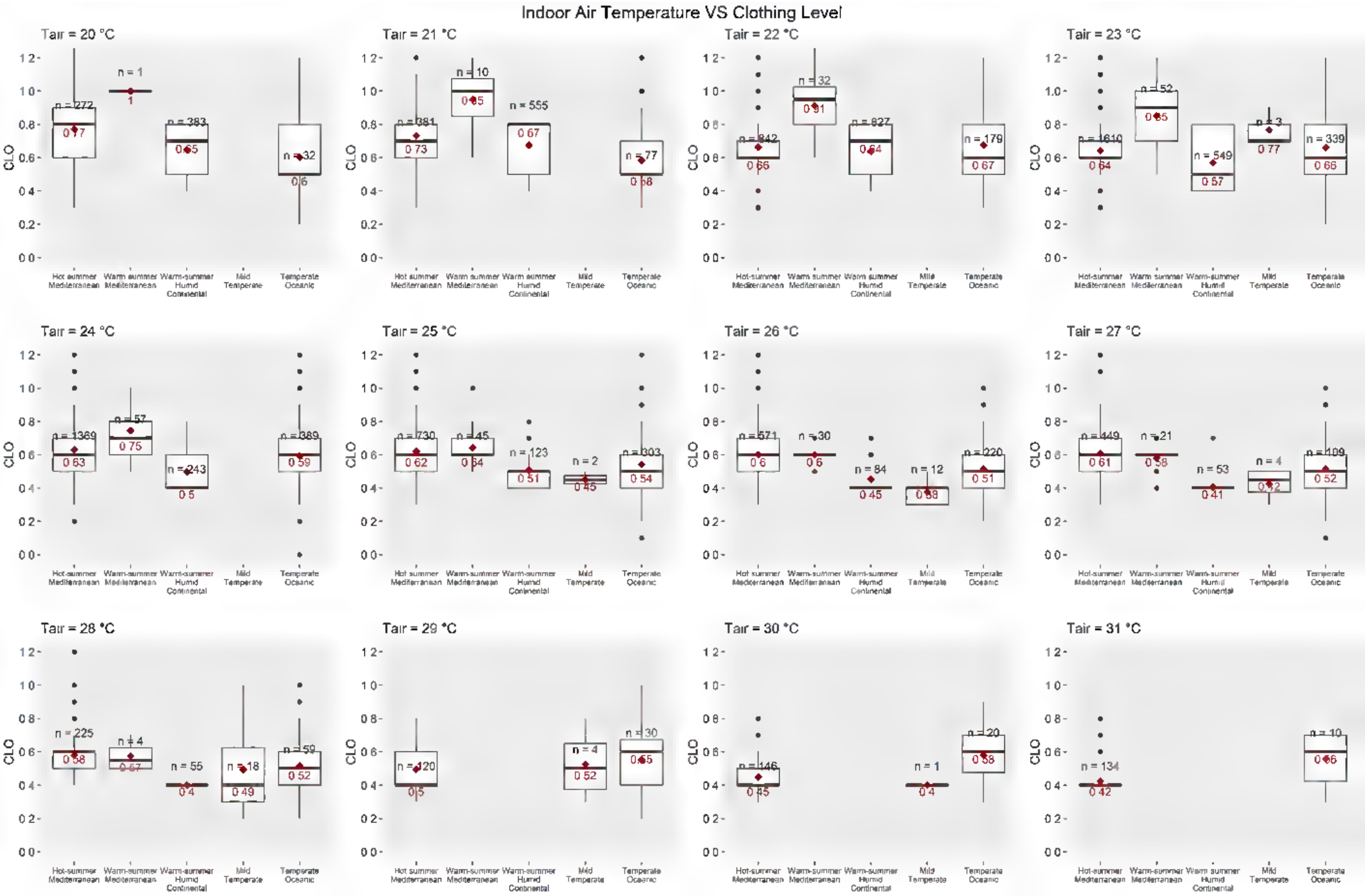


Figure 27. ASHRAE Global Thermal Comfort Database II. Spring-summer period. Indoor Air Temperature VS Clothing Level

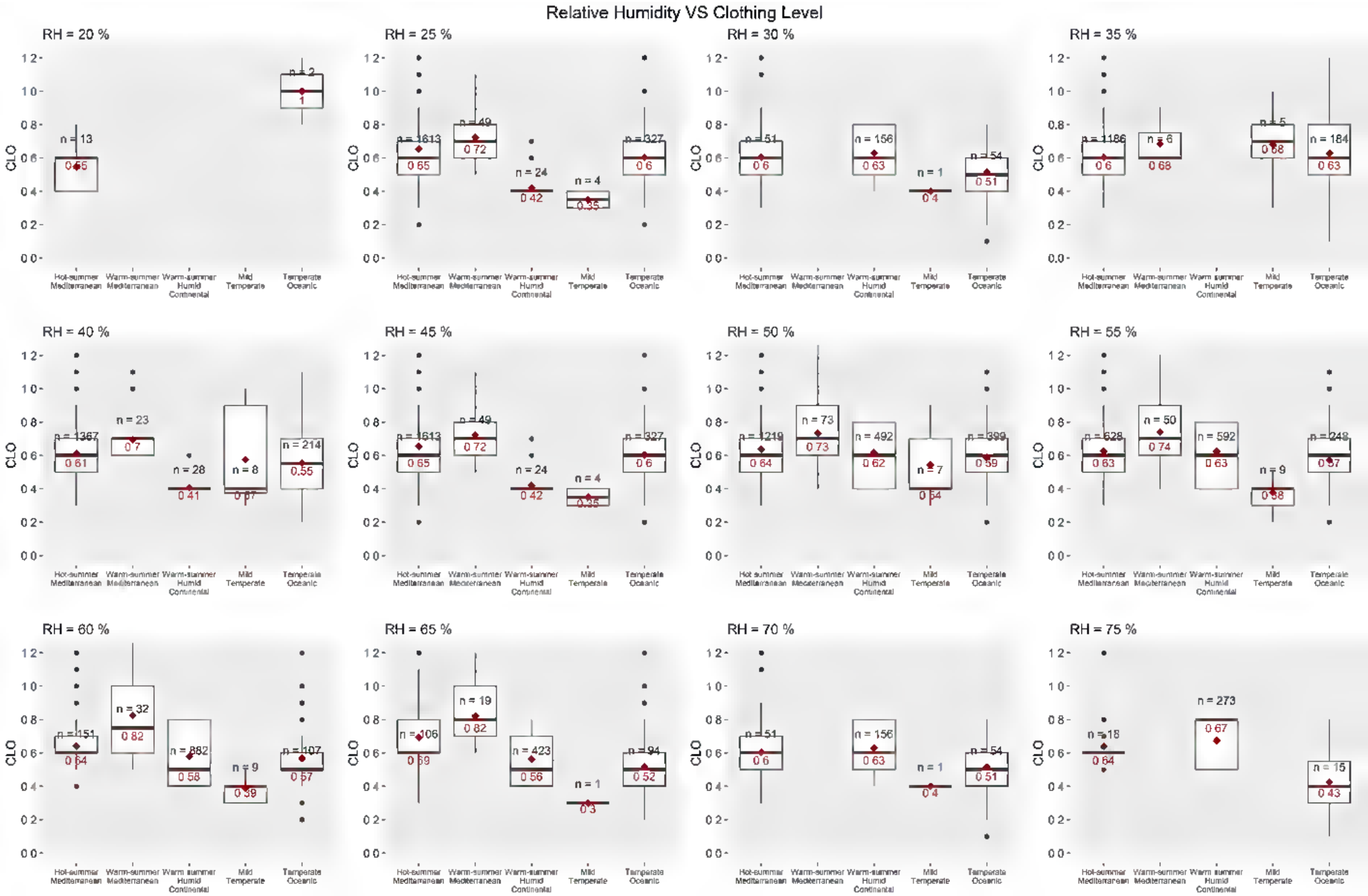


Figure 28. ASHRAE Global Thermal Comfort Database II. Spring-summer period. Relative Humidity VS Clothing Level

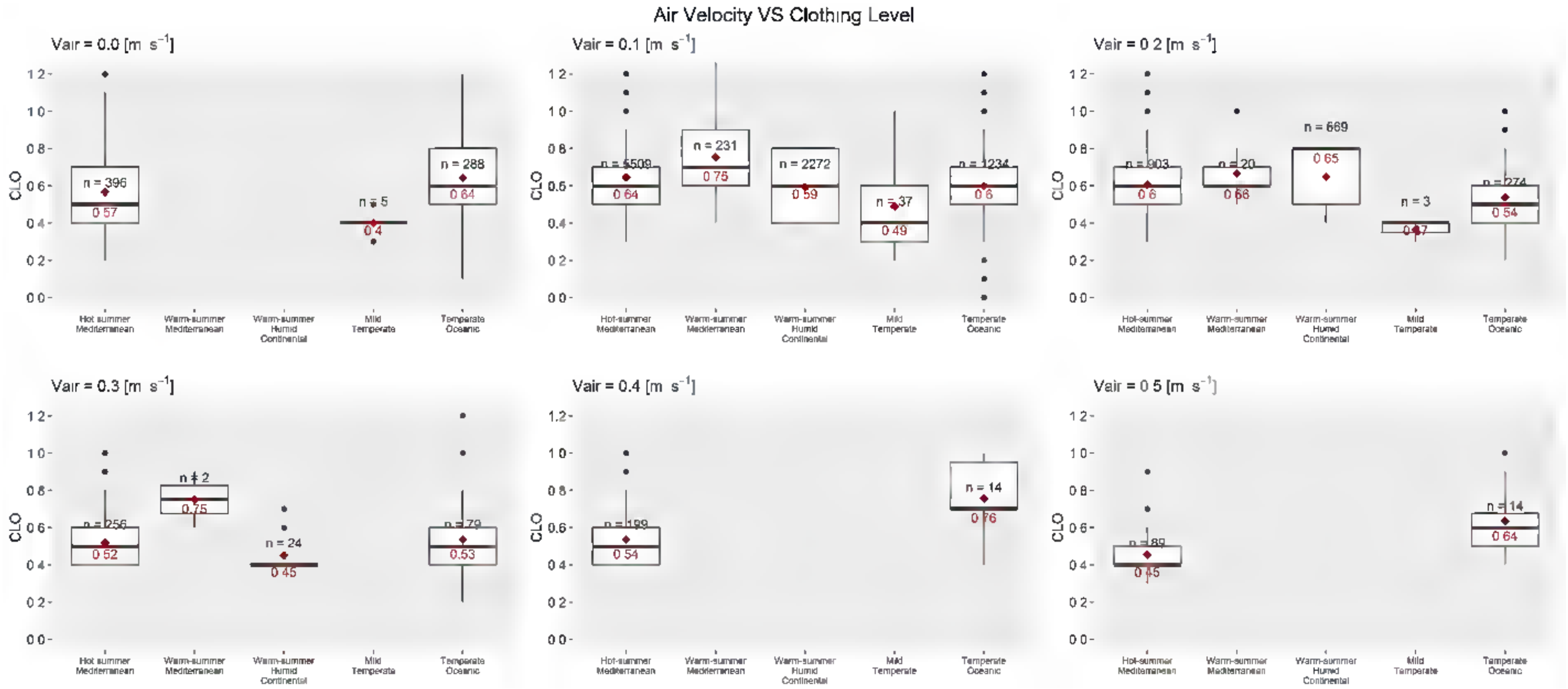


Figure 29. ASHRAE Global Thermal Comfort Database II. Spring-summer period. Air Velocity VS Clothing Level

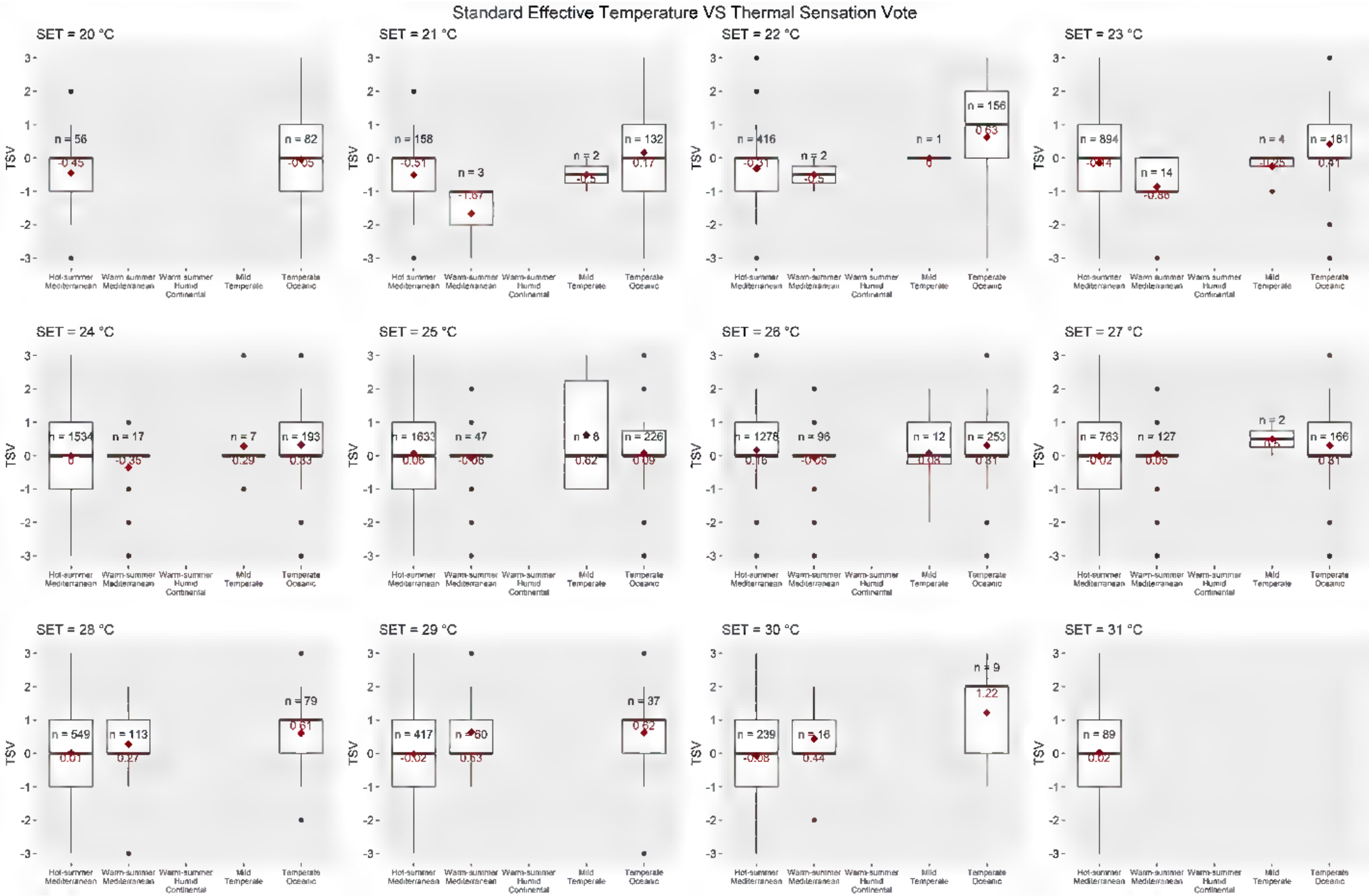


Figure 30. ASHRAE Global Thermal Comfort Database II. Autumn-winter period. Standard Effective Temperature VS Thermal Sensation Vote

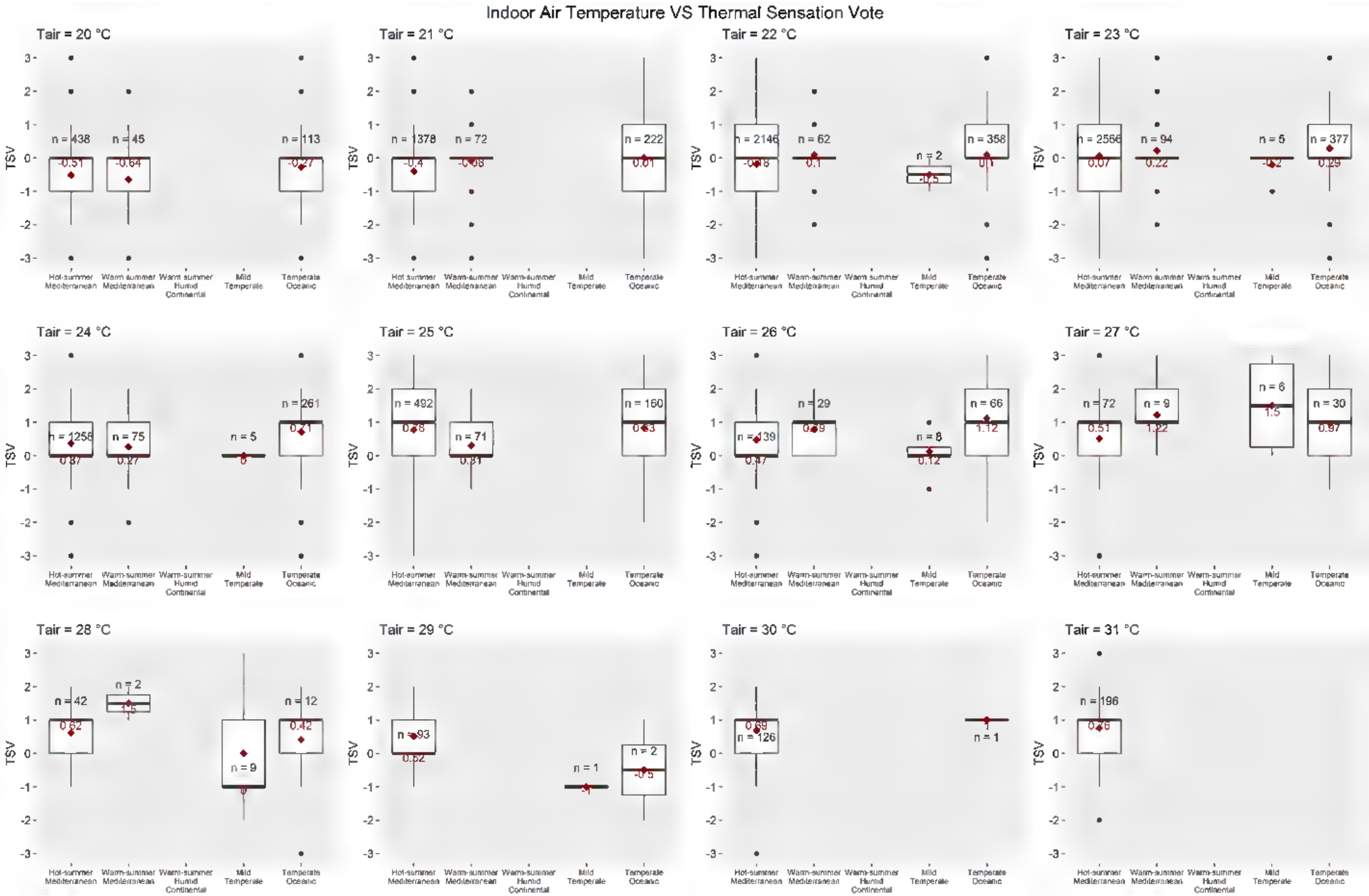


Figure 31. ASHRAE Global Thermal Comfort Database II. Autumn-winter period. Indoor Air Temperature VS Thermal Sensation Vote

