Comfort Models and Cooling of Buildings in the Mediterranean Zone

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[a]**INTRODUCTION**

In the last years one of the primary objectives of a building (that of offering a comfortable environment for human occupation) has been more explicitly defined and brought to the center of design, construction, operation and evaluation of buildings by a number of co-evolving elements.

These might be listed as: the wider availability of laboratory grade measurement instruments for monitoring in the field, the growing number of comfort monitoring and survey data, the continuing research efforts on the subject and the connected evolution of international standards related to comfort.

This paper deals with thermal comfort (excluding hence other aspects of comfort inside buildings) and how the evolution of knowledge in this subject can influence the design, operation and evaluation of buildings in the Mediterranean area.

We firstly review some of the developments in thermal comfort models and their incorporation into standards, inter alia in the form of comfort categories for different types of buildings. We discuss then some of the implications for the design, operation and evaluation of buildings in the Mediterranean area, obtained by the authors via dynamic simulation software complemented by pre and post processing tools prepared to ameliorate and speed the treatment of comfort data. We present an optimization methodology, some results in a choice of climates, and the current limitations and needs for improvement of the indexes defined in the standards.

Comfort models and their practical utilization are important to well-being and energy saving because they aim at defining quantitatively (based on large surveys of people) what range of conditions people will feel acceptable in buildings, and because the set of conditions has direct implications on energy consumption. At the same time "avoiding unnecessary use of energy and ... safeguarding comfortable indoor climatic conditions (thermal comfort) in relation to the outside temperature" are e.g. among the stated goals of the European 'Energy Performance of Buildings Directive' (European Union, 2002, comma 16 of the preambule).

Especially in the presence of a renewed research and application effort towards low or zero energy buildings the issues of fine-tuning comfort and fully understanding its connection with energy use are becoming increasingly relevant both for research and application, and mostly so in the Mediterranean zone. Critical analysis and results presented here have been developed partially under the IEE projects Commoncense and ThermCo.

[a]"STATIC" AND ADAPTIVE MODELS OF COMFORT : AN OVERVIEW

[b]Thermal Comfort surveys: choice of scales and acceptability criteria

The wealth of research by Bedford (Bedford 1936, 1964), Fanger (Fanger, 1970), Auliciems (Auliciems, 1969, 1983), Humphreys and Nicol (Humphreys and Nicol, 1998), DeDear and Brager (DeDear and Brager, 2007) Griffiths (Griffiths, 1990), Givoni (Givoni 1992) and others, has been partially uptaken and reorganised into international standards, where thermal comfort is defined as: “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (American Society of Heating, Refrigerating and Air-Conditioning Engineers 2004).
The occupant satisfaction is investigated via surveys of subjects both in laboratory settings and in actual buildings. (Fanger, 1970; (de Dear, Brager & Cooper 1997); (McCartney, Nicol 2002)) in order to determine the physical and context conditions in which a thermal environment can be evaluated as *acceptable* (American Society of Heating, Refrigerating and Air-Conditioning Engineers 2004) from the point of view of thermal comfort.
The standard ISO 10551-1995 *Ergonomics of the thermal environment - Assessment of the influence of the thermal environment using subjective judgement scales*, (International Standards Organization 1995) presents ways to formulate questions to subjects by presenting them scales about thermal comfort. It suggests to evaluate the *personal thermal state* via 3 scales:

- a scale of *perception* of personal thermal state, with seven (or nine) degrees and two-poles: from cold to hot via a 'central point of indifference' which 'corresponds to the absence of hot and cold'
- an *evaluative* scale with four degrees and one pole: *present affective assessment* from comfort to discomfort
- a *future thermal preference* scale with seven (or three) degrees and two-poles; from 'cooler' to 'warmer' with a 'central point of indecision' which corresponds to the 'absence of change'.

The same standard suggests then that an evaluation of the *thermal ambience* or 'thermal surroundings (local climate)' might be made via 2 additional scales (see a summary description in the Table 1).

	1	2	3	4	5
Type of judgement	**Perceptual**	**Affective evaluation**	**Thermal preference**	**Personal acceptability**	**Personal tolerance**
Subject under judgement	**Personal thermal state**			**Thermal ambience**	
Wording	"How do you feel (at this precise moment)?" 7 or 9 degrees, from very (or extremely) COLD to very (or extremely) HOT	"Do you find it.......?" 4 or 5 degrees, from COMFORTABLE to very (or extremely), UNCOMFORTABLE	"Please state how you would prefer to be now" 7 (or 3) degrees, from (much) COLDER to (much) WARMER	"How do you judge this environment (local climate) on a personal level?" 2 degrees, GENERALLY ACCEPTABLE, GENERALLY UNACCEPTABLE	"Is it .....? 5 degrees, from perfectly TOLERABLE to INTOLERABLE

Table 1: *Summary of subjective judgement scales as described in ISO 10551.*

These guidelines are reflected in the standards ANSI-ASHRAE 55, ISO 7730 and EN 15251, which additionally suggest what are the acceptability ranges. In the most recent revision of the ISO (International Standards Organization 1995) and EN standards (Comité Européen de Normalisation 2007) those ranges have been defined in differentiated ways giving rise to “categories” or “classes” of comfort.

A large part of the thermal comfort surveys in laboratory and in the field have been using the seven degrees scale, (*perceptual* scale in ISO 10551, often called *thermal sensation* scale or also *ASHRAE scale* since it is the one scale present in the survey suggested in the informative annex to ASHRAE 55), which offers a set of standard answers to the question: ‘how do you feel at this time?’ and a numerical scale to accompany each grade.

+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

Often this is accompanied by a second question formulated using the three point McIntyre scale of *thermal preference* (for a warmer or cooler environment or no change), or a similar five point scale as used e.g. in the SCAT study (McCartney, Nicol 2002) corresponding to the spirit of the *thermal preference* scale in ISO 10551. This second survey step seeks responses to the question: ‘how would do you prefer to be now?’ allowing a choice among:

much cooler
a bit cooler
no change
a bit warmer
much warmer

Until recently, few laboratory or field studies included the direct question about whether an environment was acceptable or not (column 4 of Table 1). Dissatisfaction and acceptability have generally been evaluated indirectly from whole-body thermal sensation votes. As for the terminology, we will follow here (Arens et al, 2009), who state: “we equate the terms ‘accept’ and ‘acceptable’ with ‘being satisfied with’ and ‘satisfactory’ … The term ‘satisfied’ is rarely used in questionnaires, even though ‘predicted percent dissatisfied’ (PPD) is a commonly invoked metric.” This seems coherent with the interpretation of Fanger: “The PMV… prescribes a certain range around neutral temperature as *acceptable*, depending on the permitted percent dissatisfied” (Fanger and Toftum, 2002).

One traditional method of indirect evaluation of acceptability is based on ISO 7730 and equates voting within the central three degrees of the ASHRAE thermal sensation scale (-1: slightly cool, 0: neutral, +1: slightly warm) with “satisfaction”. This is implicit in the definition of ISO 7730: “*thermally dissatisfied* people are those who will vote hot, warm, cool or cold on the 7-point thermal sensation scale”.

A second way of defining acceptability is to assume that only the subjects who want ‘no change’ on the ‘thermal preference’ scale are satisfied with the thermal environment.

A third way is based on the comfort scale “affective evaluation” (row 2 of Table 1). ISO 10551 suggests to assume as satisfied the subjects who vote ‘comfortable’. It has been proposed (Brager et al. 1993) to extend the acceptability to ‘slightly uncomfortable’.

Among the studies well documented which did ask directly the ‘acceptability’ question (row 4 in Table 1) in parallel to the questions related to the other scales and to accurate measurements of physical parameter in proximity of the interviewed people are e.g. the ASHRAE RP-702 projects in Townsville, Australia, ASHRAE RP-921 in Kalgoorlie–Boulder, Australia, and ASHRAE RP-821 in Montreal, Canada. All 45 buildings in these three field surveys were centrally air-conditioned office buildings.

As for the Mediterranean condition one study (Fato et Al, 2004) collected responses by subjects in real buildings both air conditioned and naturally ventilated in southern Italy (5 buildings, 1840 valid questionnaires) at the same time on 4 scales (thermal sensation, thermal preference, affective evaluation and personal acceptability). Fato reports : “Thermal acceptability was investigated by means of all four scales, showing that the indirect estimation of acceptability (based on the three central categories of the ASHRAE scale) only provided partial information about occupants’ conditions”.

ASHRAE RP-884 states for example: "With various aspects of perceived indoor climates being assessed with different questionnaire items, there is a possibility that the indoor temperatures defined as optimal for a particular building and climatic context may in fact vary, depending on whether one is talking in terms of thermal sensation (neutrality), thermal acceptability (satisfaction) or thermal preference (preferred temperatures). …The RP-884 database contains 55 buildings in which both thermal sensations (ASH) and thermal preferences were registered, and so each of these buildings had both a neutrality and a preferred temperature available in the meta-analysis. A new variable called "semantic discrepancy" (discrep) was calculated as neutrality minus preferred temperature and expressed in degrees (°C)."

It is then of importance for research and application that the scales adopted and the criteria of acceptability are very explicitly stated in each survey, analysis and design guidelines.

[b]**Comfort models and their areas of application**

The data taken in laboratory and in the field have then been interpreted and meaningful correlations between variables have been searched for, giving rise to what are generally called "comfort models" eg the Fanger whole body steady state heat balance model (Fanger, 1967, 1970), the Pierce Two-Node Model (Gagge et.al. 1970), the Kansas State University Two-Node Model, Wissler model which divides the body into hundreds of segments and includes complex regulatory algorithms etc (Byron 2002) and their suitability to interpret the data derived from laboratory and field studies and to predict thermal comfort sensations and preferences by occupants of buildings in everyday conditions have been subject of research and debate. For research and application in moderate environments such as in buildings two models have been prevailing: Fanger model also called PMV model and "static" model (Fanger, 1967, 1970) and the "adaptive" model (Auliciems….) ((Nicol, Humphreys 1973))
See e.g. *Energy and buildings special issue on thermal comfort standards* where researchers compared their findings and interpretations and tried to develop explanations of the discrepancies observed (e.g. Fanger, 2002; (de Dear, Brager 2002); (Byron 2002, Olesen, Parsons 2002))

ASHRAE RP-884 project ((de Dear, Brager & Cooper 1997, de Dear, Brager 2002)) has reviewed a large amount of field surveys around the world, selecting the ones with highly reliable data documentation and based on their analysis has proposed the inclusion of an adaptive comfort model in the revision of ASHRAE 55, with average monthly outdoor temperature as the independent variable. On the basis of responses to a questionnaire, raw field data were acquired from researchers whose:

- measurement techniques, both physical and subjective, approximated " laboratory-grade,"
- data structures allowed each set of questionnaire responses to be linked to a concurrent set of indoor and outdoor climate observations, and
- indoor climatic observations were comprehensive enough to enable heat-balance indices such as PMV and ET* (the "static model") to be calculated for each questionnaire respondent.

After each raw field data file was quality controlled and standardised within a set of carefully defined variables, the database was broken down according to season (summer/winter) and building type (centrally-controlled buildings - HVAC), naturally ventilated buildings (NV), and mixed-mode buildings.
The classification of buildings largely depended on the judgment of the original researchers supplying raw data, but the main distinction between centrally-controlled HVAC and naturally ventilated buildings was that individual occupants in the former had little or no control over their immediate thermal environment, while occupants in naturally ventilated buildings at least had access to operable windows. It should be pointed out that most of the naturally ventilated buildings were only studied in the summer, and so the type of heating system was irrelevant. The few that were studied in winter may still have had a heating system in operation, but it was of the type that permitted occupant control. The sample included too few mixed-mode buildings to permit meaningful analysis, so ASHRAE RP-884 develops the analysis using the two categories of NV and HVAC buildings (having inserted the hybrid within the HVAC ensemble).

Similarly the SCAT database (Nicol, 2001) contains data about measurements and surveys in 26 buildings (located in France, Greece, Portugal and UK) that have been classified as NV naturally ventilated (heating in winter, free running (no cooling or mechanical ventilation) in summer, AC centrally air conditioned (heating and cooling), MV mechanically ventilated (no cooling in summer), MM mixed mode (heating in winter, cooling when needed in summer), PP a mixture of AC and NV in the same building. In some of the analysis they are aggregated in modes: heated or cooled mode, free running mode and mixed. The analysis brought to an improved evaluation of parameters in the adaptive model based fitted to EU data (McCartney, Nicol 2002) and using a running mean of outdoor temperatures as independent variable. The results of the study and some further analysis were fed into the revision process leading to EN15251-2007 (Nicol, Pagliano 2007).

ASHRAE 55-2004 and EN 15251-2007 both propose that acceptable temperature ranges actually depend on the type of system used to provide summer comfort.
EN 15251 distinguish buildings into two types, those with mechanical cooling and those without, and for the analysis of the latter in summer both Fanger and adaptive models are allowed. In the definition section, 'buildings without mechanical cooling' are defined in the standard as 'buildings that do not have any mechanical cooling and rely on other techniques to reduce high indoor temperature during the warm season like moderately-sized windows, adequate sun shielding, use of building mass, natural ventilation, night time ventilation etc. for preventing overheating'. Mechanical cooling is in turn defined as 'cooling of the indoor environment by mechanical means used to provide cooling of supply air, fan coil units, cooled surfaces, etc. The description of situations where to use Adaptive is further detailed in the section A.2 'In order for this optional method to apply, the spaces in question shall be equipped with operable windows which open to the outdoors and which can be readily opened and adjusted by the occupants of the spaces. There shall be no mechanical cooling in operation in the space. Mechanical ventilation with unconditioned air (in summer) may be utilized, but opening and closing of windows shall be of primary importance as a means of regulating thermal conditions in the space. There may in addition be other low-energy methods of personally controlling the indoor environment such as fans, shutters, night ventilation etc.'

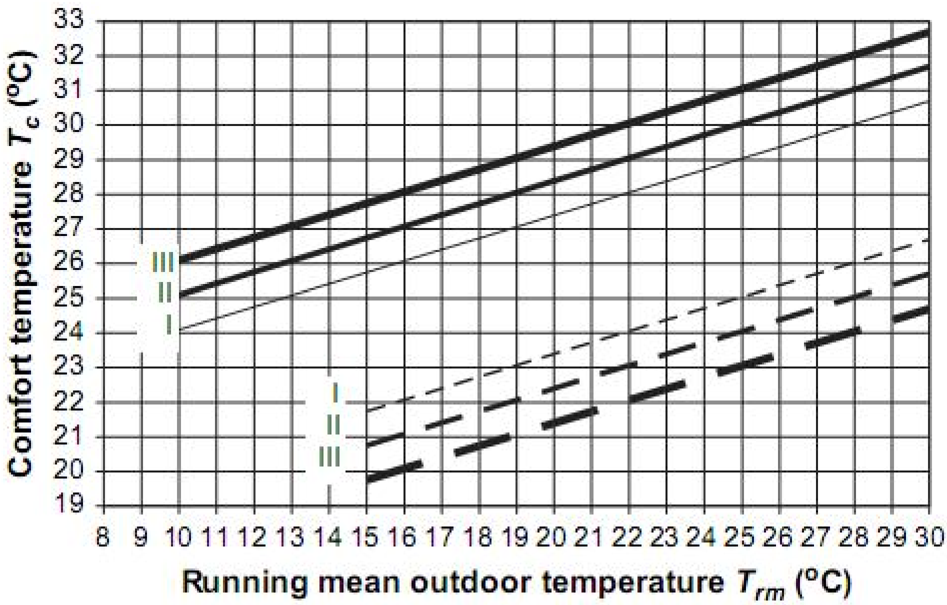


Figure 1 *Acceptable indoor operative temperature ranges (cooling season) for buildings without mechanical cooling systems as a function of outdoor air daily running mean temperature (from EN 15251)*

ASHRAE 55-2004 makes a similar distinction but not exactly with the same wording, allowing the application of an adaptive model (based on outdoor monthly average temperatures), in 'occupant-controlled naturally conditioned spaces' defined as 'those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of windows'.

A number of researchers have observed that some buildings will not fall exactly into the two ensembles and some of the interesting technologies for low energy and passive cooling are among those of uncertain classification both on the ground of the available data in the databases and of the wording of the standards (see e.g. (Pfafferott et al. 2007)). A clarification of the terminology and further exploration in the field about the sensations and preferences of occupants in the overlapping area are subjects requiring additional research.

Generally the application of the adaptive model(s) indicates that indoor thermal comfort is achieved with a wider range of temperatures than does the implementation of the Fanger model. In consequence in some situations it proves possible to maintain a building's interior conditions within the adaptive comfort limits entirely by natural means. In these cases there is no energy use associated with achieving indoor summer comfort.
The implications are described in (de Dear, Brager 2002): "If a building's interior conditions were able to be maintained within the Adaptive Comfort limits entirely by natural means, then one could potentially save 100% of the cooling energy that would otherwise be used by an airconditioner to maintain conditions within the more narrow ASHRAE Standard 55 (based on Fanger model) comfort zone. If one were to apply the Adaptive Comfort to a mixed-mode building, however, the airconditioner might be used in a limited way to keep the more extreme temperatures from rising past the acceptability limits of the Adaptive Comfort Standard. In this case, the energy savings would be proportional to the difference between
set-points defined by the upper limit of the Adaptive Comfort Standard, compared to typical setpoints used in an air-conditioned building. (…) Savings are likely to be much higher than indicated [note: in the article] since it is more common to find buildings operating at the center of the ASRHAE Standard 55 comfort zone (approximately 23° C) than at the upper end of 26° C."

From ASHRAE RP-884 report:
' We believe that the split between "adaptive" and "static" heat balance models, or schools of thought, is not as irreconcilable as the protagonists have suggested. As mentioned previously, the terms "static" and "constancy" have given rise to a mistaken idea that models such as PMV and 2-node, plus the thermal comfort standards based on them, prescribe a single, constant temperature for thermal comfort the world over. But the PMV and 2-node models do, in fact, predict comfort temperatures moving in the direction of prevailing outdoor climate (…) . So the static model of comfort is in reality an "adaptive" model in its own right -- the fundamental distinction between the static and adaptive models is their underlying basis or postulated cause for the shift in comfort temperatures. The former permits only behavioral adjustments (personal/technological) to heat balance variables such as clothing or air velocity, whereas the original adaptive models were premised on changing physiological (i.e. acclimatization) and psychological (i.e. expectations/habituation) setpoints. While this may seem to be a fine distinction, failure to appreciate it has, in the opinion of the authors, been responsible for unnecessary controversy between the two sides of this debate. '
One of the aims of this paper is to show some of the ways in which the two models may be used in synergy for helping the design of low energy comfortable buildings.