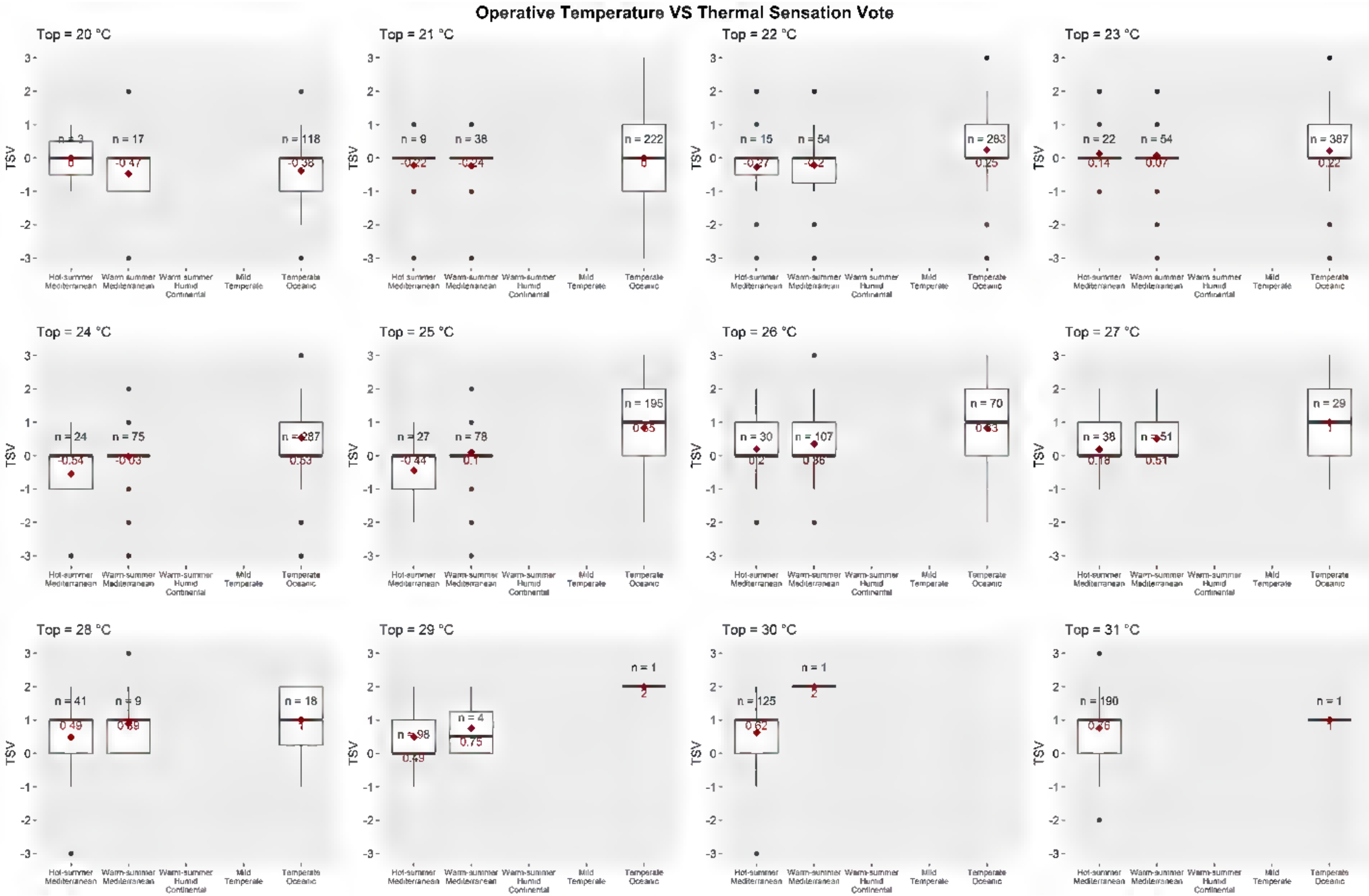


Figure 32. ASHRAE Global Thermal Comfort Database II. Autumn-winter period. Operative Temperature VS Thermal Sensation Vote

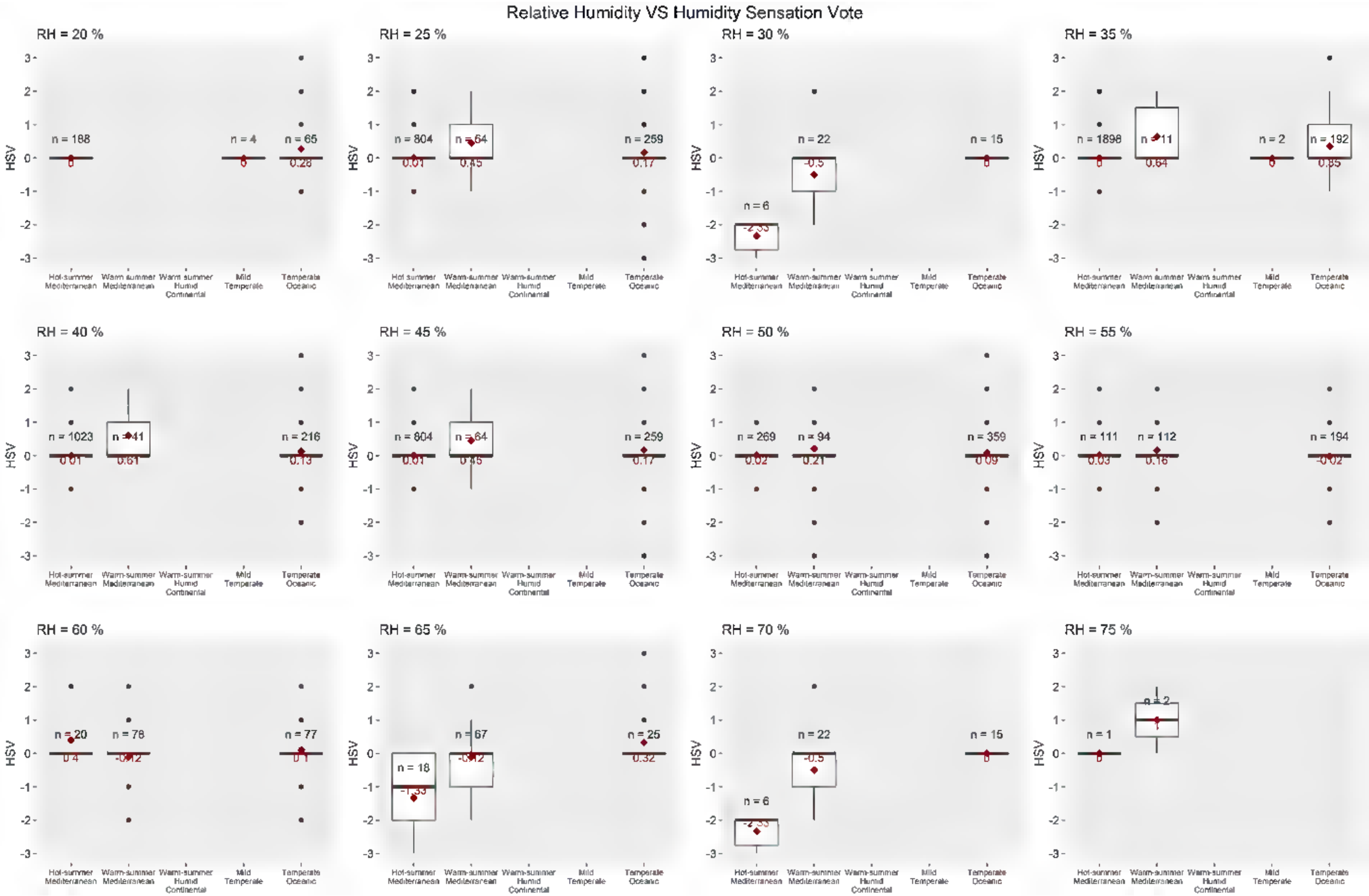


Figure 33. ASHRAE Global Thermal Comfort Database II. Autumn-winter period. Relative Humidity VS Humidity Sensation Vote

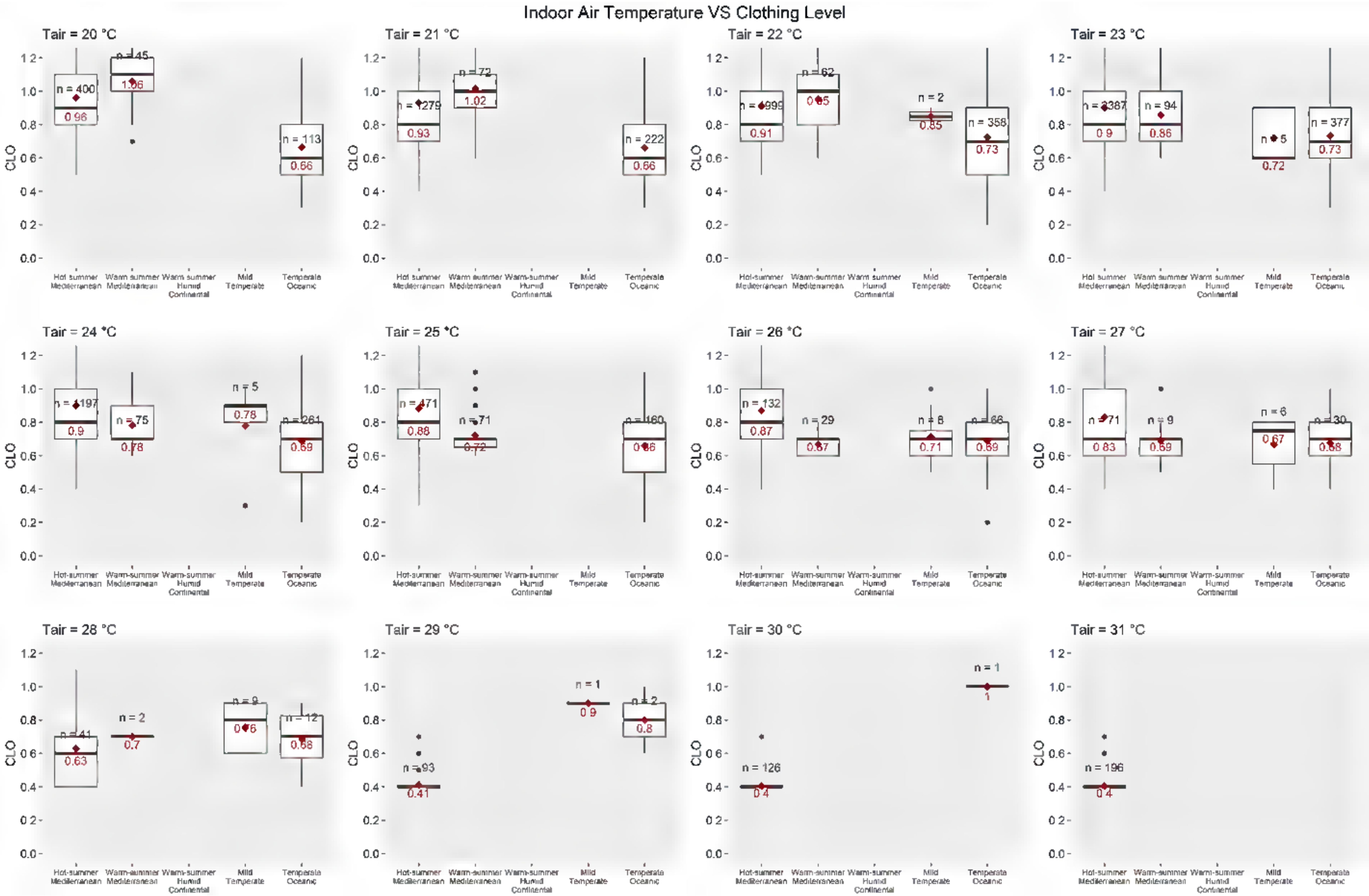


Figure 34. ASHRAE Global Thermal Comfort Database II. Autumn-winter period. Indoor Air Temperature VS Clothing Level

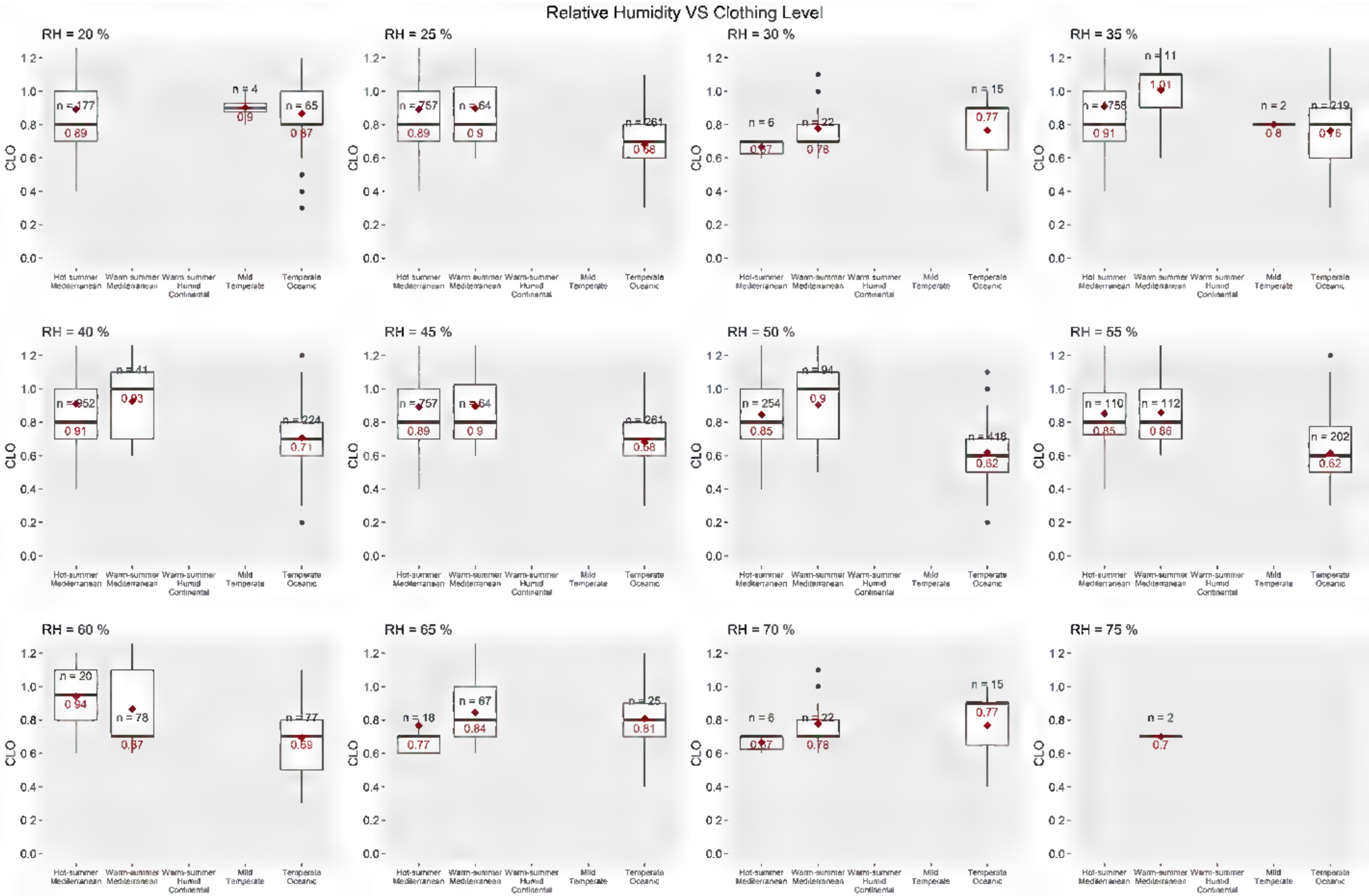


Figure 35. ASHRAE Global Thermal Comfort Database II. Autumn-winter period. Relative Humidity VS Clothing Level

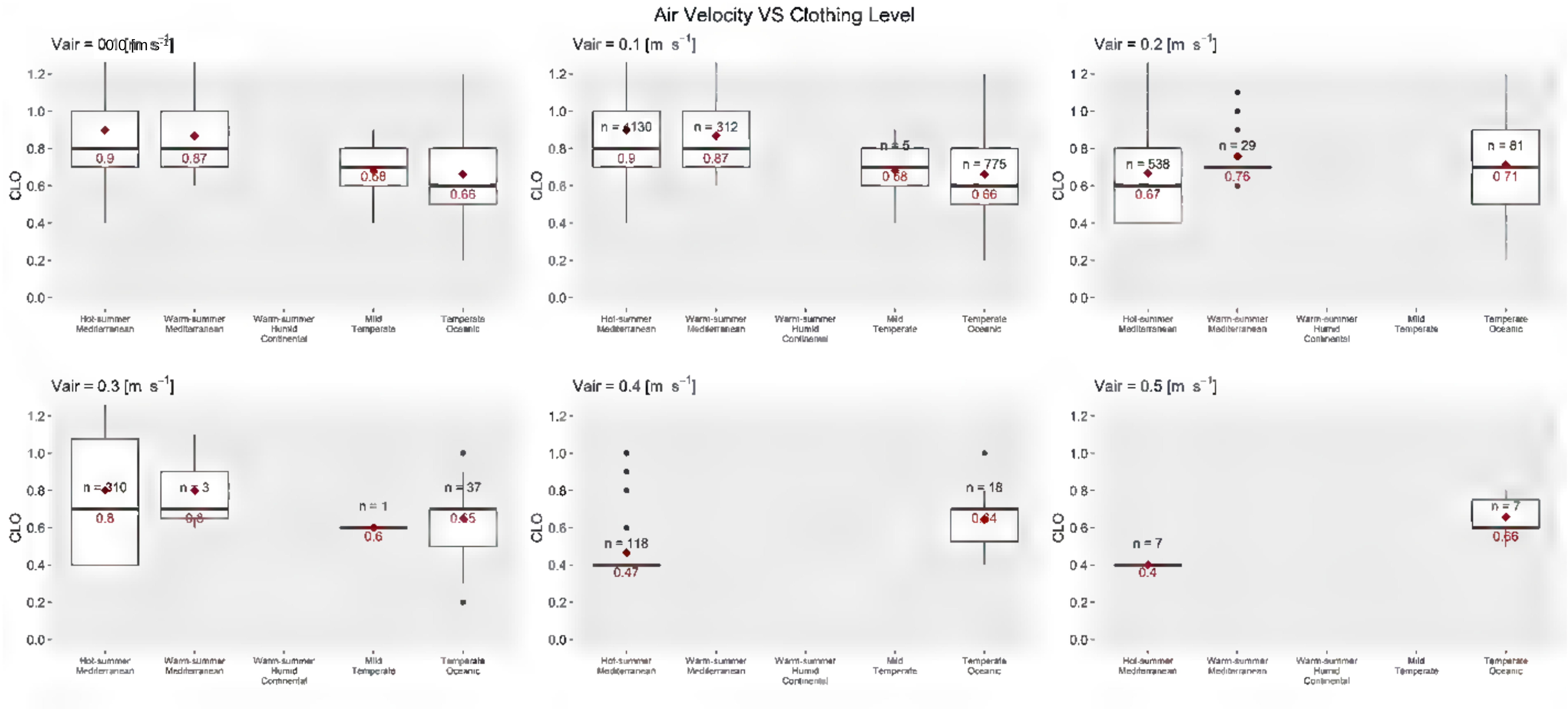


Figure 36. ASHRAE Global Thermal Comfort Database II. Autumn-winter period. Air Velocity VS Clothing Level

APPENDIX B

Smart Controls and Thermal Comfort (SCATs) database

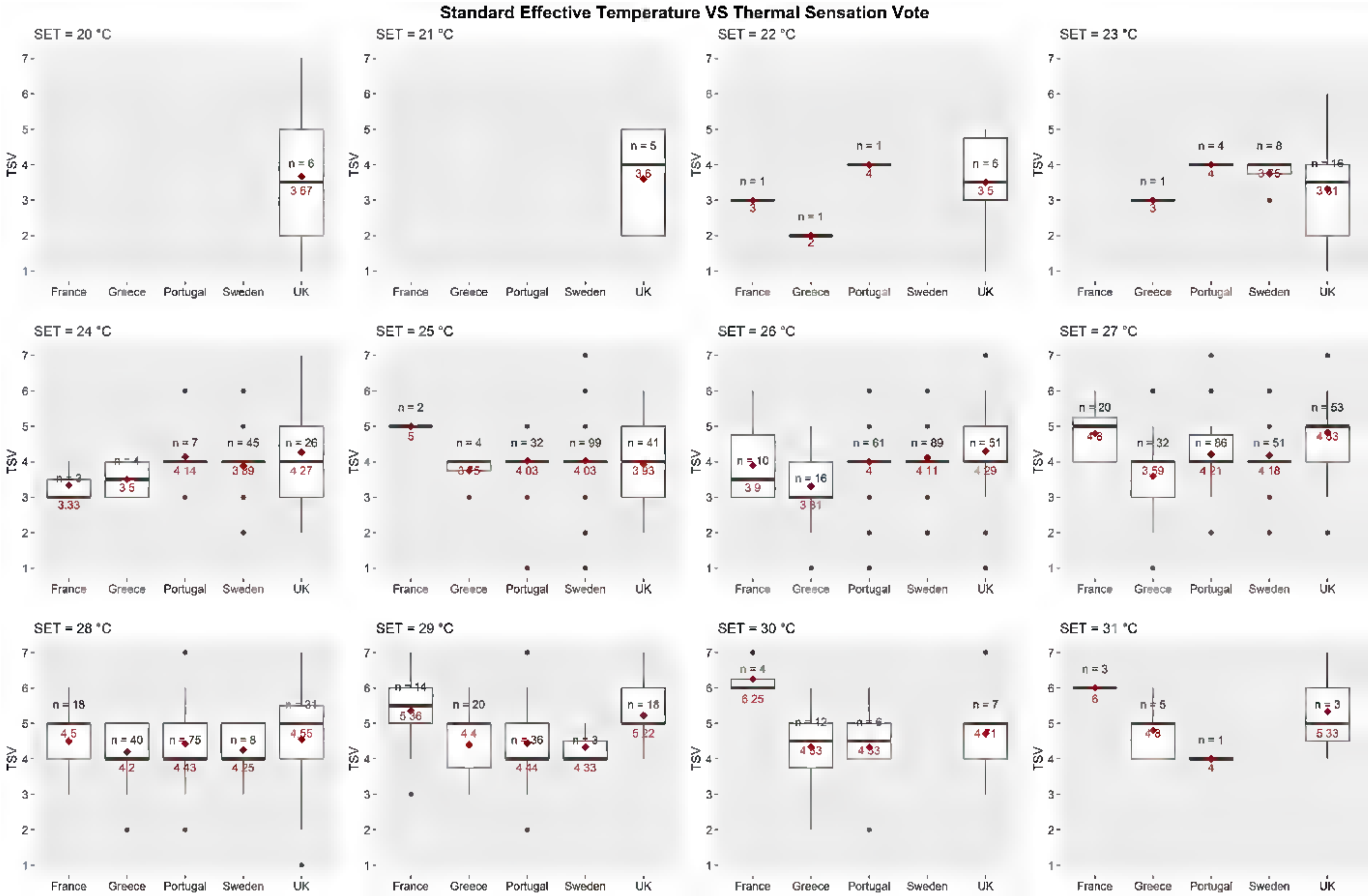


Figure 37. Smart Controls and Thermal Comfort database. Spring-summer period. Standard Effective Temperature VS Thermal Sensation Vote

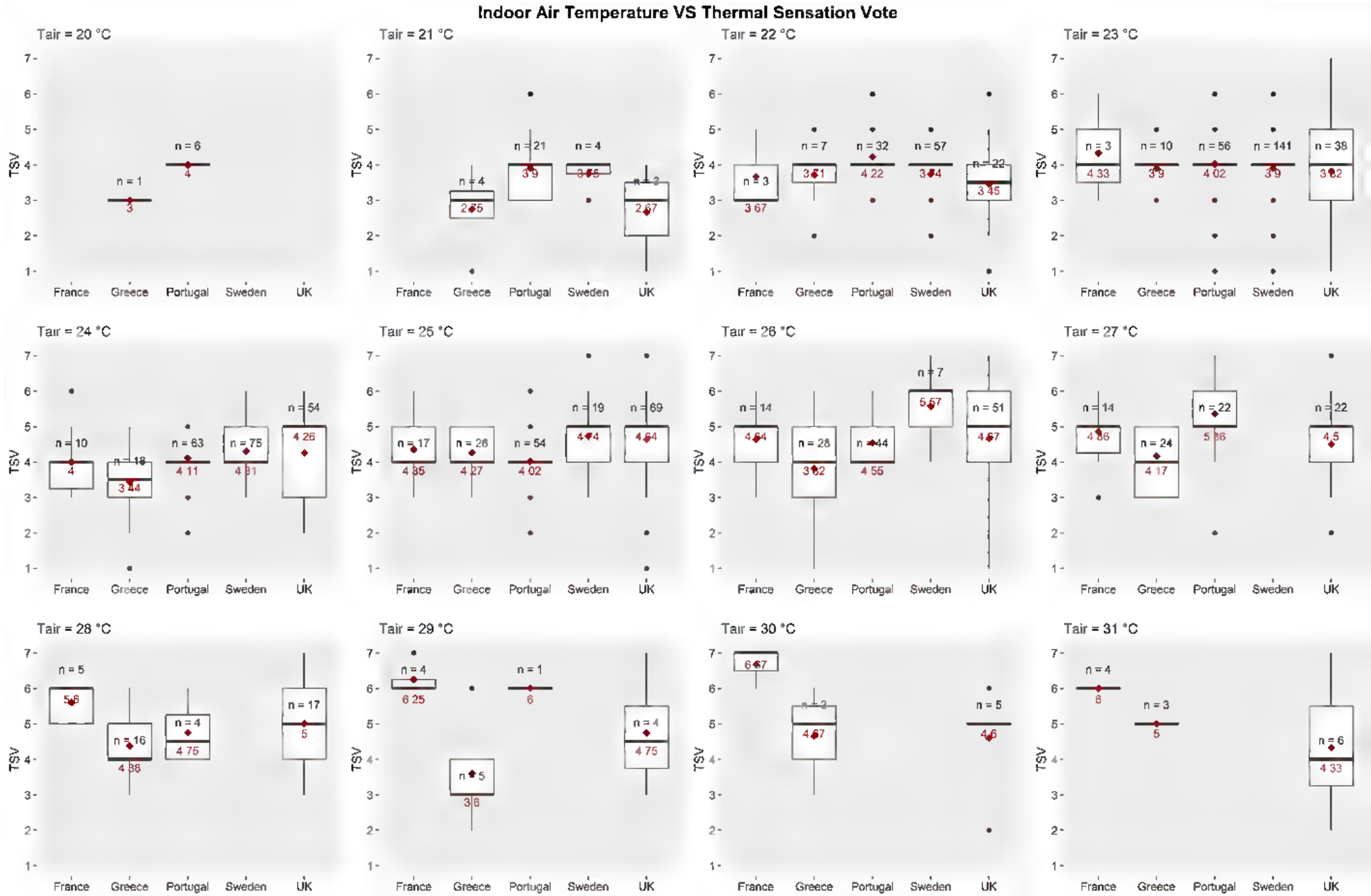


Figure 38. Smart Controls and Thermal Comfort database. Spring-summer period. Indoor Air Temperature VS Thermal Sensation Vote

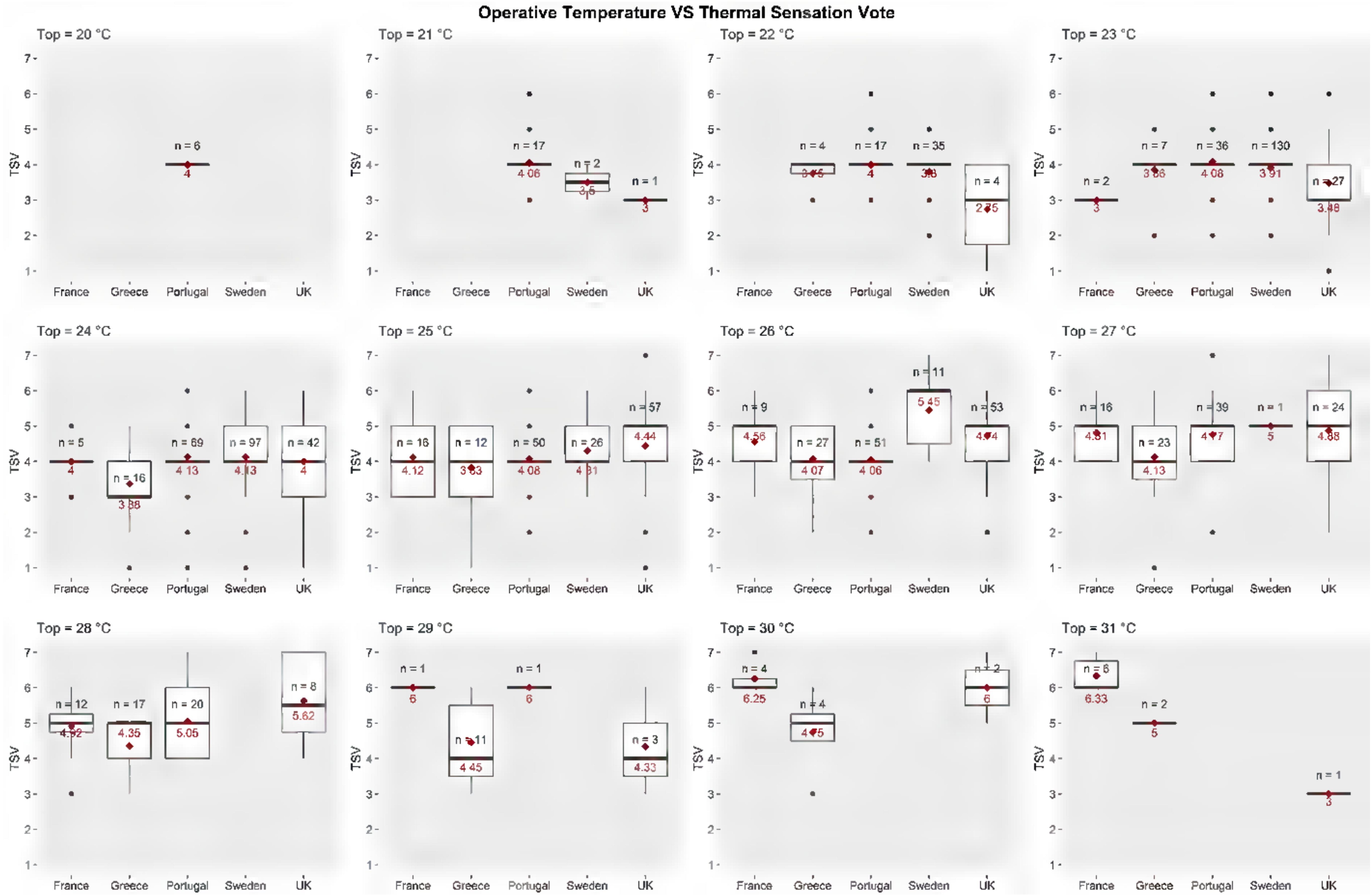


Figure 39. Smart Controls and Thermal Comfort database. Spring-summer period. Operative temperature VS Thermal Sensation Vote

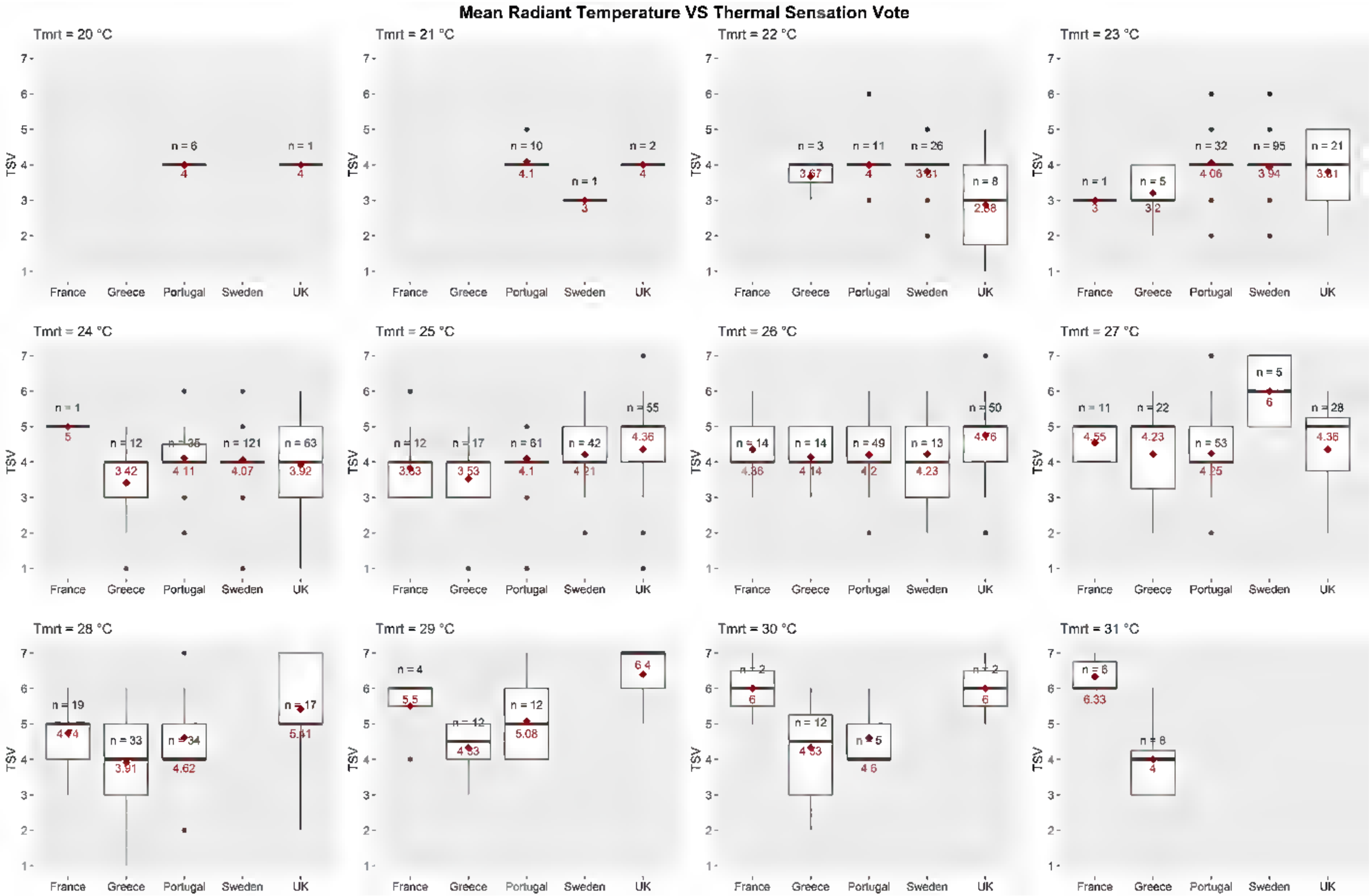


Figure 40. Smart Controls and Thermal Comfort database. Spring-summer period. Mean Radiant Temperature VS Thermal Sensation Vote