[a]COMFORT CATEGORIES IN RELATIONSHIP TO COMFORT MODELS IN RECENT STANDARDS (ASHRAE 55-2004, ISO7730-2005 ; EN15251-2007)

ISO7730-2005 proposes three categories of comfort (A, B, C), only for the Fanger model, defined by the ranges of PMV: ±0,2, ±0,5, ±0,7 and leaves open choice about to which buildings apply a certain category.
EN15251-2007 proposes three categories of comfort (called I, II, III) for the Fanger model defined by the same ranges of PMV ±0,2, ±0,5, ±0,7 ; it also defines categories of comfort I, II, III for the Adaptive model.
ASHRAE 55 in the revision of 2004 maintains the previous definition of acceptable range defined by means of PMV ±0,5, without introducing categories.

In EN15251-2007 categories are meant to apply to different types of buildings. Category I is suggested to be applied to buildings occupied by very sensitive and fragile persons, category II for new buildings, category III for existing buildings. Category IV is for buildings which fail to meet category III specifications.

Category	PMV	PPD %
A (I)	-0,2 < PMV < +0,2	< 6
B (II)	-0,5 < PMV < +0,5	< 10
C (III)	-0,7 < PMV < +0,7	< 15

Table 2: *Categories of comfort based on Fanger approach and hence defined in terms of PMV and PPD values*

Analysis are ongoing to ascertain whether people can actually distinguish among the proposed categories. A recent analysis (Arens et al., 2009) of data from the ASHRAE, SCAT and Berkely databases of field surveys concludes that category A (and possibly B) is too narrow to be discriminated by occupants of buildings.
On the side of possible discrimination via measurement of physical parameters and the calculation of PMV (Alfano et al. 2006) note that: “the PMV range required by A-category can be practically equal to the error due to the measurements accuracy and/or the estimation of parameters affecting the index itself (Alfano et al. 2001) ; as a matter of fact, the errors accepted by EN ISO 7726 in terms of required accuracy give large errors in the PMV value, as in Figure 2”

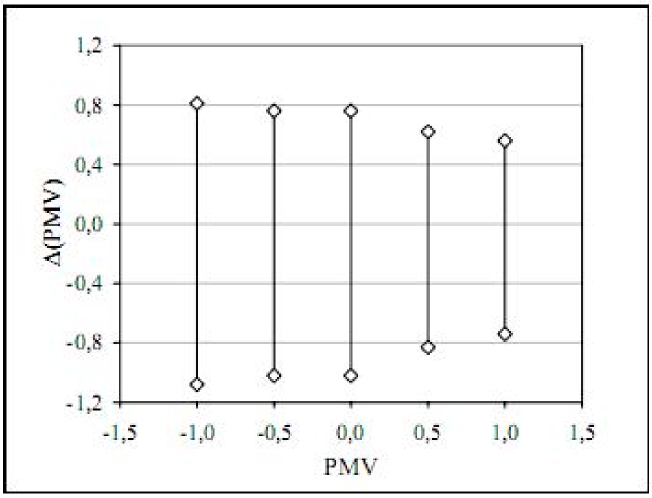


Figure 2: *sensibility of PMV to all the six variables, evaluated according to EN ISO 7726 with the required accuracies for the physical parameters (Alfano et al. 2006).*

In fact ISO 7730-2005 acknowledges that “Owing to the accuracy of instrumentation for measuring the input parameters, it can be difficult to verify that the PMV conforms to the Class A category (−0,2 < PMV < +0,2). Instead, the verification may be based on the equivalent operative temperature range, as specified in A.2 and in Table A.5.” This is probably equivalent to setting to zero the uncertainties on all the other variables besides temperatures.
More fundamentally the question might be posed whether it is possible to discriminate a range of 0,2 x 2 = 0,4 points on the thermal sensation scale when the surveys and the judgments of people go in steps of 1,0 point on that scale. McIntyre (McIntyre 1980) suggests that a seven-point (versus three- or twentyfive-point) scale is appropriate for psychological measurement. He observes that when people are presented with a set of stimuli that vary in one dimension only, the number of stimuli that can be unambiguously identified is relatively small. Subjects can identify about six different tones and five degrees of loudness without error. For several different types of stimuli, Miller (Miller, 1956) found that people cannot generally deal with more than about seven levels of sensation without confusion.

The Adaptive approach being described by the only physical variable operative temperature, the categories are defined as ranges of operative temperature. Analytically these ranges are described by means of linear equations with the outdoor running mean temperature as independent variable (Nicol, Pagliano 2007), (Comité Européen de Normalisation 2007).

Comfort ranges are one of the basis inputs for design and assessment of comfort and energy performance of buildings. E.g. in EN15251 they are part of how design criteria are proposed for dimensioning of building envelope and systems and of the definition of inputs for building energy calculation and long term evaluation of the indoor environment. The standard also identifies parameters to be used for monitoring and displaying of the indoor environment as recommended in the Energy Performance of Buildings Directive according to comfort range assigned to the categories.

EN15251 proposes also that the different parameters for the indoor environment of the building meet the criteria of a specified comfort category when the parameter in the rooms representing 95 % of the occupied space is for e.g 97% (or 95%) of occupied hours a day, a week, a month and a year inside the limits of the specified category. This has some relevant implications for simulations (for design or evaluation purposes) and for metering-surveys for the evaluation of the category in which a building can be classified. We will discuss some implications on simulations in the next paragraph; we are analysing some of the implications for metering-survey within the IEE project Commoncense.

[a]**LONG TERM COMFORT INDEXES (EN15251) AS DESIGN OPTIMIZATION FUNCTIONS. ABOUT THEIR USE AND LIMITATIONS IN MEDITERRANEAN CLIMATES**

The authors have developed, partially under the IEE project ThermCo, (Thermco 2009) a methodology for the application of the long term discomfort indexes suggested by EN15251 to the design of buildings for comfort and low energy, in particular in the Mediterranean climates. In this section we describe the methodology, some results in a choice of climates, and the current limitations and needs for improvement of the indexes defined in the standards.

EN 15251 states that: "The temperature limits presented in A.2 [author note: adaptive comfort range] should be used for the *dimensioning of passive means* to prevent overheating in summer conditions. Dimensioning and orientation of *windows*, dimensioning of *solar shading* and the *thermal capacity* of the building's construction. Where the adaptive temperature limits presented in A.2 (upper limits) cannot be guaranteed by passive means mechanical cooling is unavoidable. In such cases the design criteria for buildings WITH mechanical cooling should be used." [italics emphasis by the author]

So one could devise a procedure where building envelope parameters are varied in order to minimise an "adaptive discomfort index " and in case the adaptive temperature limits cannot be guaranteed, turn to minimise a "Fanger discomfort index", choosing these indexes among the ones proposed in EN 15251 Annex F (informative) *Long term evaluation of the general thermal comfort conditions.* Reducing the discomfort indexes by choice of passive means implies also a reduction of the energy need for heating and or cooling of the building and hence of its energy consumption when active means are applied to further reduce the discomfort (if still needed).

As for the list of physical parameters to be modified in order to optimise the thermal comfort behaviour of the building, we chose to follow an approach similar to the one adopted by Switzerland Society of Engineers and Architects (SIA) and to adapt it to the Mediterranean climates.

Thermo-physical requirements to minimize the cooling consumption of a building are listed in the SIA standards, developed in the course of the '90s by the Switzerland Society of Engineers and Architects (SIA) and revised in 2007 (Société suisse des ingénieurs et des architectes, 2007). According to this approach, the building or the part of building at issue must fulfil the criteria shown in Table 3 as a prerequisite for approval of installation of an air conditioning system.

Table 3: *Requirements of SIA 382/1:2007.*

Parameter		Limit Requirement	Target Requirement
Thermal Transmittance	external walls	≤ 0,3 W/m^{2}K	≤ 0,2 W/m^{2}K
	Roof	≤ 0,3 W/m^{2}K	≤ 0,2 W/m^{2}K
	windows	≤ 1,7 W/m^{2}K	≤ 1,2 W/m^{2}K
Air infiltrations		≤ 0,5 m^3/h/m^2	
Specific Storage Mass		≥ 30 Wh/m^2/K	
Solar factor	N	≤ MIN(0,20/f_g; 1,00)	
	NE, NO	≤ MIN(0,13/f_g; 0,28)	
	E, SE, S, SO, O	≤ MIN(0,07/f_g; 0,15)	

Where:

- The thermal protection of the building envelope is described by the thermal transmittance (U-value in W/m^{2}K) of external walls, roof and windows, proposed by SIA 380/1 ((Société suisse des ingénieurs et des architectes 2009).
- Its level of air permeability by the hourly volume of infiltration for the total (opaque and transparent) vertical surface (in m^3/h/m^2).
- The capacity to accumulate internal energy is described by the specific storage mass in Wh/K for m^2 of floor area (calculated for a typical room, starting from the method described in ISO 13786:2007).
- Heat gains through transparent surfaces (or transparent surfaces equipped with solar protections) are represented by the solar factor coefficient. The SIA approach proposes to minimize the solar factor by setting targets as a function of the orientation and the ratio of window area to opaque area (identified by f_g in Table 3).

The goal becomes then:

- to use the EN 15251 suggestions to build an explicit optimisation method and check its consistency and applicability
- to analyse how the optimal values of the physical parameters (thermal mass, air permeability, thermal transmittance, solar factor) for each considered climate, can improve comfort as summarised via the metrics of the long term indexes, when coupled to a passive cooling strategy as natural night ventilation.

In order to test the methodology three Italian climates have been chosen in order to roughly represent the variety of Mediterranean climates. Two of them are south, warm locations, one with relatively small day-night temperature variations (Palermo), the other with more ample temperature swings (Foggia), in order to take into account different potentialities of night ventilation strategies.

The optimization has been performed by means of a dynamic simulation software able to simulate both energy and air flows through the building (EnergyPlus, version 2.2.0) and to calculate in each thermal zone air temperatures (possibly also at various heights), surface temperatures and view factors from the center of the zone or from a specified point to the various surfaces.

EN 15251 requires that 95 % of the occupied space is for e.g 97% (or 95%) of occupied hours inside a certain comfort range in order to assign a building to the corresponding comfort category. Hence implicitly requires that simulations be carried on with sufficient detail (e.g. sufficient number of thermal zones) to evaluate local room parameters rather than building averages and to be able to detect disuniformities; in this it is more demanding than simulations oriented only to estimate yearly energy consumption where sometimes less detail may be considered sufficient (or apparently sufficient, since comfort conditions are less explicitly defined). Due to this we chose as a reference building a large office building with 5 floors and we modelled it with a certain detail as for the description of internal thermal zones. The standard floor has been divided in five main thermal zones: south-east zone (20 office rooms, 710 m^2); north-west zone (21 office rooms, 514 m^2); north-east zone (3 office rooms, 66 m^2); south-west zone (3 office rooms, 33 m^2); internal zone (corridors, WC zones and stair-lift zones, 935 m^2).

The baseline building has solar factor equal to 0,7 (double glass without solar shading), specific storage mass of 50 Wh/m^2K (referred to unit *floor* area) and U-values of building components that are different in different climate zones (described by their heating Degree Days), in compliance with the Italian DLgs 311:2006, valid for new buildings built from 2010 onward (Table 4). The S/V ratio of the building is 0,26 m^{-1} (external surface of 8 501 m^2 and occupied volume of 32 706 m^3) and the value of the ratio between window area and total façade area is 40%.

The two wider office zones (south-east and north-west) are organised in small and medium size office rooms, and we focus on two types of office rooms: "Office A" has 3 occupants and is exposed south-east, while "Office B" has 1 occupant, and is exposed north-west. We have analysed the thermal behaviour of the 2 typical office rooms A and B when located in 3 floors (ground floor, 2nd floor and 4th floor), for a total of 6 office rooms. In figure 3 the geometry of the standard floor is shown; table 3 describes the characteristics of two standard office rooms.

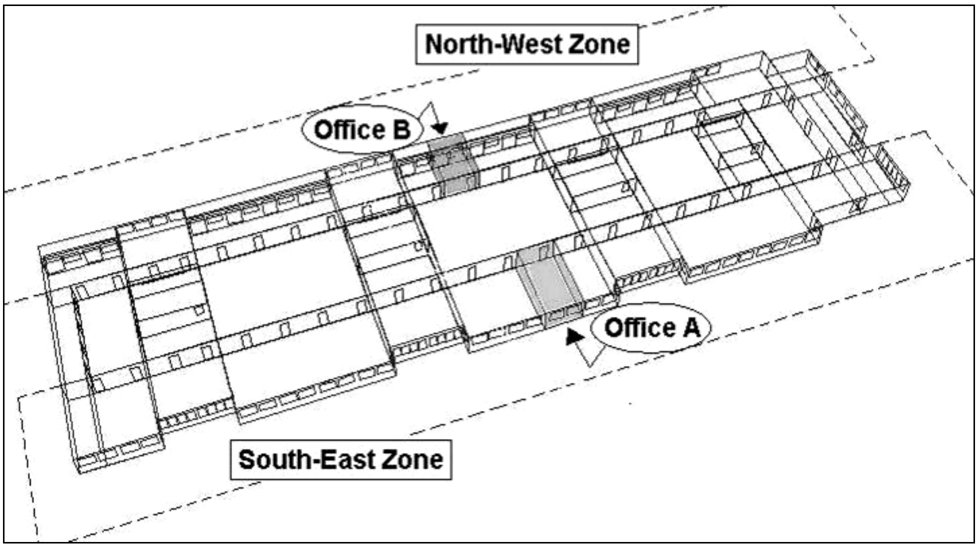


Figure 3: *Standard floor model.*

Table 3: *Standard offices characteristics.*

	Orientation	Floor Area	Windows area	Number of Occupants	Installed Electric Power (lighting and equipment)
Office A	South-East	39,6 m^2	5,26 m^2	3	23 W/m^2 (909 W)
Office B	North-West	20,9 m^2	7,14 m^2	1	23 W/m^2 (486 W)

Table 4: *U-values [W/m^2K] limits according to Italian DLgs 311 for buildings built from 2010 onward*

City	Winter Climatic Zone	External Wall	Roof	Basement	Window
	A	0,62	0,38	0,65	4,60
Palermo	B	0,48	0,38	0,49	3,00
	C	0,40	0,38	0,42	2,60
Foggia	D	0,36	0,32	0,36	2,40
Milan	E	0,34	0,30	0,33	2,20
	F	0,33	0,29	0,32	2,00

As for internal gain, the building has been characterized with schedules typical of office buildings and daylight availability coherent with geographical position.

Italian climate is classified by Law 10/91 in winter climate zones based on heating degree days from the warmest Zone A (< 600 heating Degree Days) to the coldest Zone F (> 3000 heating Degree Days).
Even though the climate variety is quite ample also during the summer period, the Italian legislation does not offer a division per summer climate zones. To fill the gap we make use here of the classification proposed by Consiglio Nazionale delle Ricerche (CNR) which identifies seven summer climate zones (from the coldest one, n. 7, to the hottest, n. 1) based on the main climate local parameters (relative humidity, wind speed, air temperature and solar irradiation).
We have performed the analysis for the climate conditions of Milan, Palermo and Foggia. Table 5 shows the main characteristics of these climates. The simulations have been performed using EnergyPlus Weather File (EPW) produced by IWEC (International Weather for Energy Calculations format from ASHRAE).

Table 5: *Main characteristics of the considered climates, for the period from 1/June to the 31/August, extracted from the EPW files of IWEC.*

City	Summer Climatic Zone (CNR)	Mean Hourly Air Temp	Max Hourly Air Temp	Mean Day-Night Temp Difference	Mean Wind Speed	Mean Relative Humidity	Mean Solar Irradiation
		[°C]	[°C]	[°C]	[m/s]		[Wh/m^2]
Milan	7	21,7	32,6	8,9	1,0	71%	4855
Palermo	1	25,1	34,0	4,0	3,3	74%	6471
Foggia	3	23,9	38,0	11,7	3,3	58%	4427

The objective functions to be minimised by the building in free floating mode (without the use of mechanical cooling) have been constructed in such a way to measure the cumulative seasonal departure from comfort ranges defined on the base of both the Fanger model and the Adaptive model in standard EN 15251, since the standard leaves a choice between the two models for non mechanically cooled buildings (see its section 6.2.2). We have hence considered all the long term evaluation indexes proposed by the Annex F of the standard:

- the percentage of hours outside the comfort range (method A, in the two variants Fanger and Adaptive)
- the Degree Hours criteria (method B, in the two variants Fanger and Adaptive)
- the PPD weighted criteria (method C, applicable only by using the Fanger model)

where the methods B and C weight each hourly time step with its 'distance' from the boundaries of comfort ranges. In particular:

Method A: percentage outside the range, requires to calculate the number or % of hours of occupation when the PMV or the operative temperature is outside a specified range (e.g one of the ranges corresponding to category I, II or III for the Fanger or Adaptive approach).

According to *Method B: degree hours criteria,* the time during which the actual operative temperature exceeds the specified range during the occupied hours is weighted by a factor $wf = \left|\Theta_o - \Theta_{o,\,limit}\right|$, which is the module of the difference between actual (calculated) operative temperature Θ_o at a certain hour and respectively the lower or upper limit $\Theta_{o,\,limit}$ of the comfort range specified (note that this implies that if the range is specified in terms of PMV it has to be translated to operative temperature by making assumptions on clo, met, air velocity, humidity).
For a characteristic period during a year, the product of the weighting factor and time is summed. EN15251 specifies that in the warm period the summation is extended only to the hours when $\Theta_o > \Theta_{o,limit,upper}$. Similarly for the cold period the summation is extended only to the hours when $\Theta_o < \Theta_{o,limit,upper}$.

According to *Method C: PPD weighted criteria*, the time during which the actual (calculated) PMV exceeds the comfort boundaries is weighted by a factor wf, which is set to zero for $PMV_{limit,lower} < PMV < PMV_{limit,upper}$ where PMV_{limit} are the limits of the specified comfort range, and is calculated as $wf = \frac{PPD_{actualPMV}}{PPD_{PMV\,\lim it}}$ when PMV is outside the specified range. The product of the weigthing factor and the time is summed for a warm period only on the upper side: $\sum wf \cdot$ time for PMV > $PMV_{limit,upper}$, and for a cold period only on the lower side: $\sum wf \cdot$ time for PMV < $PMV_{limit,lower}$.

For our purposes (optimization of the parameters during the design of a new building) we are guided by EN15251 to choose comfort category II ('normal level of expectation and should be used for new buildings and renovations') and its upper and lower limits as described in the standard. It is important to note here that, while the definition of method A (percentage outside the range) considers both upper and lower comfort limits, in methods B and C, in warm periods, only the upper side is considered.
Indexes generally used in practice for design optimization in the past have been e.g the number of hours above a certain temperature level but they were generally not weighted for distance from comfort conditions and the comfort conditions themselves were not explicitly defined in relationship with the comfort models.