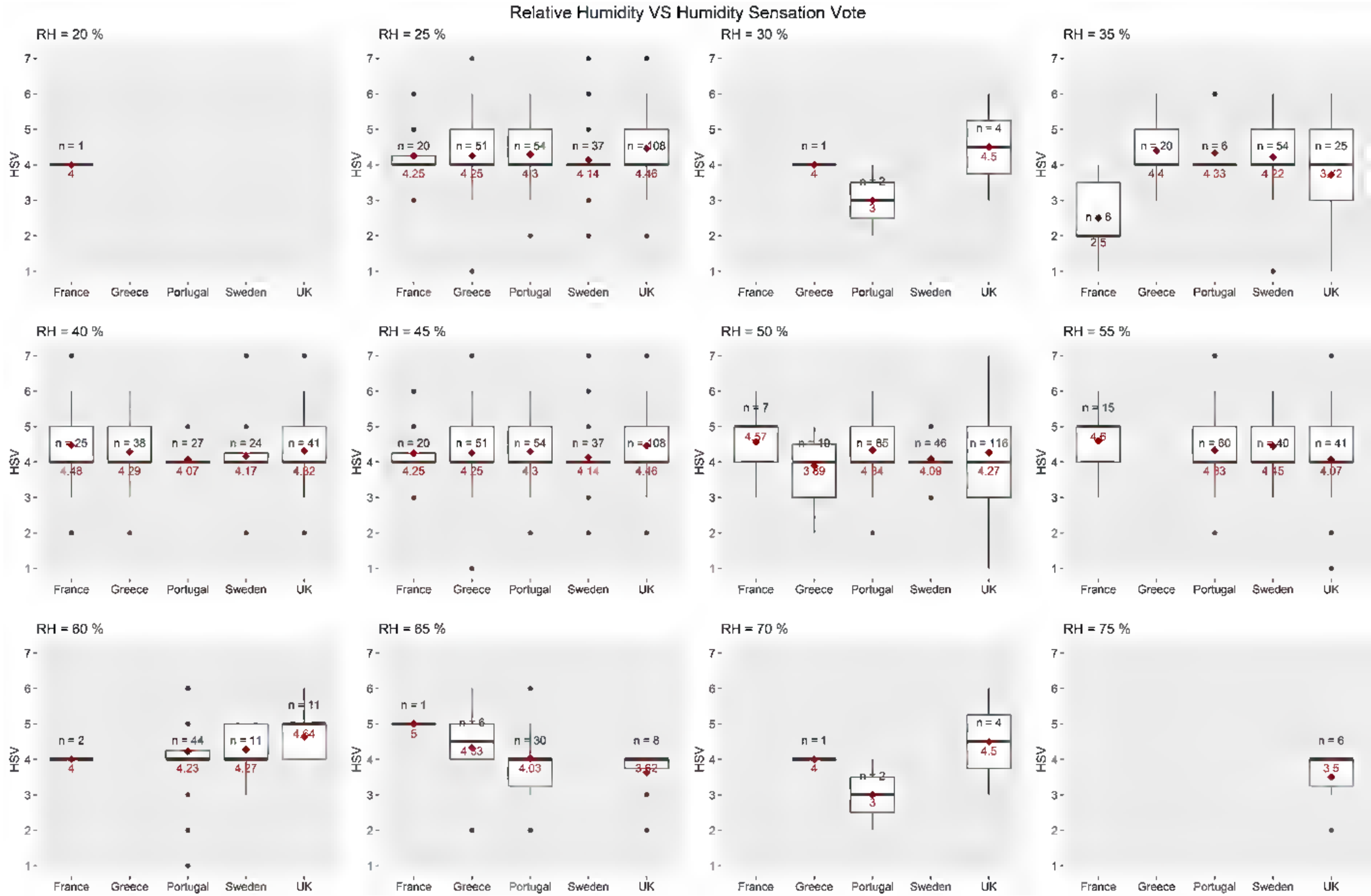


Figure 41. Smart Controls and Thermal Comfort database. Spring-summer period. Relative Humidity VS Humidity Sensation Vote

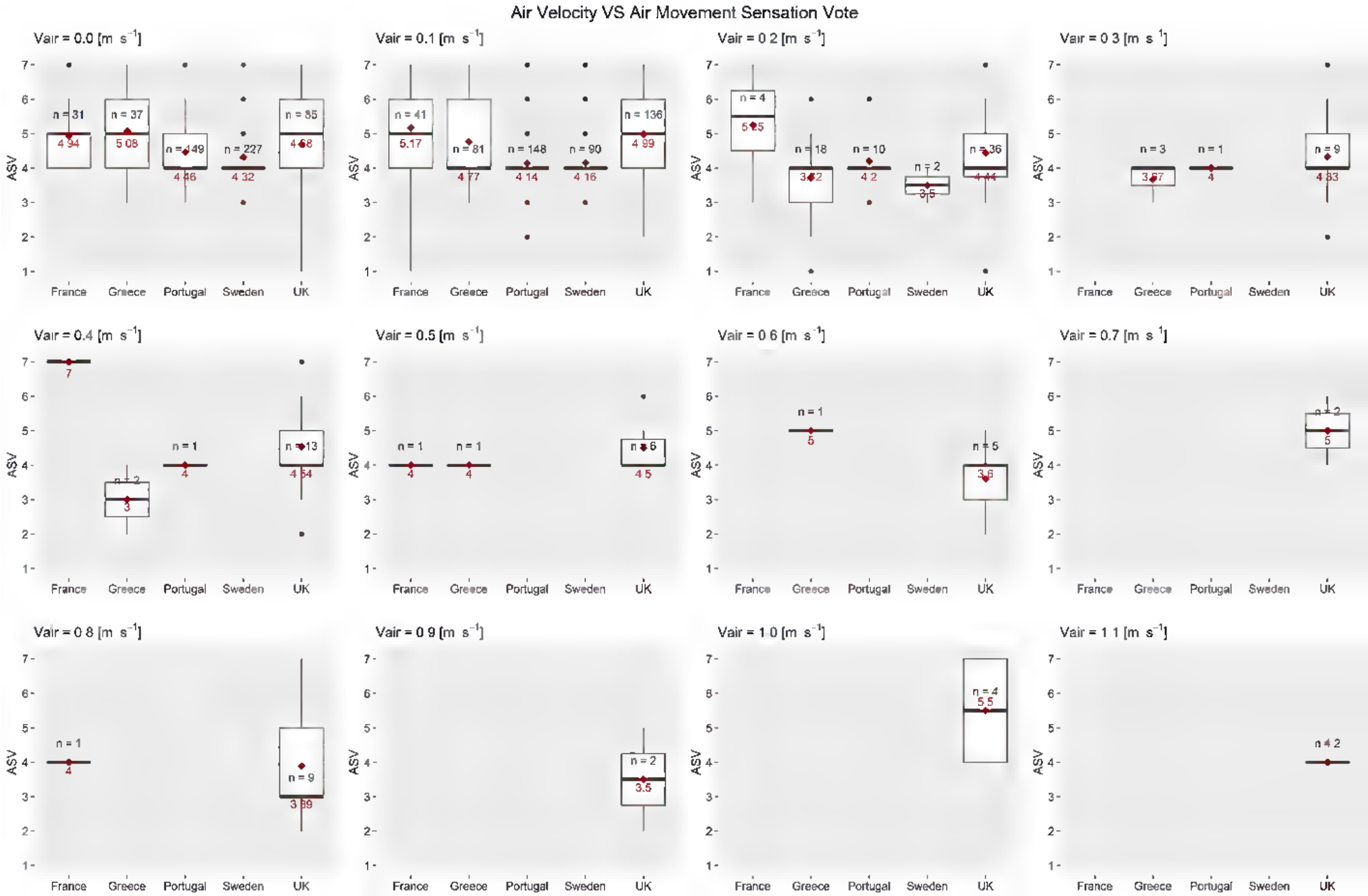


Figure 42. Smart Controls and Thermal Comfort database. Spring-summer period. Air Velocity VS Air Movement Sensation Vote

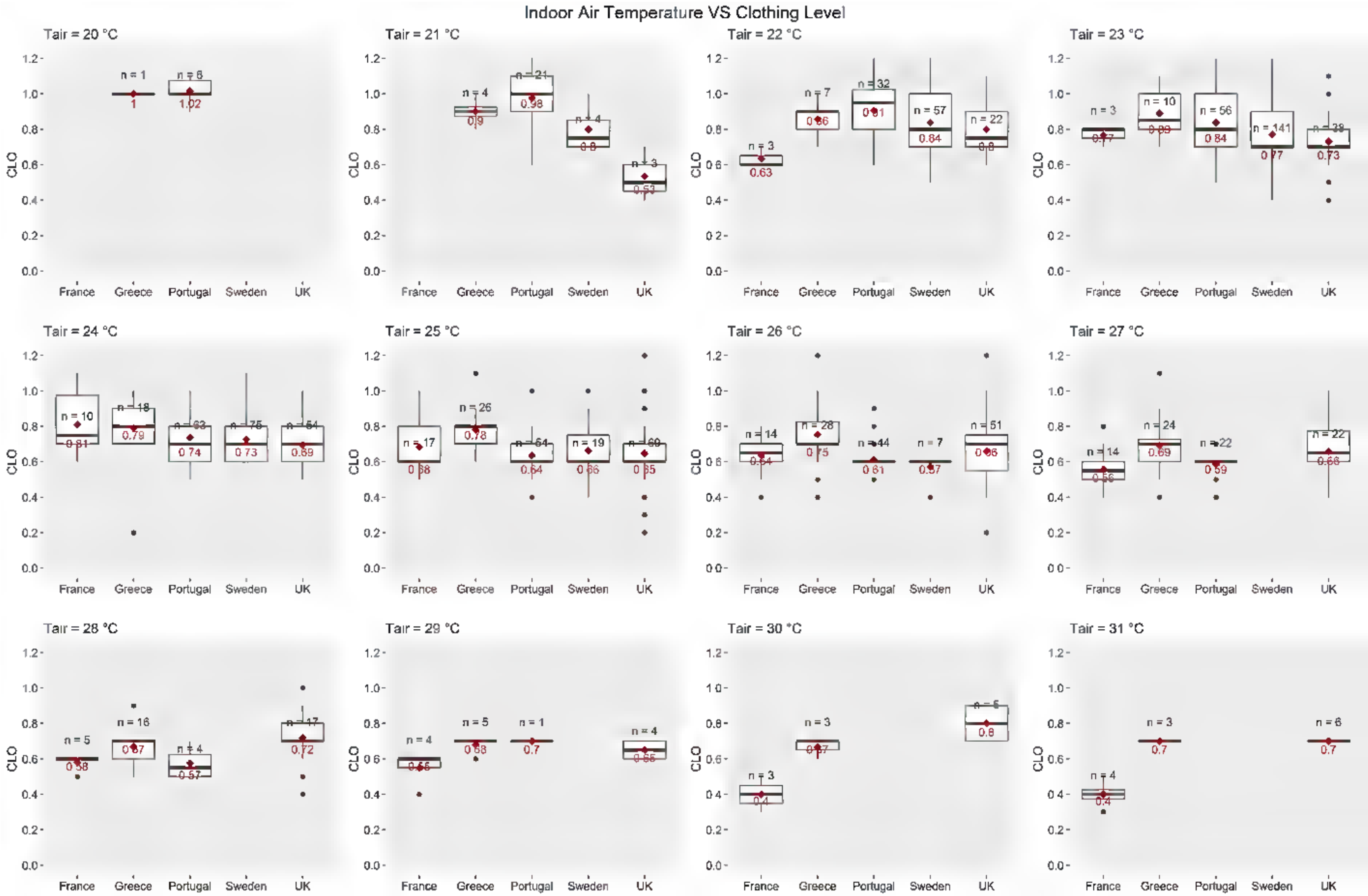


Figure 43. Smart Controls and Thermal Comfort database. Spring-summer period. Indoor Air Temperature VS Clothing Level

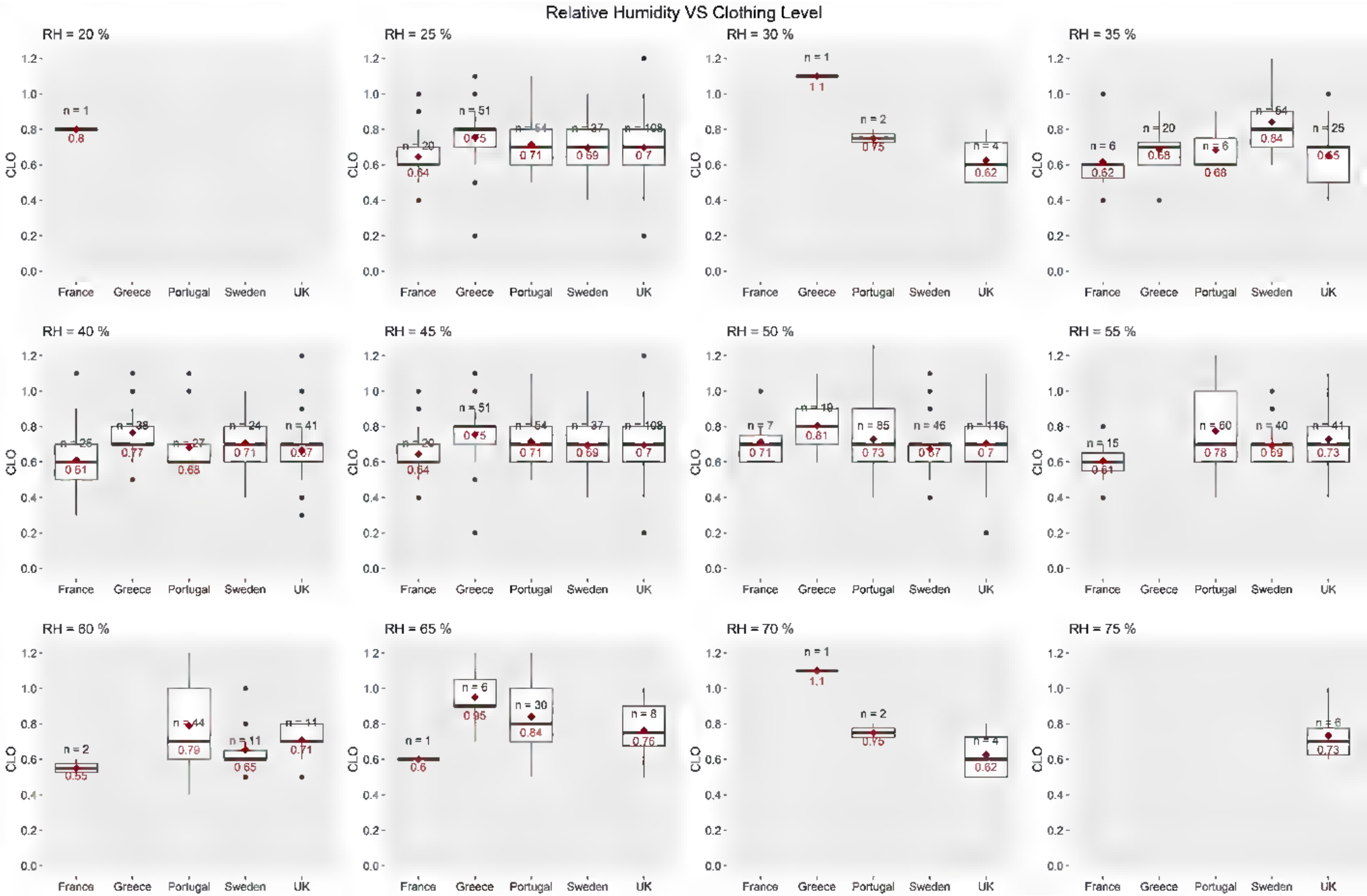


Figure 44. Smart Controls and Thermal Comfort database. Spring-summer period. Relative Humidity VS Clothing Level

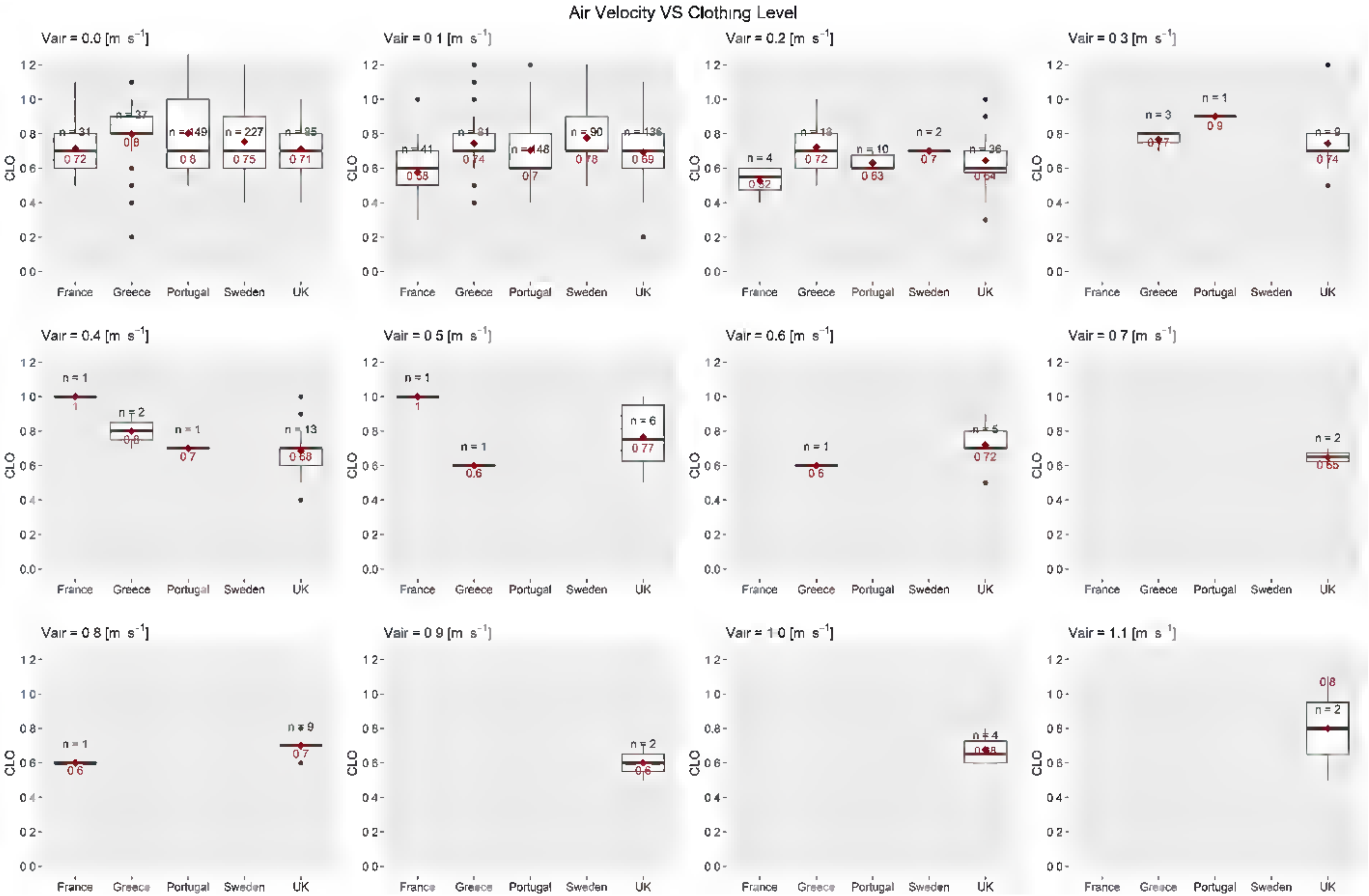


Figure 45. Smart Controls and Thermal Comfort database. Spring-summer period. Air Velocity VS Clothing Level