In our analysis the summations have been done:

- from 15 May to 15 September;
- during working hours (7:00 to 21:00 during workdays and 7:00 to 14:00 during Saturdays);
- excluding Sundays and public holidays and the period 5 to 24 August which are assumed as days where there is no occupancy.

With EnergyPlus we calculated the mean hourly values of air temperature, mean radiant temperature, air velocity and relative humidity, for each typical office.

We have developed some pre-processing and post-processing tools to achieve calculations not yet or not fully included in energy-plus. The tools allow to calculate PMV using the algorithm of ISO 7730, having as input the hourly values of air temperature, mean radiant temperature, air velocity and relative humidity and appropriate values of clothing resistance (clo) and metabolic rate (met), with the possibility to change the last two parameters during the season, based eg on external climate conditions. The same tool allows also to take into account the air velocity correction as described in ASHRAE 55-2004. As for Adaptive comfort, the same tool build the hourly comfort temperature profile for each climate, that is a series of hourly values of internal comfort operative temperatures calculated through the correlation with external running mean temperature defined in EN15251 for the adaptive comfort model and feeds it into energyplus as a movig setpoint.

Starting from the values proposed by SIA 382/1:2007 (and adding hypothesis for night ventilation where this standard does not make prescriptions), each of the parameters specific storage mass, solar factor of transparent surfaces, hourly air changes for night ventilation has been varied on a scale of 3 values. Thermal transmittance and air tightness have been varied on 2 values. In total we have analysed 54 combinations for each climate, summarised in table 6. Keeping all the other variables unchanged with respect to the original building we calculated the influence of each of the above parameters on the thermal comfort of rooms as described by our discomfort indexes.

The variation of the ventilation rates via night cross-ventilation has been obtained by modifying the fraction of external windows and internal doors which is left open at night (table 6), that is we set the amount of windows and doors opening and calculate ventilation rates due to wind pressure and temperature distributions, via the AirFlowNetwork model included in EnergyPlus. If used, the night ventilation starts at 20:00, stops at 7:00 and works only if the outside (air) temperature is lower than the indoor (air) temperature, with a difference in temperature of no more than 10°C. As for the model to determine air speed at the specific location, starting form the data of the meteorological station, generally located outside the city, we used the standard model embedded in EnergyPlus, and chose parameters which might correspond to a suburban area (terrain number 2, or 5).

Table 6: *Summary of variations on main parameter.*

Key variable		Values and their justification			
U-value (Uv) and Air Permeability (AP)	**o**	Italian New (DGls 311) (it depends on location and S/V)	Roof	0.36	W/m^{2}K
			Wall	0.32	W/m^{2}K
			Basement	0.36	W/m^{2}K
			Window	2.4	W/m^{2}K
			Air Permeab	5	m^3/h/m^2
	+	SIA Refurbishment: target values	Roof	0.2	W/m^{2}K
			Wall	0.2	W/m^{2}K
			Basement	0.2	W/m^{2}K
			Window	1.2	W/m^{2}K
			Air Permeab	0.5	m^3/h/m^2
Solar Factor (SF)	**-**	Existing typical	Façade N	-	-
			Façade NE-NO	0.7	-
			Façade E-SE-S-SO-O	0.7	-
	o	Medium	Façade N	-	-
			Façade NE-NO	0.4	-
			Façade E-SE-S-SO-O	0.4	-
	+	SIA Refurbishment	Façade N	-	-
			Façade NE-NO	0.27	-
			Façade E-SE-S-SO-O	0.15	-
Thermal Mass (TM)	**-**	Low Internal Thermal Mass	External Wall	4.0	Wh/m^{2}K
			Ceiling	11.0	Wh/m^{2}K
			Floor	4.1	Wh/m^{2}K
			Internal Wall	2.3	Wh/m^{2}K
			TOTAL	20	Wh/m^{2}K
	o	Medium Internal Thermal Mass	External Wall	15.4	Wh/m^{2}K
			Ceiling	18.6	Wh/m^{2}K
			Floor	12.7	Wh/m^{2}K
			Internal Wall	8.9	Wh/m^{2}K
			TOTAL	50	Wh/m^{2}K
	+	High Internal Thermal Mass	External Wall	15.4	Wh/m^{2}K
			Ceiling	22.1	Wh/m^{2}K
			Floor	22.4	Wh/m^{2}K
			Internal Wall	18.8	Wh/m^{2}K
			TOTAL	80	Wh/m^{2}K
Natural Ventilation (NV)	**-**	No ventilation	% openings / window area	0%	-
	o	Medium ventilation	% openings / window area	25%	-
	+	Large ventilation	% openings / window area	50%	-

Some of the main results are presented in the following pages. For the considered locations, we show all the results in terms of comfort conditions, using several long term discomfort indexes referred to category II (to be used for new buildings according to EN15251):

- PPD weighted criteria (method C),
- Adaptive degree hours criteria (method B),
- percentage of hours outside the Fanger comfort range for II category (method A, Fanger),
- percentage of hours outside the Adaptive comfort range for II category (method A, Adaptive).

Also the Fanger degree hours index has been calculated, but it is not shown because it produces a ranking of models very similar to the one obtained by means of the PPD weighted index.
Based on the results of the dynamic simulation (air and radiant temperature in the zone, air velocity, humidity) and on assumptions on clothing and metabolism, we calculate PMV via our post processing tool.

This allows more flexibility than possible strictly within EnergyPlus using its built in PMV calculator. With our post processing based on the results of a certain simulation run, clo, met and air velocity can be rapidly changed in order to ascertain their influence). In the results presented below, taking into account that we are focusing on an office in Italy, where dress codes are often in force explicitly or implicitly, we have assumed an activity of 1,2 met (sedentary), and a value of clothing plus chair insulation of 1,0 (a relaxation of clo to 0,7 is presented later on). The variable clothing plus chair insulation is the variable used in the database ASHRAE RP-884, where a regression curve shows average values of this variable ranging roughly from 1,25 to 0,65 as a function of mean outdoor effective temperature (see figure 4, from (de Dear, Brager & Cooper 1997)). A value of 0,15 clo is assumed in the database for average office chairs, based on measurements and analysis by (Schiller, 1990; McCullogh and Olesen, 1994 and others). For discussion and reference see the last section of this paper.

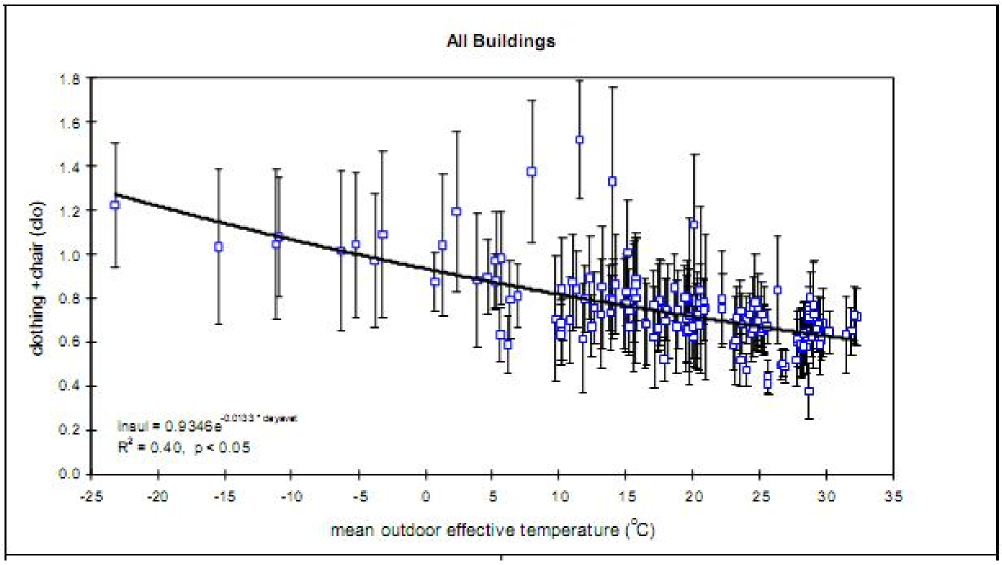


Figure 4: *Mean values of total insulation (clothing and chair) as a function of mean outdoor effective temperature in ASHRA-RP884 database.*

Each building model is described with the combination of variables and the symbolic code that is shown in table 6. The results are ordered by decreasing PPD weighted index (method C), for each climate location in figures 5, 6, 7.

For each building model, 6 office rooms were considered, in order to check the fulfilment of EN15251 request about 95% of space for the assessment of categories. In the following graphs one can read, for each configuration, the average value over the six office rooms of the discomfort index, together with the lowest and the highest values. The results are ordered by decreasing PPD weighted index (method C), for each climate location. In the best models the difference in comfort performances among the offices is largely reduced.

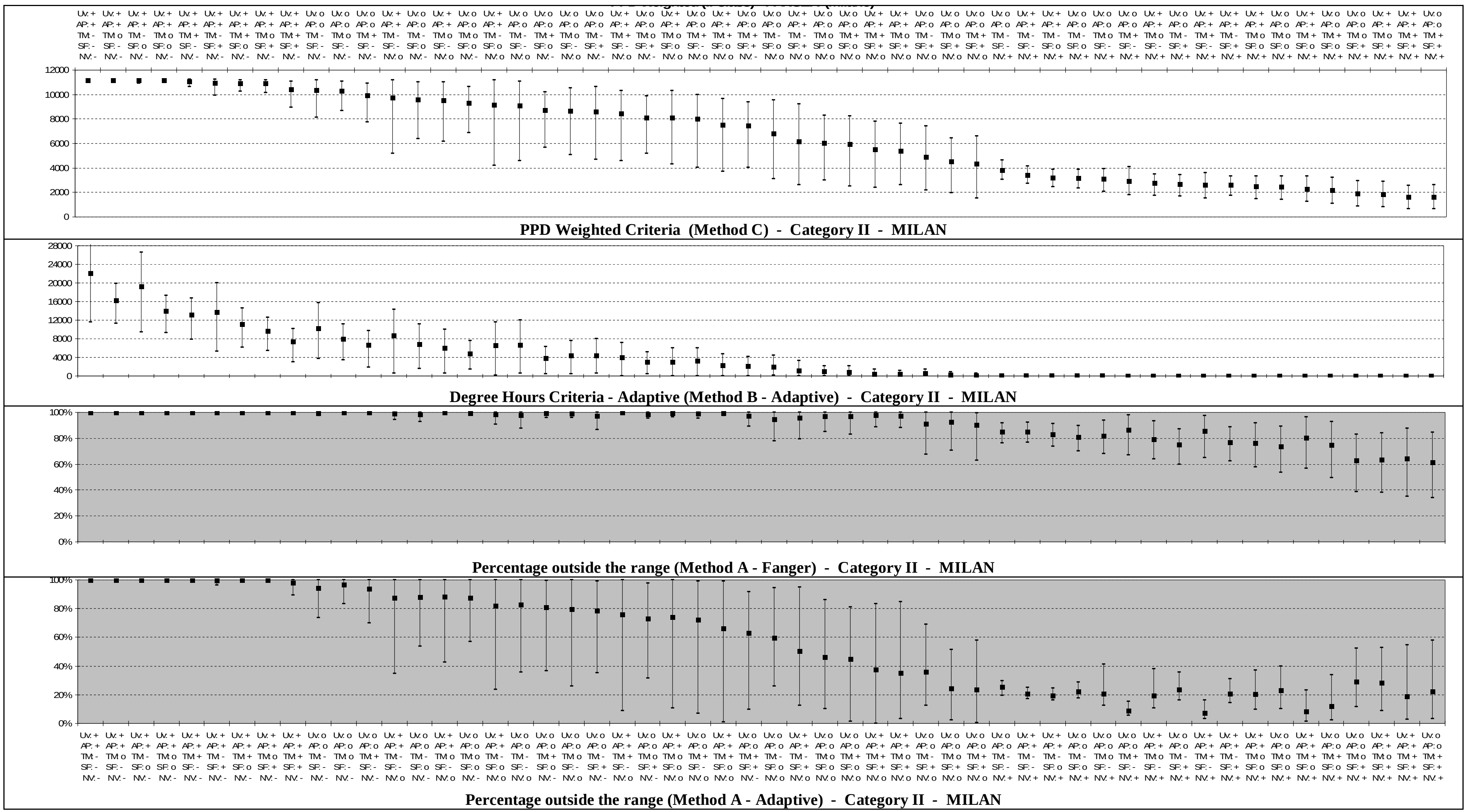


Figure 5: *Long term comfort indexes evaluated for the 54 building configurations in the climate of Milano; points are average values over the 6 office rooms, bars indicate the span between the 6 office rooms.*

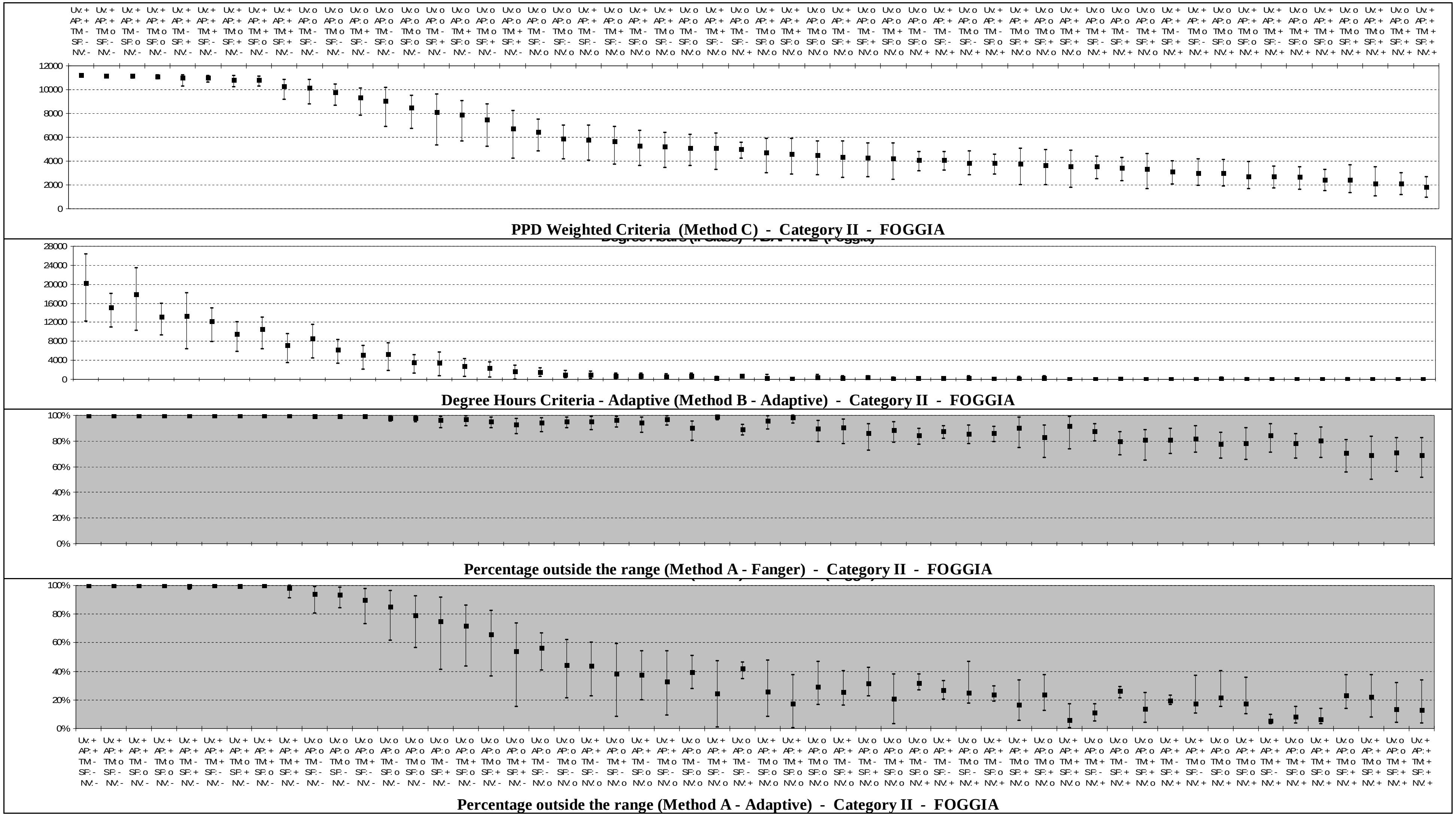


Figure 6: *Long term comfort indexes evaluated for the 54 building configurations in the climate of Foggia; points are average values over the 6 office rooms, bars indicate the span between the 6 office rooms.*