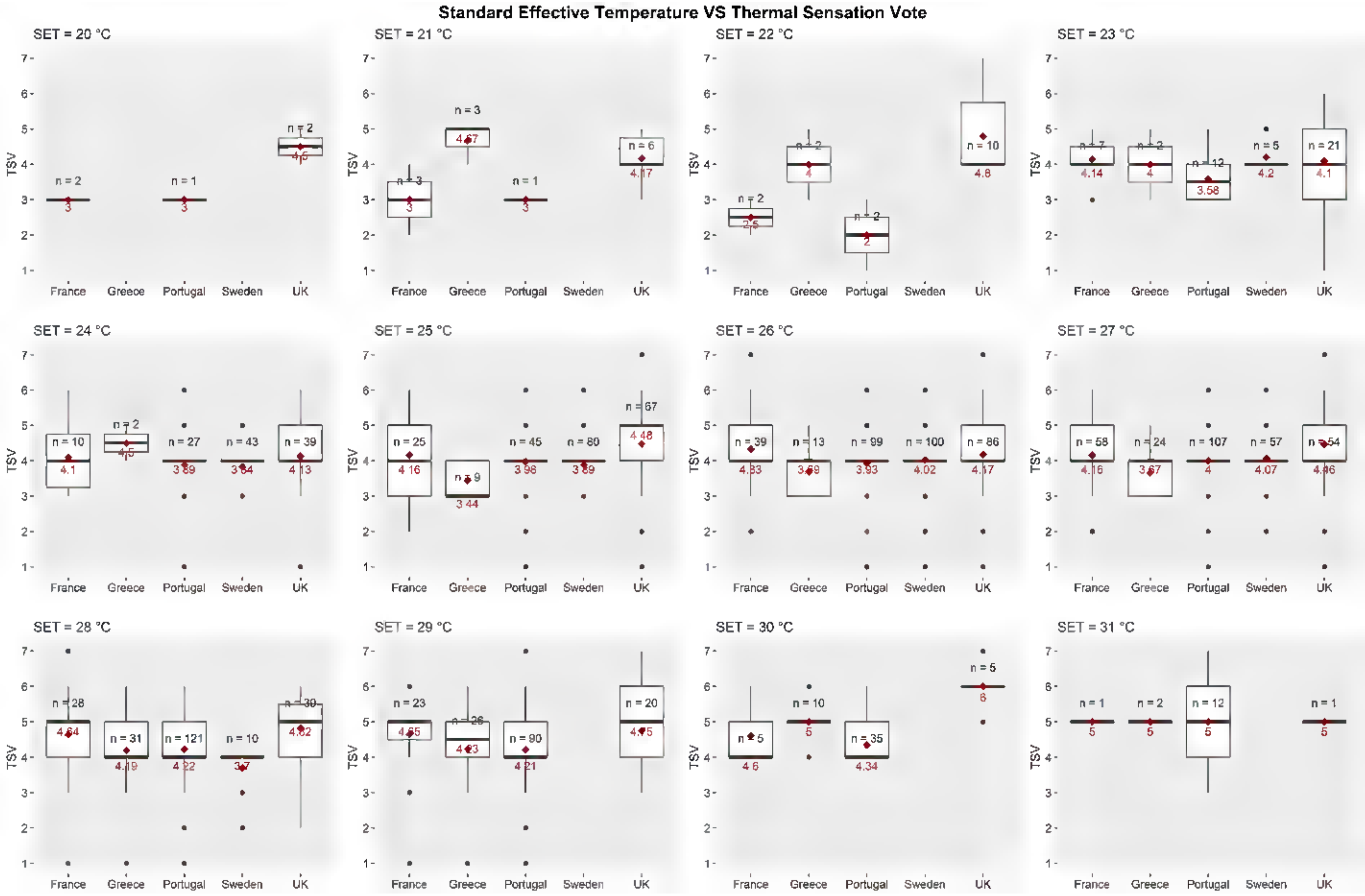


Figure 46. Smart Controls and Thermal Comfort database. Autumn-winter period. Standard Effective Temperature VS Thermal Sensation Vote

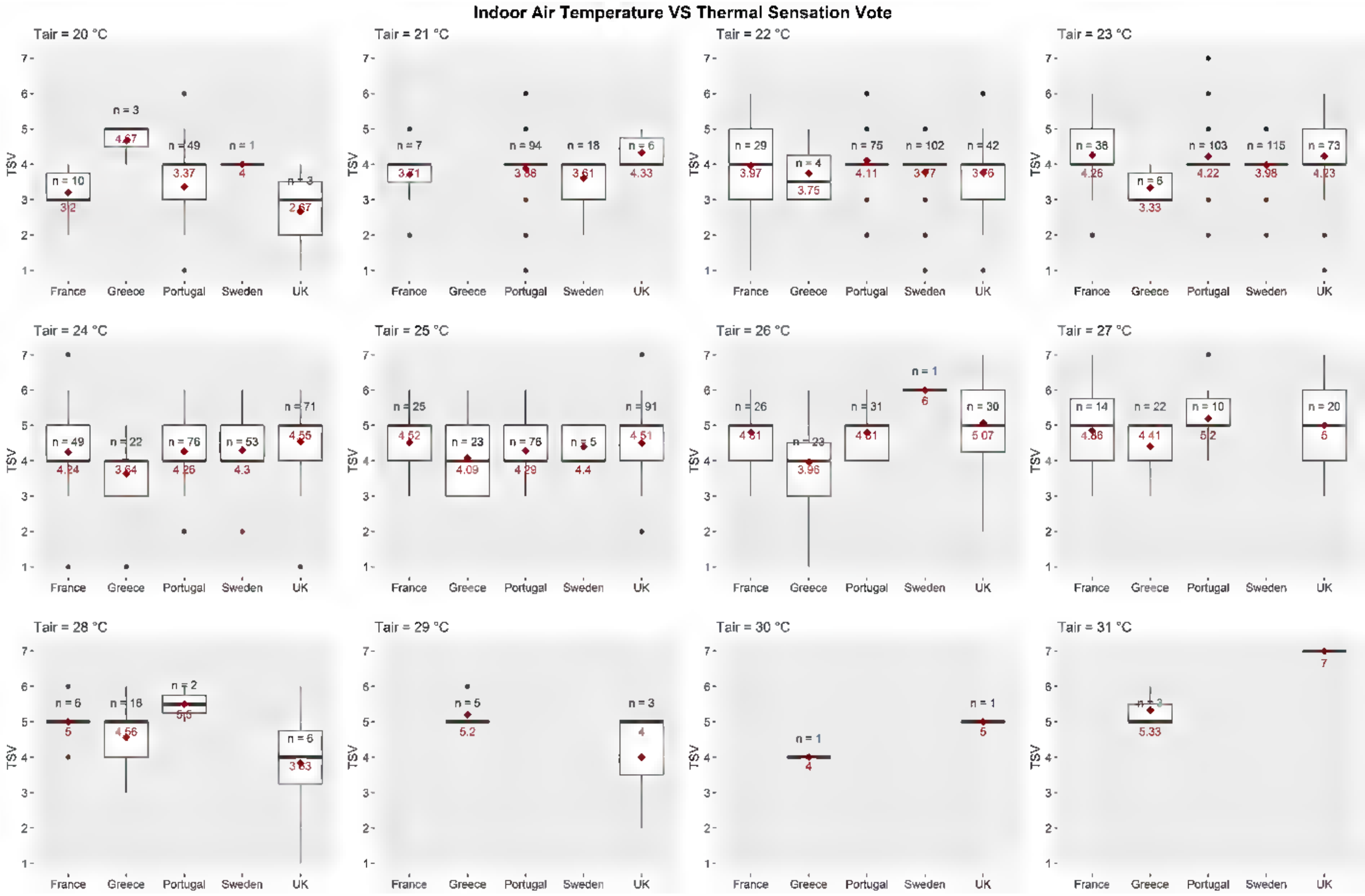


Figure 47. Smart Controls and Thermal Comfort database. Autumn-winter period. Indoor Air Temperature VS Thermal Sensation Vote

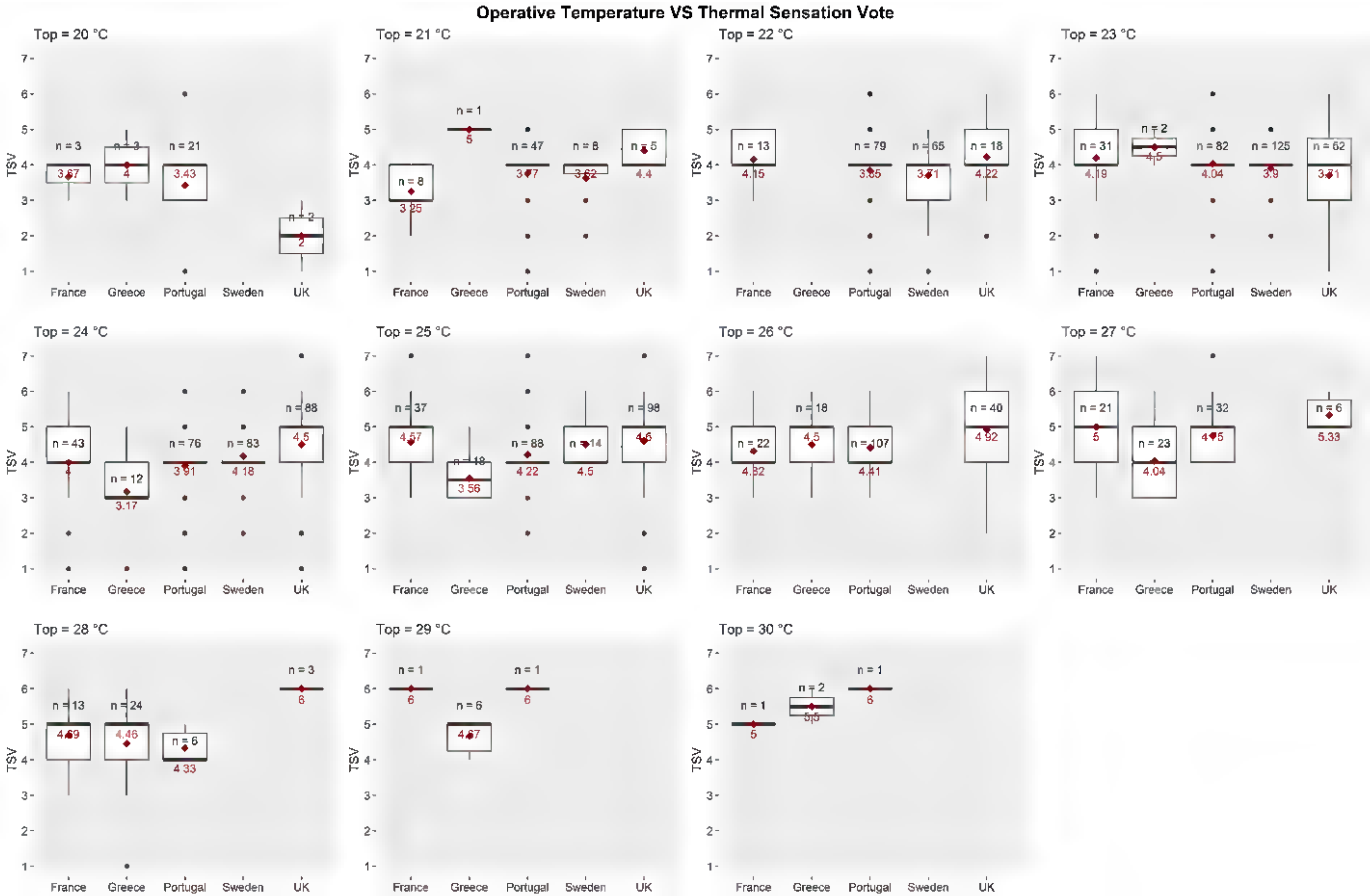


Figure 48. Smart Controls and Thermal Comfort database. Autumn-winter period. Operative temperature VS Thermal Sensation Vote

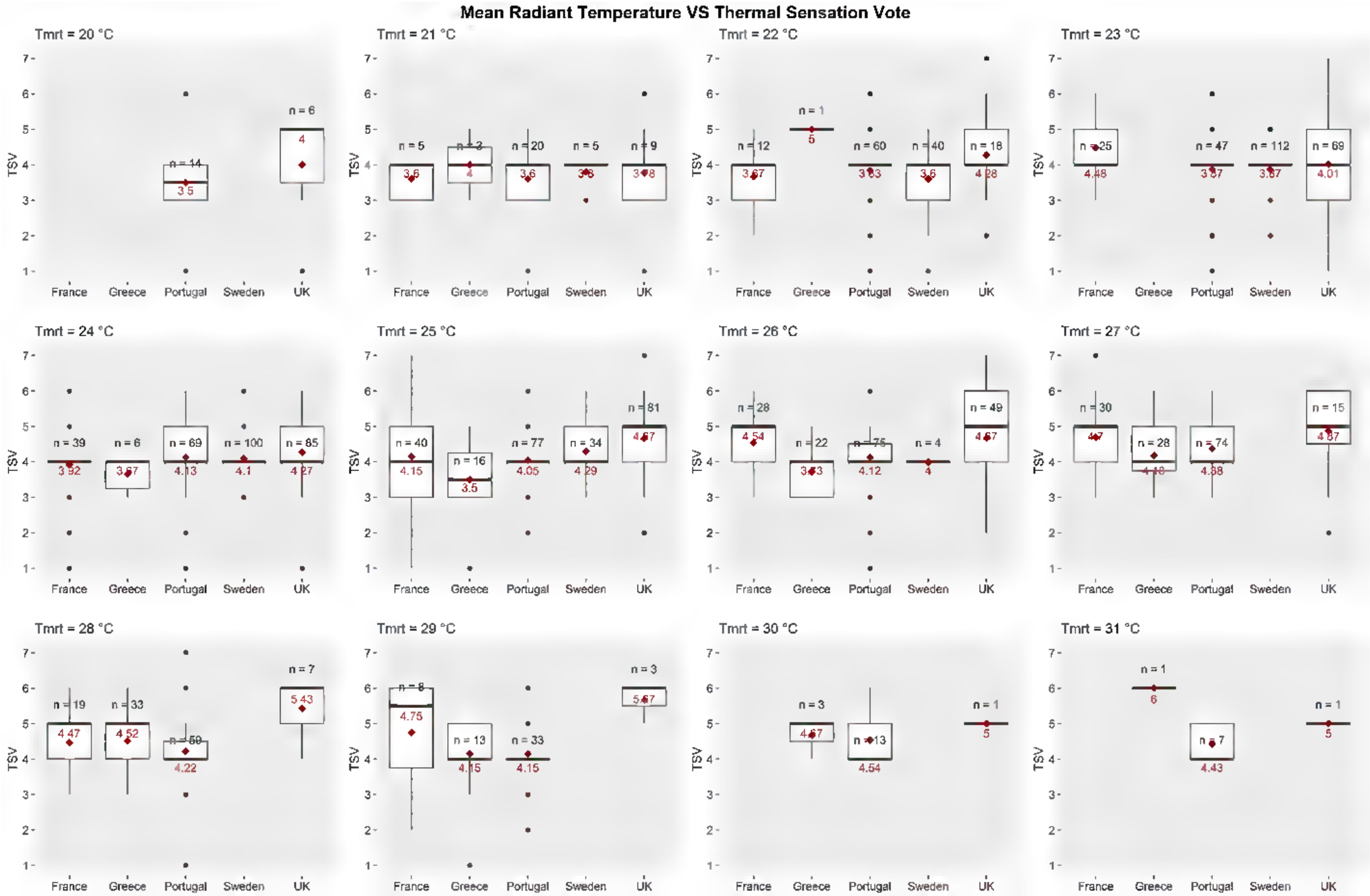


Figure 49. Smart Controls and Thermal Comfort database. Autumn-winter period. Mean Radiant Temperature VS Thermal Sensation Vote

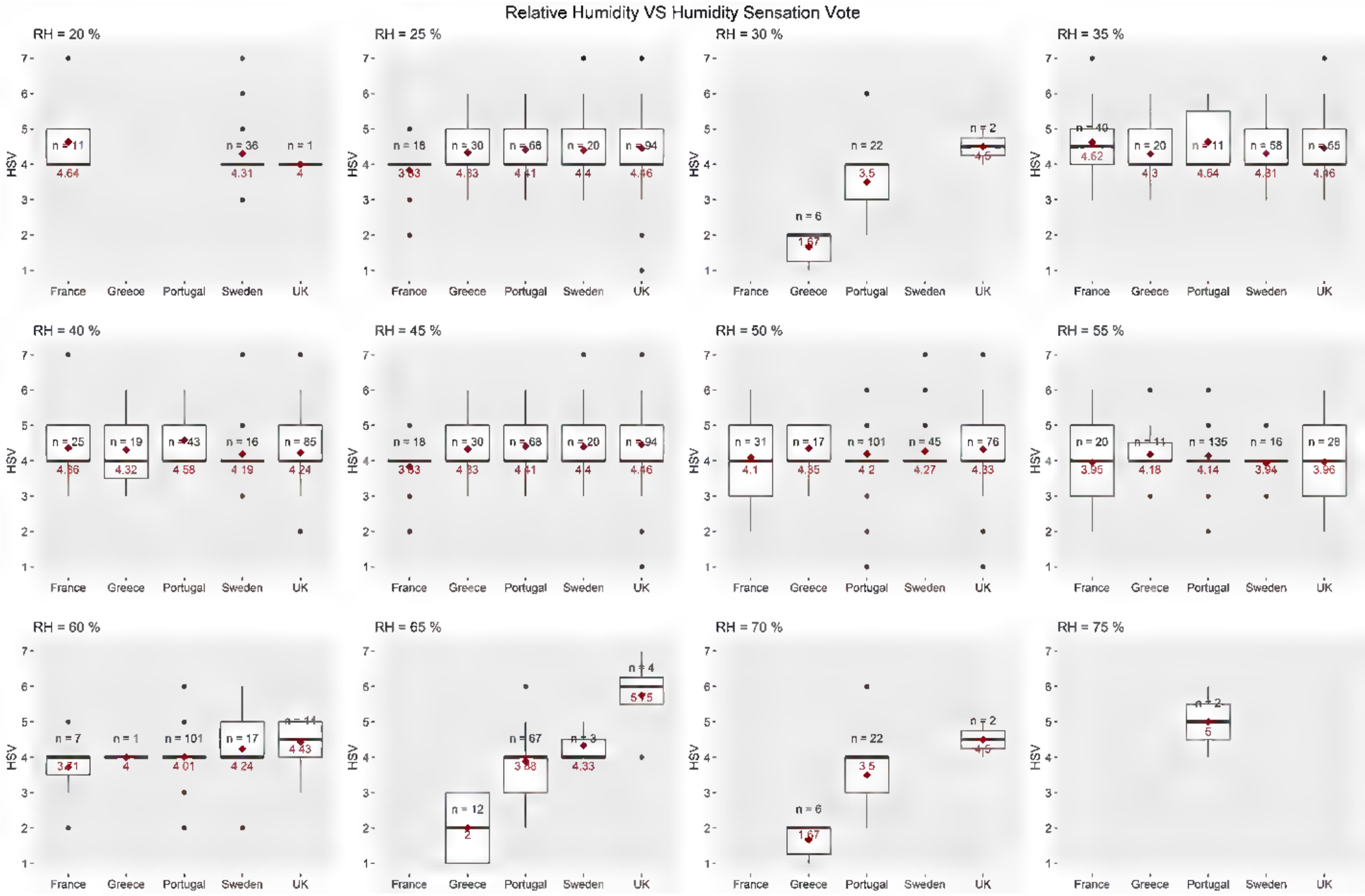


Figure 50. Smart Controls and Thermal Comfort database. Autumn-winter period. Relative Humidity VS Humidity Sensation Vote

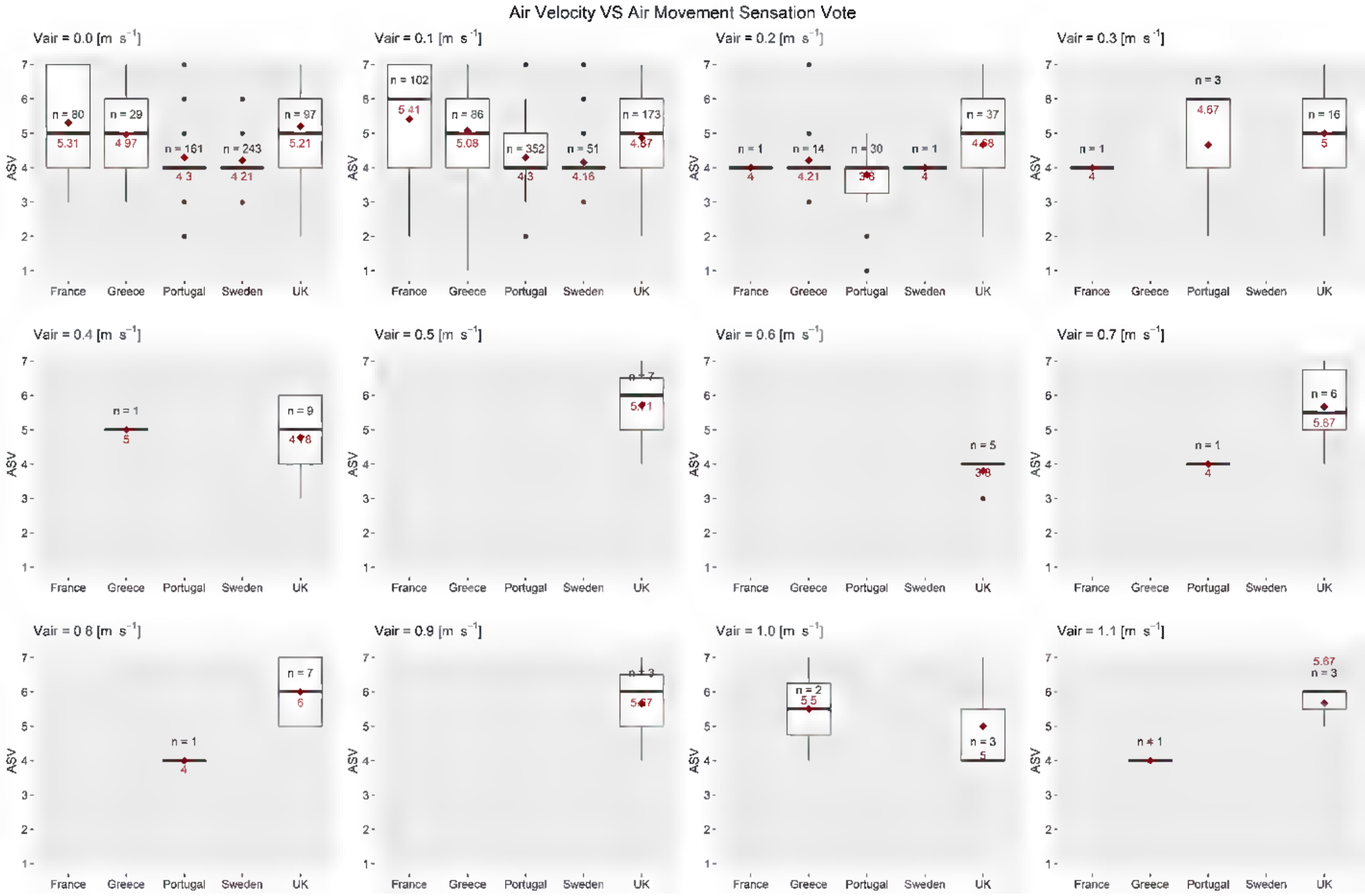


Figure 51. Smart Controls and Thermal Comfort database. Autumn-winter period. Air Velocity VS Air Movement Sensation Vote

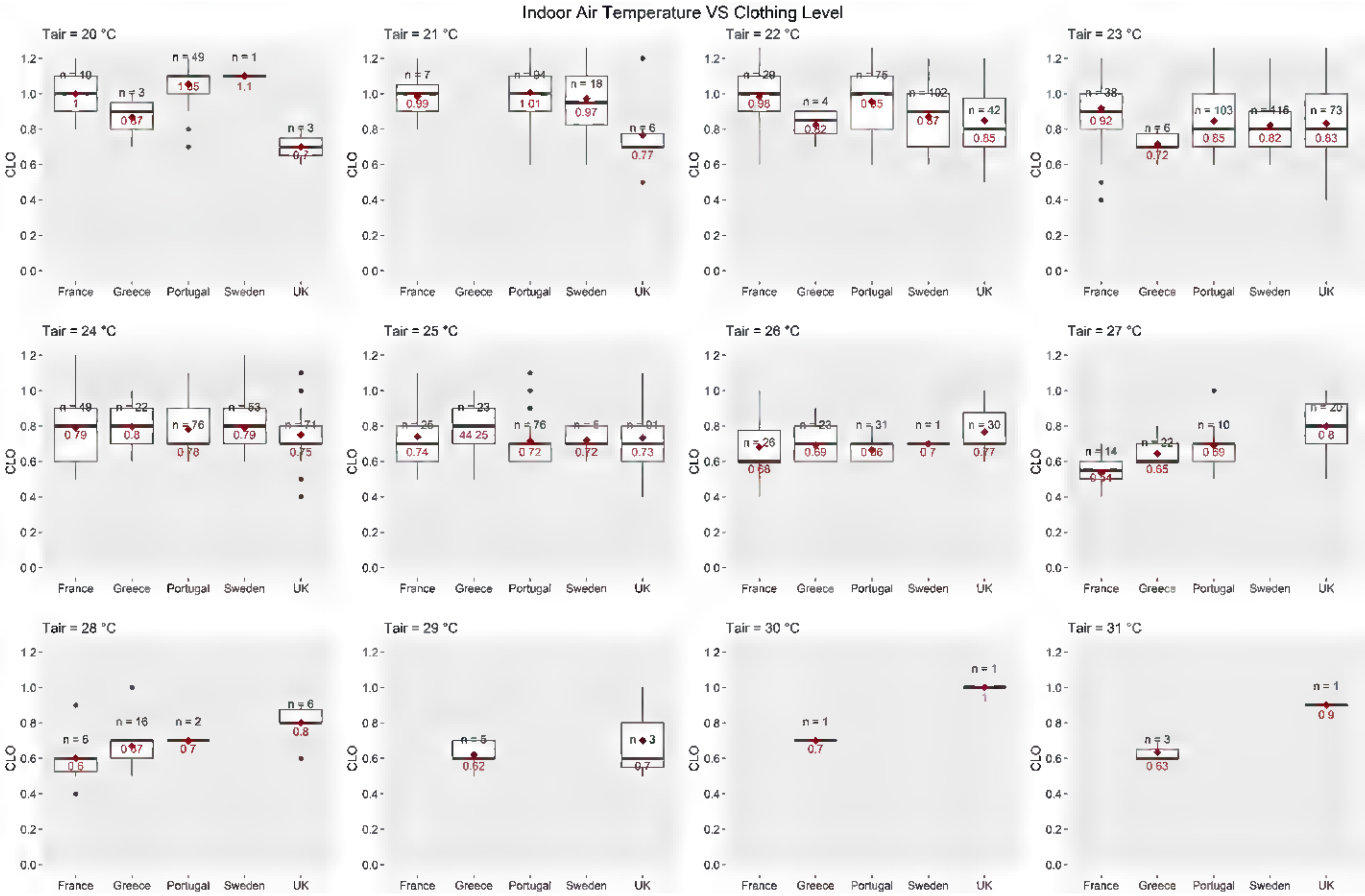


Figure 52. Smart Controls and Thermal Comfort database. Autumn-winter period. Indoor Air Temperature VS Clothing Level

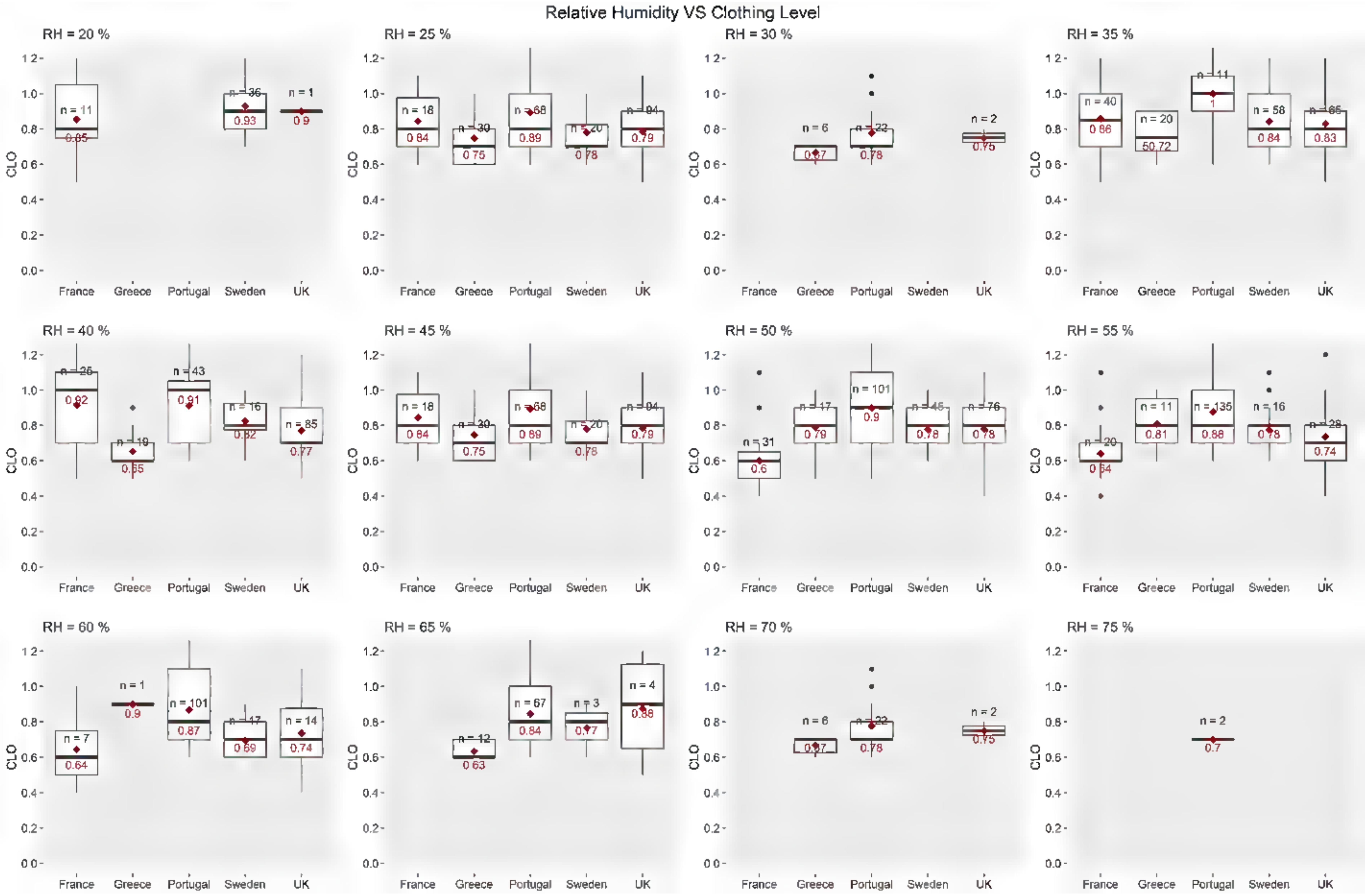


Figure 53. Smart Controls and Thermal Comfort database. Autumn-winter period. Relative Humidity VS Clothing Level

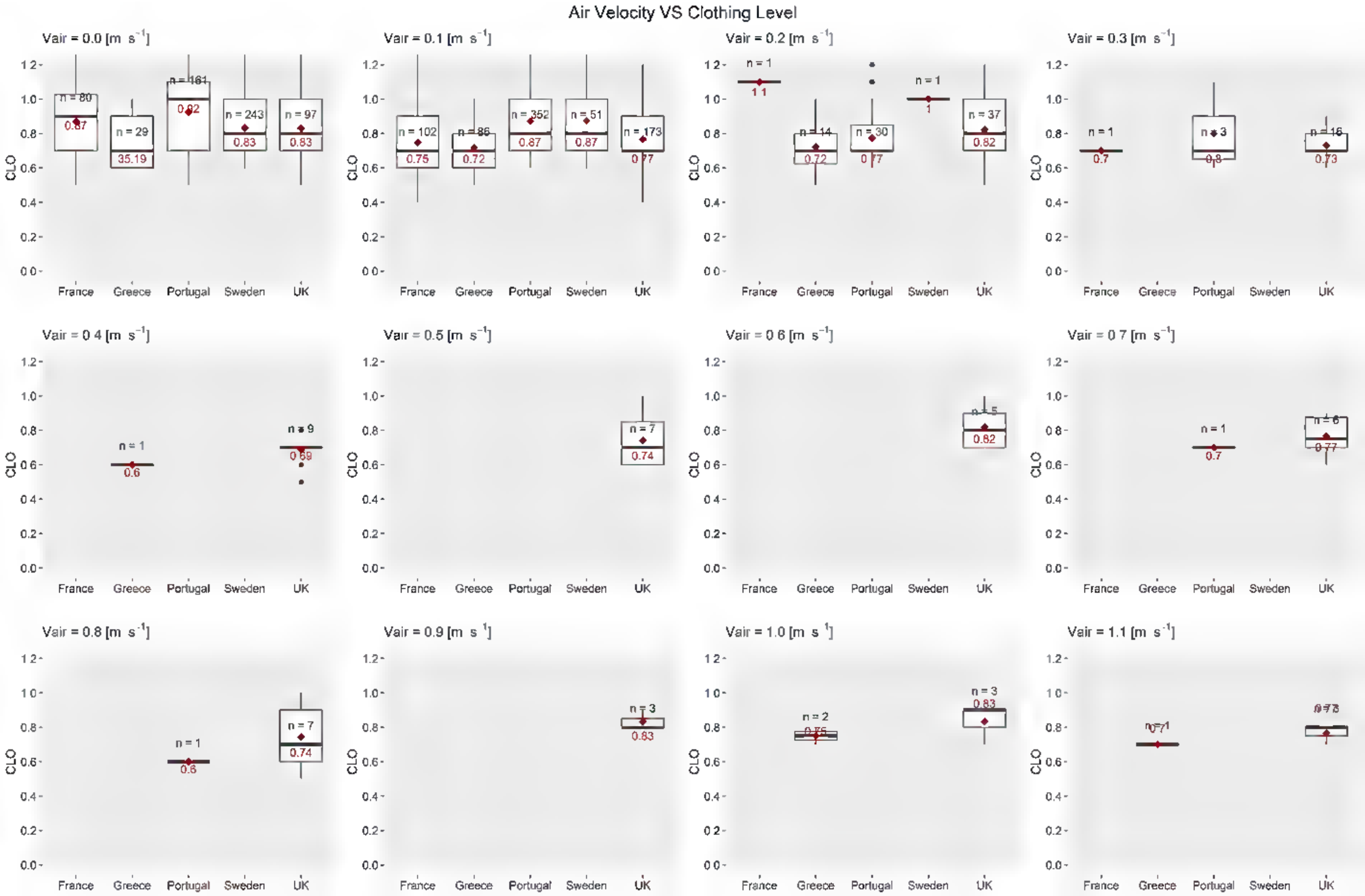


Figure 54. Smart Controls and Thermal Comfort database. Autumn-winter period. Air Velocity VS Clothing Level

Q: For the following items, please indicate how important it is to you to have personal control over them (i.e. you can physically make adjustments yourself). Please answer regardless of whether or not you have the control available in your building.