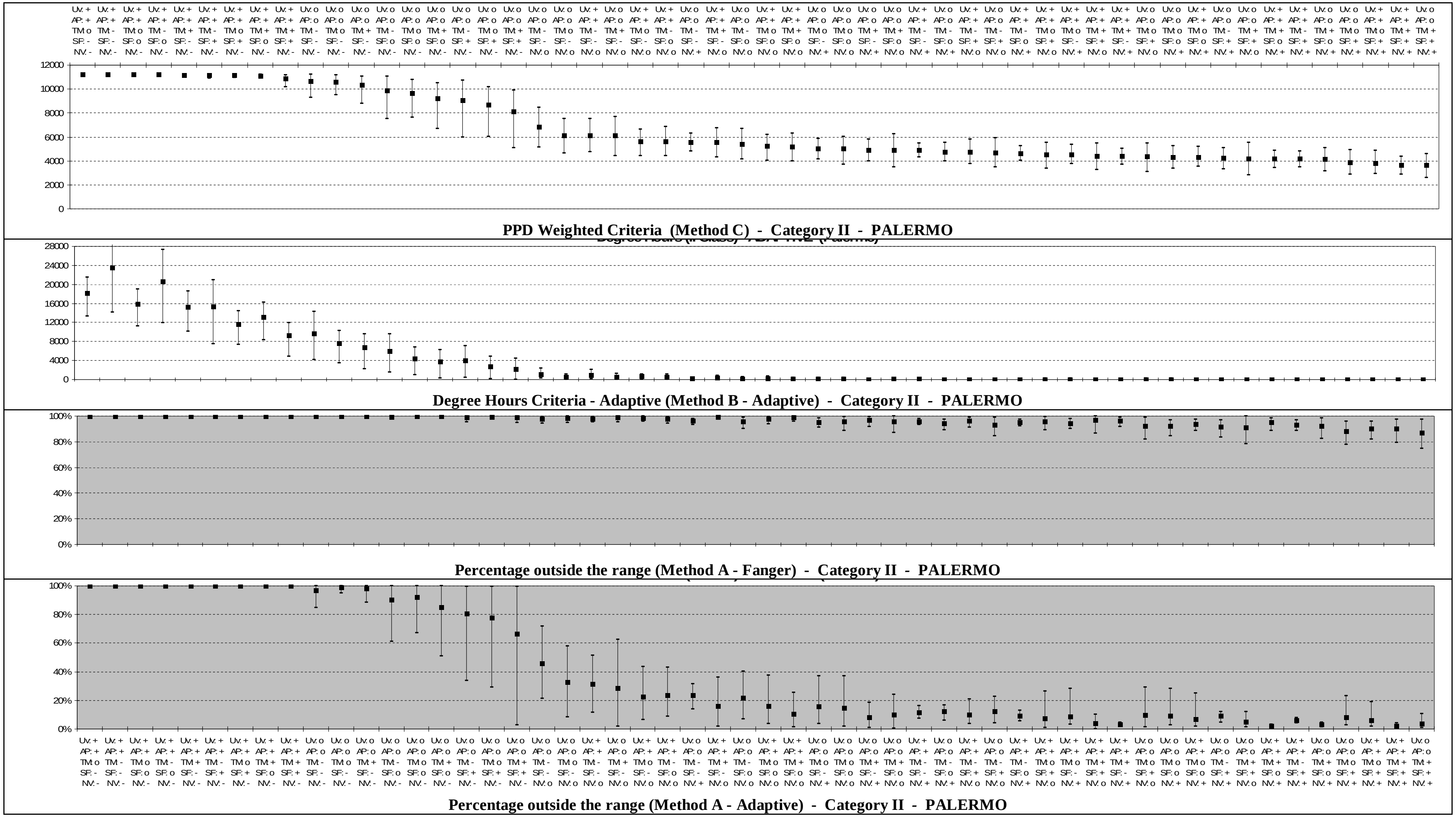


Figure 7: *Long term comfort indexes evaluated for the 54 building configurations in the climate of Palermo; points are average values over the 6 office rooms, bars indicate the span between the 6 office rooms.*

The analysis of the energy simulations, delivers some useful results (eg on the useful combination of parameters and on differences in the long term comfort performance of the 6 thermal zones representing the office rooms with different orientation and floor location in the building) and at the same time suggests that the methodology of the long term comfort evaluation methods and definition of the indexes might be worth refinements in order to be fully exploited as a design tool. In this paper we concentrate on the methodological issues.

Summarising, based on EN 15251 we have constructed an explicit procedure and some tools with the goal to minimise i) an "adaptive discomfort index " and in case the adaptive temperature limits cannot be guaranteed, turn to minimise a ii) "Fanger discomfort".

One problem of the procedure is that if there is a discontinuity in the indications offered by the two objective functions to be minimised (i and ii), designers might encounter difficulties when shifting from one to the other as suggested by EN15251. Let's examine if there are cases which might present such type of discontinuity, in particular when optimising for the warm period of the year.

Let's consider the fact that EN 15251 standard (in Annex F) proposes that PPD weighted criteria (method C) and adaptive Degree Hours criteria (method B) are to be applied without considering the hours when temperatures are below the comfort range, in the warm period. On the other hand, the standard indicates that percentage outside the range (method A) is to be applied considering both the hours when temperatures are above and below the comfort range.

Using this latter method (A), and choosing category II (new buildings) for the definition of the comfort range, the Adaptive variant allows to reach better thermal comfort results than Fanger model, but the first one shows a ranking of possible best solutions in a less sharp way (see figures 5, 6 and 7). In fact, considering the simulations for South-European climate, when applying the Adaptive variant of method A many of the simulated cases give good thermal comfort results and several combination of parameters could be chosen as the optimal case; on the other hand, when using the Fanger variant many of the simulated cases fail to reach high levels of thermal comfort but they are ranked from worst to best in a sharper way.

Furthermore, some cases that reach the best comfort results for the Fanger variant, are not as good when evaluated via the Adaptive variant. A closer analysis shows that this fact is due in some cases to the higher importance of discomfort caused by hours below the range when using the Adaptive variant compared to the Fanger one, because of different position of the comfort range in the two variants. This fact implies a discontinuity in the optimization process when one switches from Adaptive to Fanger variants as suggested by EN15251. We note here that the results presented in the tables refer to a case where night ventilation ends at 7am and calculation of the discomfort indexes starts at the same hour.

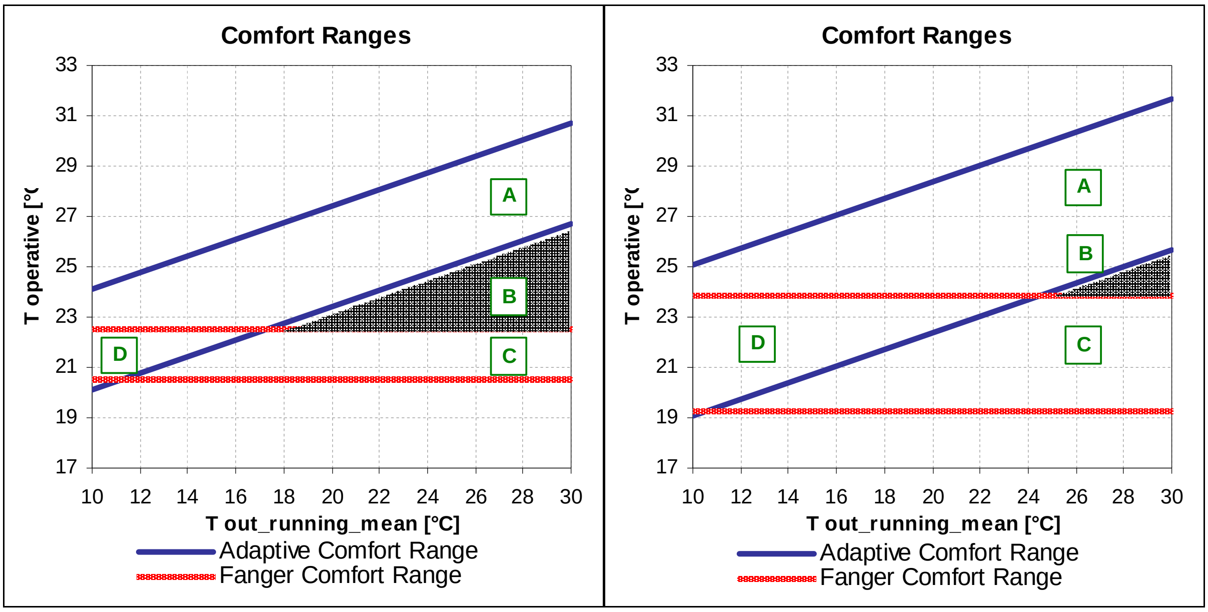


Figure 8: *Comfort ranges for category I (also called category A according to ISO7730 terminology) and II (also called category B) for the Fanger and Adaptive models. PMV is calculated with the assumptions: metabolic activity 1,2 met, total (clothing + chair) insulation 1,0 clo, relative humidity 50%, air velocity 0,1 m/s*