Figure 55. Smart Controls and Thermal Comfort database. Estimation of personal control importance. Evaluating scale from 1 (very important) to 4 (unimportant)

Q: For the following items, please indicate whether or not you actually have personal control over their adjustment.

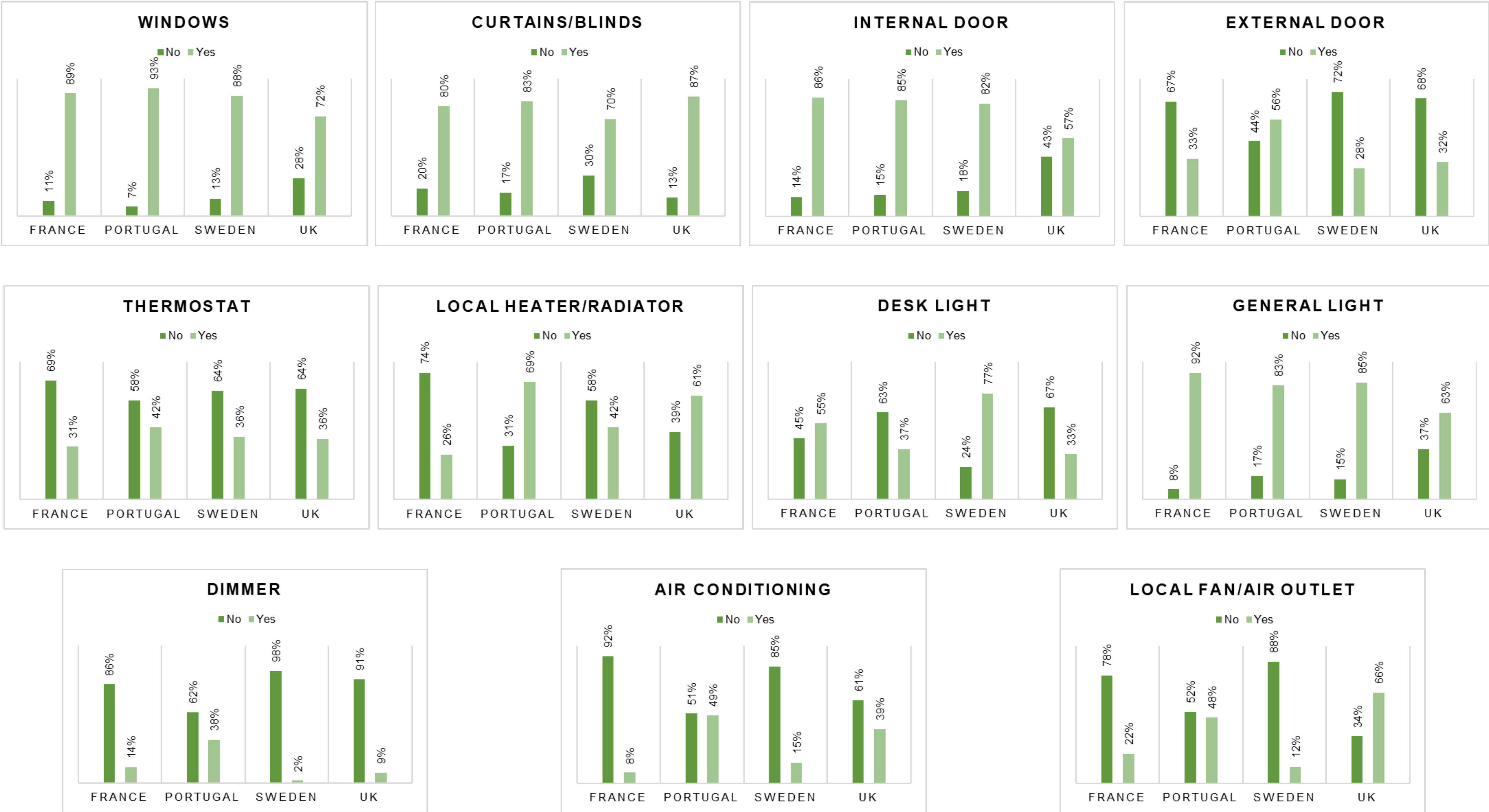


Figure 56. Smart Controls and Thermal Comfort database. Use of personal control. Evaluating scale 0(No)-1(Yes)

Q: If YES, how often do you actually make adjustments?

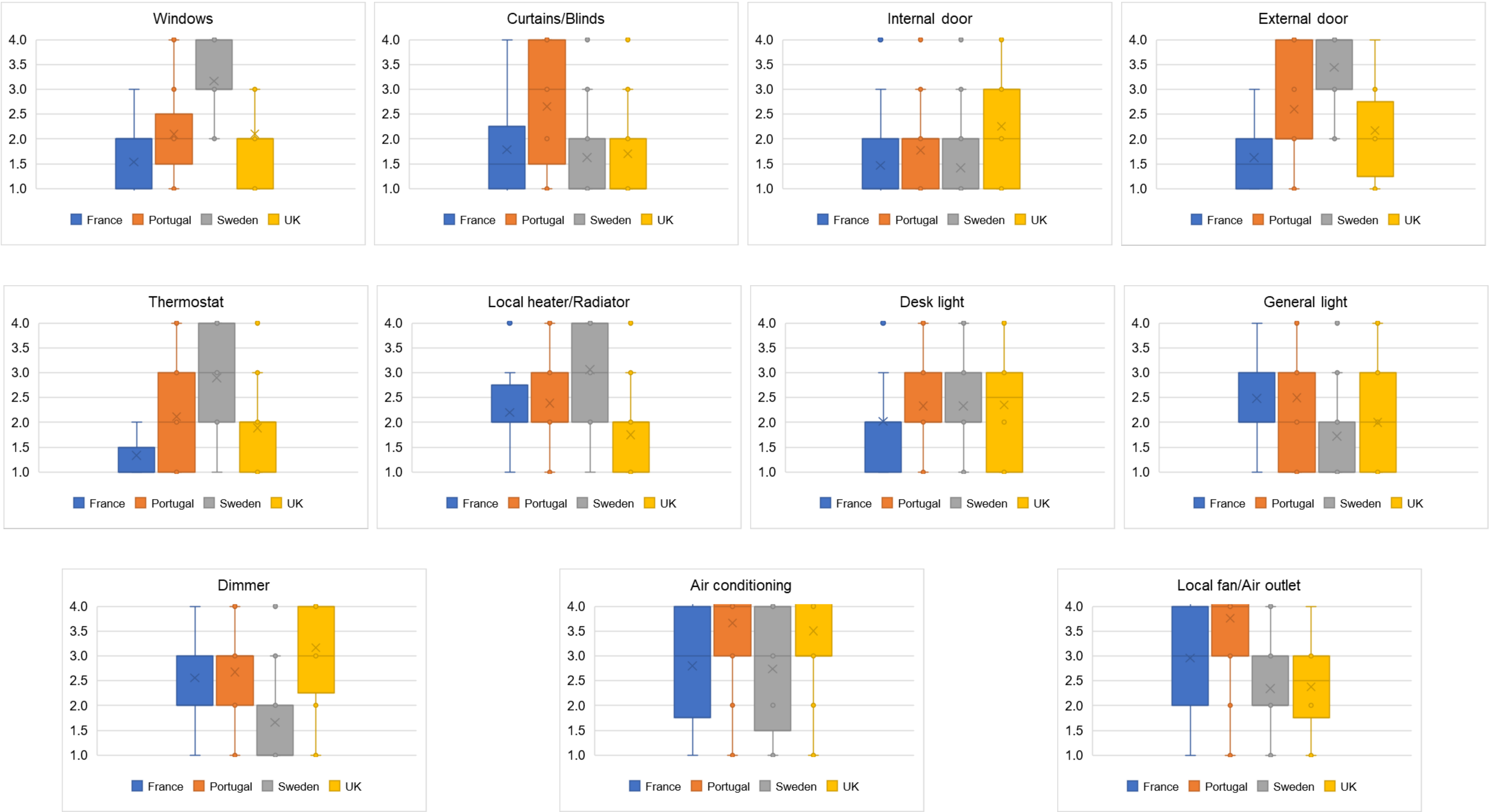


Figure 57. Smart Controls and Thermal Comfort database. Frequency of use of personal controls. Evaluating scale from 1 (often) to 4 (never)

Q: For the controls that you are able to personally adjust, does altering them bring effective relief to any discomfort?

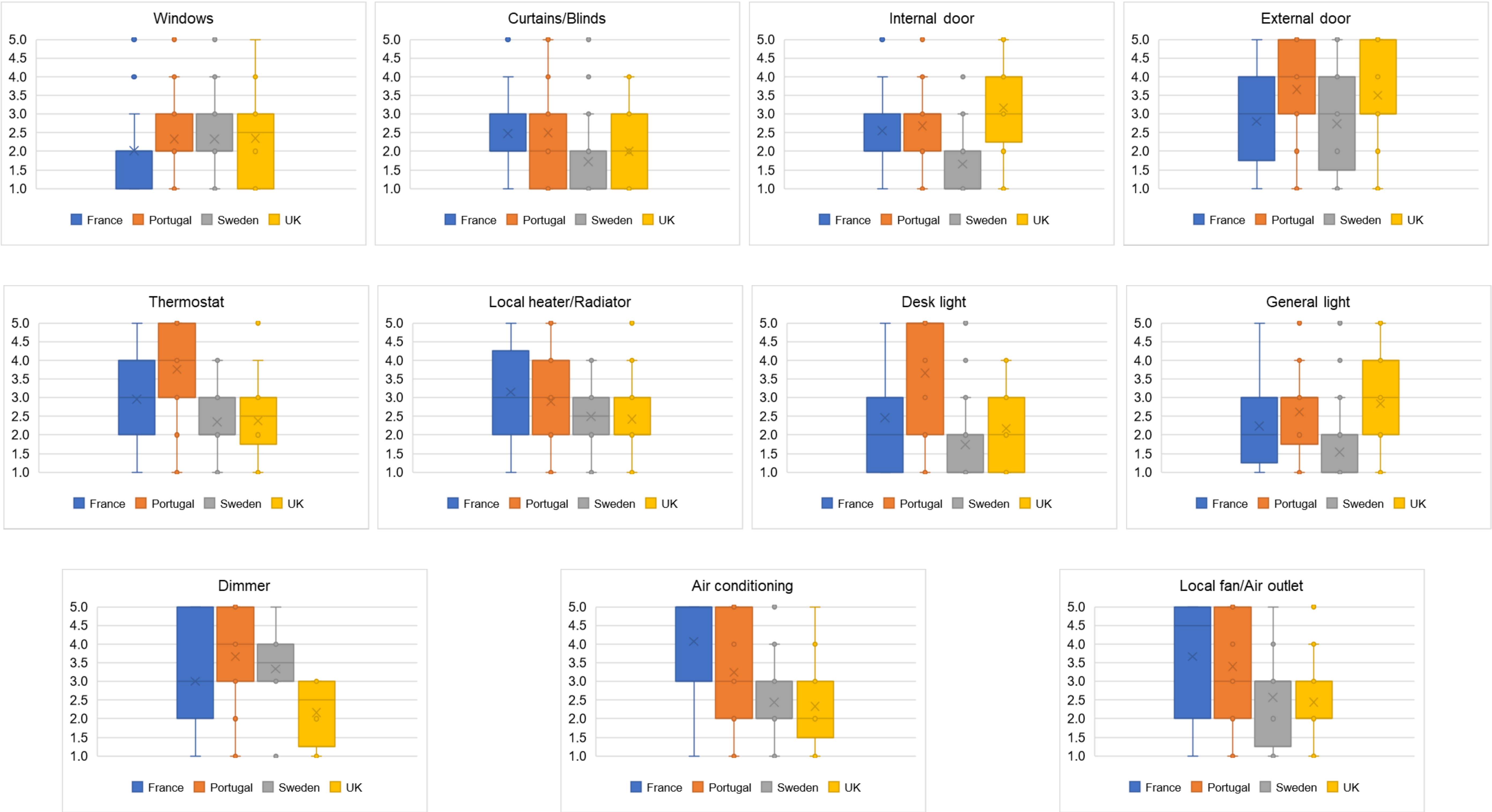


Figure 58. Smart Controls and Thermal Comfort database. Relief given by personal control. Evaluating scale from 1 (always) to 5 (never)

Q: For the controls that you are able to personally adjust, how quickly does a change bring effective comfort?

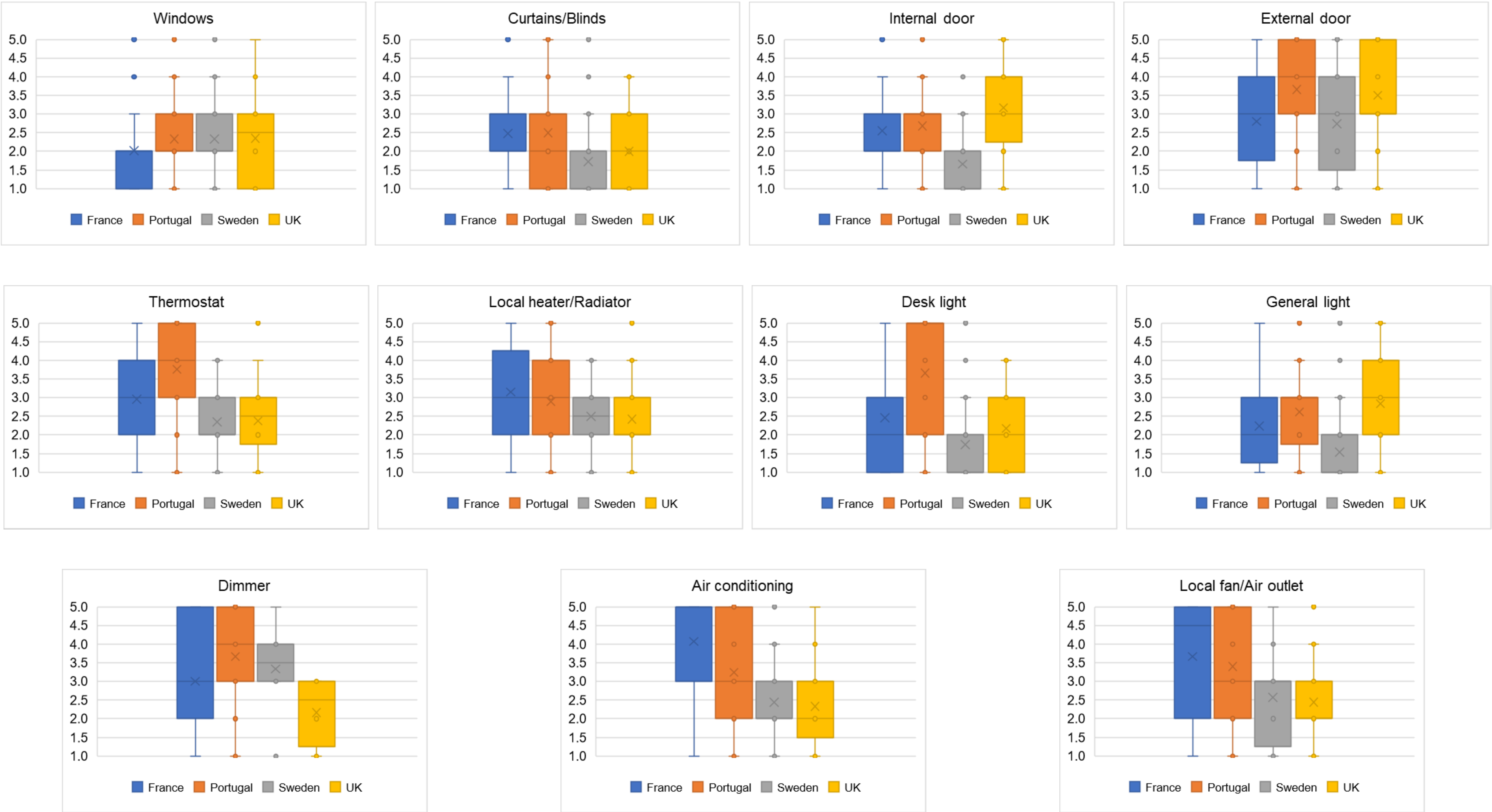


Figure 59. Smart Controls and Thermal Comfort database. Velocity of relief given by personal control. Evaluating scale from 1 (instantly) to 5 (never)

Q: Listed below are a number of factors which may or may not affect the working environment. Please indicate on the scale how important you consider these factors to be in establishing a good working environment.

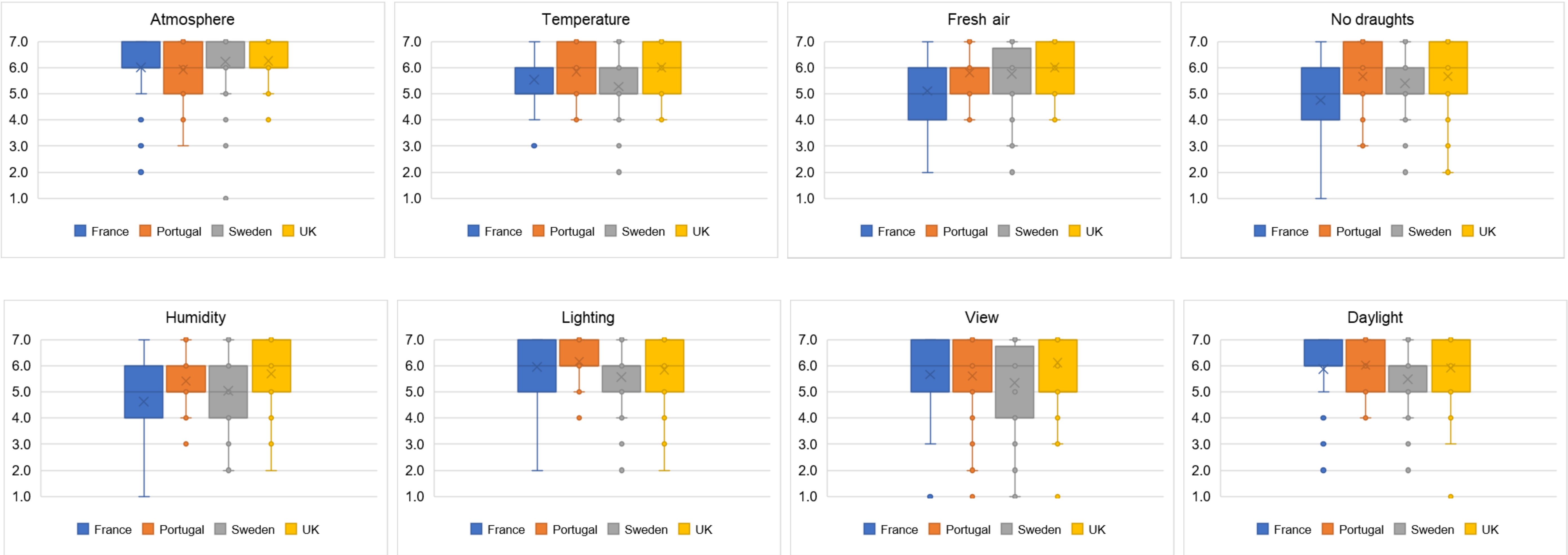


Figure 60. Smart Controls and Thermal Comfort database. Importance of different environmental aspects pt. I. Evaluating scale from 1 (not all important) to 7 (very important)

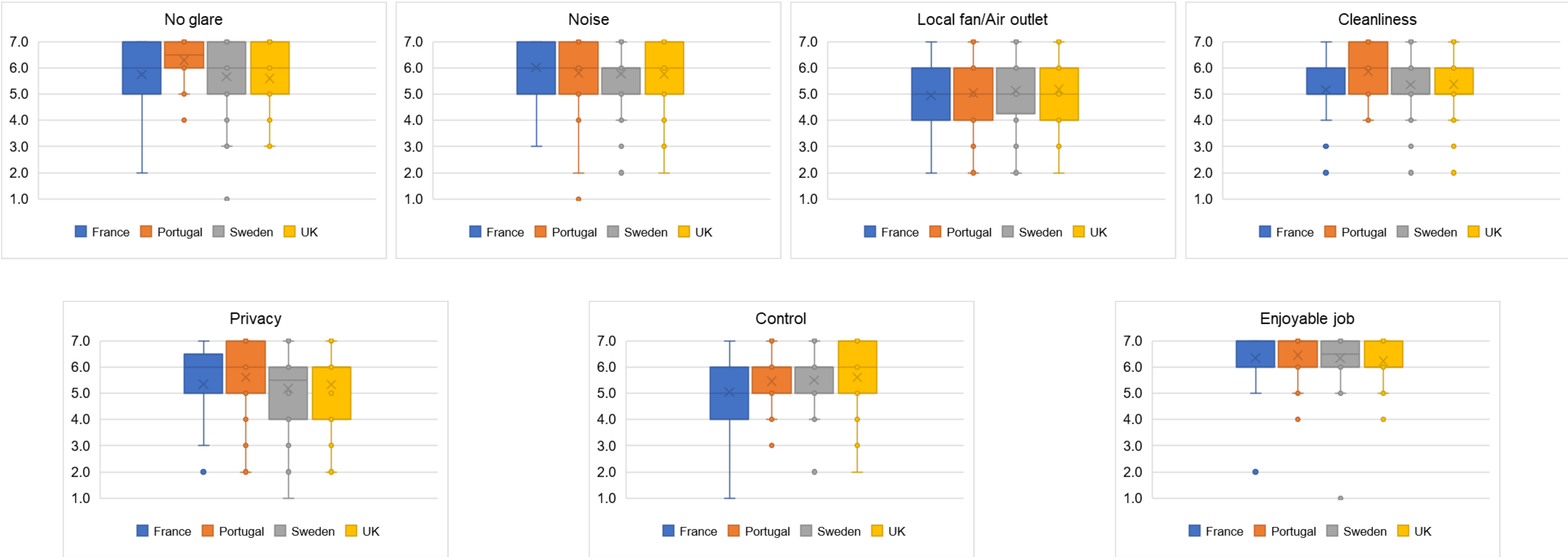


Figure 61. Smart Controls and Thermal Comfort database. Importance of different environmental aspects pt. II. Evaluating scale from 1 (not all important) to 7 (very important)

References

Altman, I., Rapoport, A. & Wohlwill, J. F., 1980. Human Behavior and Environment. In: *Volume 4: Environment and Culture.* New York: Springer Science+Business Media, LLC.

Amin, R., Teli, D., James, P. & Bourikas, L., 2016. The influence of a student's 'home' climate on room temperature and indoor environmental controls use in a modern halls of residence. *Energy and Buildings,* Volume 119, pp. 331-339.

ANSI/ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017. *Standard 55: Thermal Environmental Conditions for Human Occupancy,* Atlanta: s.n.

Arens, A., Humphreys, M. A., de Dear , R. & Zhang, H., 2010. *Are 'class A' temperature requirements realistic or desirable?.* s.l.:s.n.

Arrindell, W. A., 2003. *Book review of Culture's consequences: Comparing values, behaviors, institutions, and organizations across nations by G. Hofstede, Behaviour Research and Therapy.* s.l.:s.n.

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017. *Standard 55 - Thermal Environmental Conditions for Human Occupancy,* Atlanta: s.n.

Attia, S. et al., 2017. Overview and future challenges of nearly zero energy buildings (nZEB) design in Southern Europe. *Energy and Buildings,* Issue http://dx.doi.org/10.1016/j.enbuild.2017.09.043, p. 19.

Badescu, V., Rotar, N. & Udrea, I., 2015. Considerations concerning the feasibility of the German Passivhaus concept in Southern Hemisphere. *Energy Efficiency,* Issue 10.1007/s12053-015-9332-8.

Barbosa, R., Bartak, M., Hensen, J. L. M. & Loomans, M. G. L. C., 2015. Ventilative cooling control strategies applied to passive house in order to avoid indoor overheating. *International Building Performance Simulation Association (IBPSA),* Issue http://www.bs2015.in/.

Bauman, F., Carter, T., Baughman, A. & Arens, E., 1998. Field study of the impact of a desktop task/ambient conditioning system in office buildings. *ASHRAE Transactions,* Volume 104.

Berge, M. & Mathisen, H., 2013. *Post-Occupancy Evaluation of Low-Energy and Passive House Apartments in the Løvåshagen Cooperative — Occupant Behavior and Satisfaction.* Gothenburg, Passivhus Norden 2013.

Beshir, M. Y. & Ramsey, J. D., 1981. Comparison between male and female subjective estimates of thermal effects and sensations. *Applied Ergonomics,* Volume 12, pp. 29-33.

Brager, G. & de Dear, R., 2003. Historical and Cultural Influences on Comfort Expectations. In: L. R. Cole R.J., ed. *Buildings, Culture and Environment: Informing Local and Global Practices.* s.l.:Wiley-Blackwell, pp. 177-201.

Brager, G. & de Dear, R., 2008. Historical and Cultural Influences on Comfort Expectations. In: L. R. Cole R.J., ed. *Buildings, Culture and Environment: Informing Local and Global Practices.* s.l.: Wiley-Blackwell, pp. 177-201.

Brager, G., Paliaga, G. & de Dear, R., 2004. Operable windows, personal control and occupant comfort.

Carlucci, S., Pagliano, L. & Zangheri, P., 2013. Optimization by Discomfort Minimization for Designing a Comfortable Net Zero Energy Building in the Mediterranean Climate. *Advanced Materials Research,* Issue 10.4028/www.scientific.net/AMR.689.44.

CEN - European Commitee of Standardization, 2005. *EN ISO 7730: Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria,* Brussels: s.n.

CEN - European Committee of Standardization, 2007. *EN 15251: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics,* Brussels: s.n.

Chatterton, T., 2011. An introduction to thinking about 'energy behaviour': A multi-model approach.

CULTURAL-E - Climate and cultural based design and market valuable technology solutions for Plus Energy Houses, 2020. *Deliverable D2.1 - Climate and cultural differences in energy use in domestic buildings,* s.l.: s.n.

d'Ambrosio Alfano, F. R., Olesen, B. W. & Palella, B. I., 2017. Povl Ole Fanger's impact ten years later. *Energy and Buildings,* Volume 152, pp. 243-249.

de Dear, R., 2011. Revisiting an old hypothesis of human thermal perception: Alliesthesia. *Building Research and Information,* Volume 39, pp. 108-117.

de Dear, R. & Brager, G., 2002. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and Buildings,* Volume 34, pp. 549-561.

Douglas, M., 1982. *Natural Symbols: Explorations in Cosmology.* London: Barrie & Rockliff.

Douglas, M. & Wildavsky, A., 1982. *Risk and Culture: An Essay on the Selection of Technical and Environmental Dangers.* s.l.:University of California Press, Berkeley (CA).

ENERGISE, 2019. *Deliverable 1.3: publication of conceptual framework,* s.l.: s.n.

Erickson, R., 1997. *Paper or Plastic? Energy, Environment and Consumerism in Sweden and America.* Westport: Praeger.

European Commission, n.d. *EU Energy Poverty Observatory.* [Online] Available at: https://www.energypoverty.eu/ [Accessed August 2020].

European Parliament and the Council of European Union, 2010. *Directive 2010/31/EU on energy performance of buildings,* s.l.: Official Journal of the European Union.

Fitch, J. M., 1970. The future of architecture. *Journal of Aesthetic Education,* Volume 4.

Földváry Ličina, et al., 2018. Development of the ASHRAE Global Thermal Comfort Database II. *Building and Environment,* Volume 142, pp. 502-512.

Frederiks, E. R., Stenner, K. & Hobman, E., 2015. Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews,* Volume 41, pp. 1385-1394.

Frontczak, M. & Wargocki, P., 2011. Literature survey on how different factors influence human comfort in indoor environments. *Building and Environment,* Volume 46, pp. 922-937.

Fuji, H. & Lutzenhiser, L., 1992. Japanese residential air-conditioning: natural cooling and intelligent systems. *Energy and Buildings,* Volume 18, pp. 193-200.

Grivel, F. & Candas, V., 1991. Ambient temperatures preferred by young European males and females at rest. *Ergonomics,* Volume 34, pp. 365-378.

Guillen-Lambea, S., Rodríguez Soria, B. & Marin, J. M., 2017. Comfort settings and energy demand for residential nZEB in warm climates. *Applied Energy,* Issue 10.1016/j.apenergy.2017.05.163.

Hill, L. D., Webb, L. H. & Parsons, K. C., 2000. *Carers' Views of the Thermal Comfort Requirements of People with Physical Disabilities.* s.l., s.n.

Hofstede, G., 1991. *Cultures and Organizations: Software of the Mind.* London: McGrawHill.

Hofstede, G., 2001. *Culture's consequences: Comparing values, behaviors, institutions, and organizations across nations.* s.l.:Sage Publications.

Horta, A., Wilhite, H., Schmidt, L. & Bartiaux, F., 2014. Socio-technical and cultural approaches to energy consumption: An introduction. *Nature and Culture,* 9(2), pp. 115-121.

Humphreys, M. A., 1978. Outdoor temperature and comfort indoors. *Building Research and Practice,* Volume 6, pp. 92-105.

Indraganti, M. & Rao, K. D., 2010. Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations. *Energy and Buildings,* Volume 42, pp. 273-281.

Kahneman, D., Knetsch, J. L. & Thaler, R. H., 1991. Anomalies: the endowment effect, loss aversion, and status quo bias. *Journal of Economic Perspectives,* Volume 5, pp. 193-206.

Karjalainen, S., 2012. Thermal comfort and gender: a literature review. *Indoor Air,* Volume 22, pp. 96-109.

Khovalyg, D. et al., 2020. Critical review of standards for indoor thermal environment and air quality. *Energy & Buildings,* Volume 213.

Khovalyg, D. et al., 2020. Critical review of standards for indoor thermal environment and air quality. *Energy and Buildings,* Volume 213.

Knowlton, B., 1999. *Silicon Valley: Living the Managed Life.* Paris: International Herald Tribune.

Lan, L., Lian, Z., Liu, W. & Liu, Y., 2008. Investigation of gender difference in thermal comfort for Chinese people. *European Journal of Applied Physiology volume,* Volume 102, pp. 471-480.

Luo, M. et al., 2015. Evaluating thermal comfort in mixed-mode buildings: A field study in a subtropical climate. *Building and Environment,* Volume 88, pp. 46-54.

Luo, M. et al., 2016a. The underlying linkage between personal control and thermal comfort: Psychological or physical effects?. *Energy and Buildings,* Volume 111, pp. 56-63.

Luo, M. et al., 2016b. The dynamics of thermal comfort expectations: The problem, challenge and impication. *Building and Environment,* Volume 95, pp. 322-329.

McCartney, K. J. & Nicol, J. F., 2002. Developing an adaptive control algorithm for Europe. *Energy and Buildings,* Volume 34, pp. 623-635.

Nicol, J. F. & Humphreys, M., 1973. Thermal comfort as part of a self-regulating system. *Building research & practice,* Volume 6, pp. 191-197.

Nicol, J. F. & Humphreys, M. A., 1972. *Thermal comfort as part of a self-regulating system*. Watford, UK, s.n.

Pagliano, L. & Zangheri, P., 2010. Comfort models and cooling of buildings in the Mediterranean zone. *Advances in Building Energy Research,* Issue 10.3763/aber.2009.0406.

Parsons, K., 2002. The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort. Volume 34, pp. 593-599.

Passiv House Institute, n.d. *Passive House Institute.* [Online] Available at: https://passivehouse.com/ [Accessed August 2020].

Peacock, A., Jenkins, D. & Kane, D., 2010. Investigating the potential of overheating in UK dwellings as a consequence of extant climate change. *Energy Policy,* Issue 10.1016/j.enpol.2010.01.021.

Prins, G., 1992. On condis and coolth. *Energy and Buildings,* Volume 18, pp. 251-258.

Rudofsky, B., 1964. *Architecture Without Architects: A Short Introduction to Non-Pedigreed Architecture.* s.l.:s.n.

Rupp, R. F., Vàsquez, N. G. & Lamberts, R., 105. A review of human thermal comfort in the built environment. *Energy and Buildings,* Volume 105, pp. 178-205.

Rybczynski, W., 1986. *Home: A Short History of an Idea.* s.l.:Penguin Books, Harmondsworth.

Satish, B., 2019. *Beyond energy- efficient built environment – examining the relationship between the users' cultural values and energy consumption.* s.l., s.n.

Segev, S., 2015. Modelling household conservation behaviour among ethnic consumers: the path from values to behaviours. *International Journal of Consumer Studies,* 39(3), pp. 193-202.

Shove, E., 2003. Converging conventions of comfort, cleanliness and convenience. *Journal of Consumer Policy,* 26(4), pp. 395-418.

Shove, E., 2005. Changing human behaviour and lifestyle: a challenge for sustainable consumption. In: I. Ropke & L. Reisch, eds. *Consumption - Perspectives from ecological economics.* s.l.:Elgar, Cheltenham, pp. 111-132.

Spurling, N. et al., n.d. *Interventions in practice: re-framing policy approaches to consumer behaviour,* s.l.: s.n.

Stephenson, J. et al., 2010. Energy cultures: A framework for understanding energy behaviours. *Energy Policy,* Volume 38, p. 6120–6129.

Taylor, N. A. S., Allsopp, N. K. & Parkes, D. G., 1995. Preferred Room Temperature of Young vs Aged Males: The Influence of Thermal Sensation, Thermal Comfort, and Affect. *The Journals of Gerontology: Series A,* Volume 50A, p. M216–M221.

Teli, D., Jentsch, M. F., James, P. A. B. & Bahaj, A. S., 2012. *Field study on thermal comfort in a UK primary school.* Windsor, UK, s.n.

Triandis, H. C., 1995. *Individualism and Collectivism.* Boulder (CO): Westview Press.

van Hoof, J. & Hensen, J., 2006. Thermal comfort and older adults. *Gerontechnology,* Volume 4, pp. 223-228.

van Hoof, J. et al., 2017. Ten questions concerning thermal comfort and ageing. *Building and Environment,* Volume 120, pp. 123-133.

Vischer, J. C., 2008. Towards a user-centred theory of the built environment. *Building Research & Information,* 36(3), pp. 231-240.

Wang, Z. et al., 2018. Individual difference in thermal comfort: A literature review. *Building and Environment,* Volume 138, pp. 181-193.

Watson, K. J., Evans, J., Karvonen, A. & Whitley, T., 2016. Re-conceiving building design quality: A review of building users in their social context. *Indoor and Built Environment,* 35(3), pp. 509-523.

Wilhite, H., 2016. Gender Implications of Energy Use and Energy Access. *Energy and Economic Growth.*

Wilhite, H. & Shove, E., 1998. *Understanding Energy Consumption: Beyond Technology and Economics.* s.l., s.n.

Wilhite, H., Shove, E. & Kempton, W., 2000. The legacy of twenty years of energy demand management. We know more about individual behavior but next to nothing about demand. In: E. S. J. a. B. D. Jochem, ed. *Society, Behaviour and Climate Change Mitigation.* London: Kluwer Academic Publishers.

Yu, J. et al., 2012. A comparison of the thermal adaptability of people accustomed to air-conditioned environments and naturally ventilated environments. *Indoor Air,* Volume 22, pp. 110-118.

Yun, H. et al., 2014. A field study of thermal comfort for kindergarten children in Korea: An assessment of existing models and preferences of children. *Building and Environment,* Volume 75, pp. 182-189.

Zhang, H. et al., 2010. Comfort, perceived air quality, and work performance in a low-power task–ambient conditioning system. *Building and Environment,* Volume 45, pp. 29-39.

Zhang, H., Arens, E. & Pasut, W., 2011. Air temperature thresholds for indoor comfort and perceived air quality. *Building Research & Information,* Volume 39, pp. 134-144.

Zhou, X. et al., 2013. Experimental study of the influence of anticipated control on human thermal sensation and thermal comfort. *Indoor Air,* Volume 24.