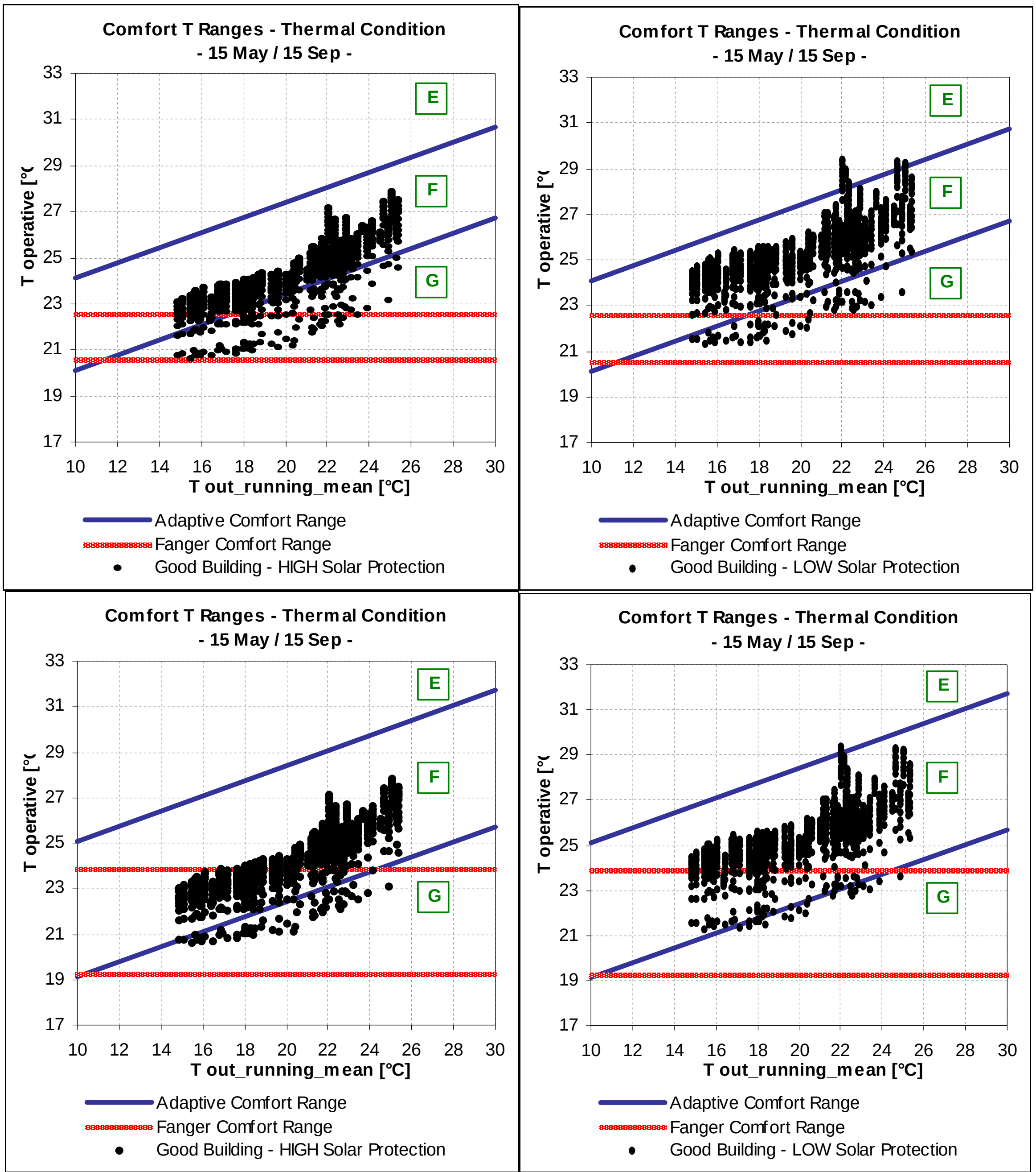
So, at least in some cases, Fanger and Adaptive variants of method A may give ambiguous signal to buildings designers when trying to optimize a certain building following the procedure set up in EN15251. In fact some thermal conditions can be considered too cold for Adaptive method, and, at the same time, too warm for Fanger method (depending obviously from the values of clothing and activity chosen to determine PMV), like we can see in “field B”, in figure 8. In the field indicated with D, Adaptive and Fanger comfort ranges coincide. Field C represents comfort conditions only for the Fanger approach, while the same field coincides with too cold conditions for the Adaptive one. Field B represents too cold conditions for Adaptive method while too warm for the Fanger one. In many previous design and evaluation methods only the situations of overheating were considered and this issue was not present. See e.g. the wide study on passive houses Cepheus (Schnieders, 2006), or the Solarbau project (Pfafferott, Herkel & Wambsganß 2004). An earlier discussion on the implication of considering symmetrically the departure from the Comfort range is presented in (Pagliano, Zangheri 2005)

The analysis of the results shows hence the need for a more explicit discussion of how to treat in the standards the issue of hours below the range in summer, and the usefulness of a careful review of the databases of comfort surveys in order to ascertain if discomfort is symmetric around the comfort range as it is assumed implicitly in the index percentage of hours outside range.

Assuming for the moment that there is an importance (whose weight might be better evaluated via further analysis) to be attached to the hours below the range, it could be interesting to analyse how the indexes can guide to select and optimise solutions to control “overcooling” phenomena in the earlier hours in the morning, and how they might also lead to non optimal choices as they are presently formulated.

As for the overcooling problem found in our optimization exercise, first obvious choice would be to make sure there is sufficient time between the end of the night ventilation process (that is from the closure of the windows and/or other openings) and the start of the occupation (the indexes are calculated taking into account only the hours of occupation). Overcooling can be reduced by optimization of air flow during the night and by improving ventilation level controls (e.g. by controlling automated operation of the ventilation openings by means of a sensor of radiant or operative temperature in the considered thermal zones). In order to find optimal air flow rate during the night, it’s possible to run simulations adopting smaller steps of variation in night air flow (steps in the opening factor).
At the opposite, reducing overall night-ventilation rate in a generalised way (rather than controlling it selectively) can reduce overcooling phenomena in the early hours of the morning in the thermal zones where

this is needed, but, at the same time, it can increase the number of hours near or above the upper side of the comfort limit. A similar effect can be seen also if, instead of changing night ventilation rates, one would reduce the solar protection of transparent surfaces, as shown in figure 9. Moving from a case with high solar protection (g = 0,15, graph (a)) to a case with low solar protection (g = 0,7, graph (b), the number of points in field G decreases, but at the same time the probability to obtain points in field E (temperature over the range) increases, and, in general the entire family of points moves upward to higher temperatures. Here again the issue of assuming or not a symmetry of acceptability below and above the comfort range is crucial in making a design decision. And the indexes as they are formulate now are probably insufficiently refined. Rather than a black and white judgement about each point (outside or inside the comfort range) there would be a need for a more precise metric with a distribution of non zero weights also inside the comfort range.



(a) (b)

Figure 9: *Operative temperatures for a building with high thermal insulation and mass, high night-ventilation rates, with high solar protection (graph a) or low solar protection (graph b) as a function of external running mean air temperature; each point represents the average over the six office rooms.*

In case the designer would choose to focus on the fine tuning and control of night ventilation based on the adaptive variant of method A, then the control algorithm for operating the openings should receive input from a sensor of operative temperature and it would not operate with a fixed setpoint and deadband but with a setpoint and deadband which will be a function of outdoor running mean temperature, according to the adaptive concept. In fact the comfort operative temperature to be reached depends from the recent history of external temperatures, hence the temperature set point (for operative or radiant temperature) at which night ventilation should be reduced/stopped cannot be set at the same level for the entire season, but it should be calculated each day based on the previous history and on the building characteristics which determine its dynamic response (see figures 10 and 11). It would also be useful to adapt simulation softwares in such a way that they can handle internally similar more sophisticated control algorithms and calculate their effect, while at the moment they generally need external input to deal with the adaptive algorithms.

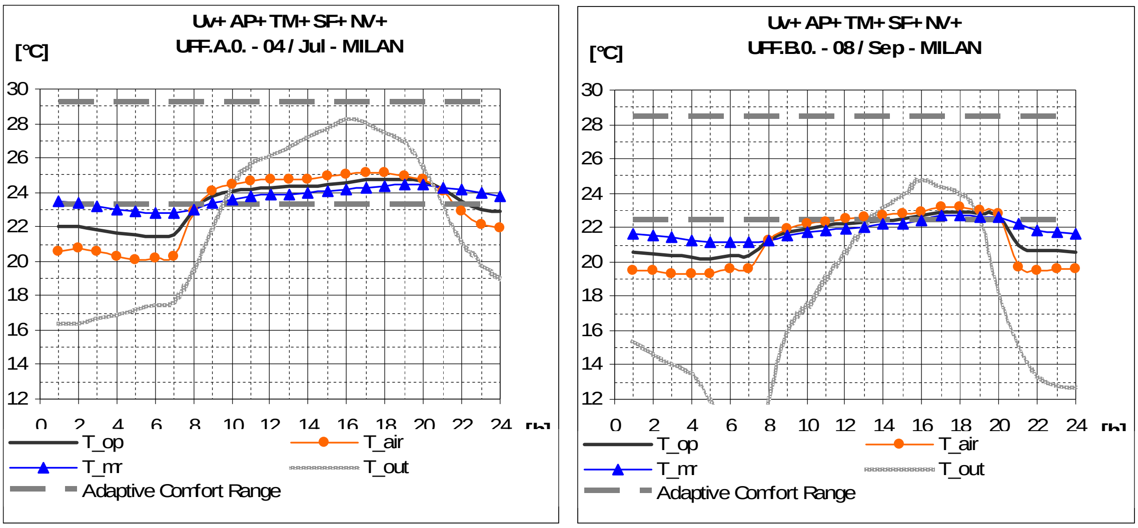


Figure 10: *Evolution of temperatures when the building is situated in the climate of Milan and night ventilation is set at high values. In the morning hours operative temperature can be below the comfort range (which in itself is shifting from day to day due to changes in the outdoor running mean temperature; here calculated for category II)*

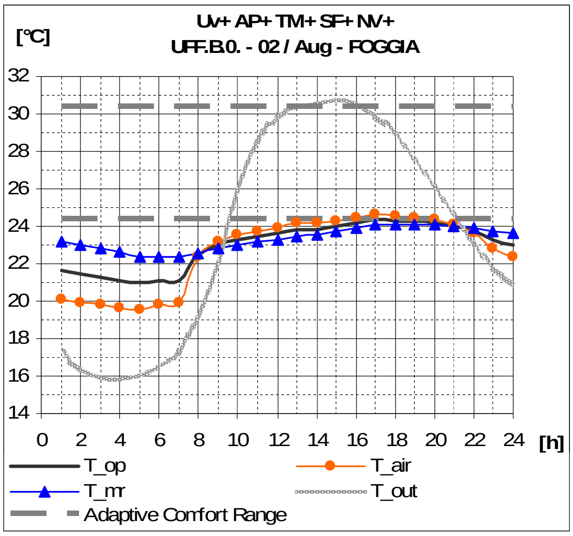


Figure 11: *Evolution of temperatures when the building is situated in the climate of Foggia and night ventilation is set at high values. In the morning hours operative temperature can be below the comfort range (which in itself is shifting from day to day due to changes in the outdoor running mean temperature; here calculated for category II)*

[a]**USE OF INSULATION ADJUSTMENTS AND INCREASED AIR VELOCITIES WITHIN THE OPTIMIZATION**

We have discussed the discrepancies and discontinuities that might arise when trying to develop and use a concrete methodology for designing envelope and passive features of buildings based on the long term discomfort indexes and suggestions contained in EN15251. We discuss in this section the fact that the gap between the two methods is in reality smaller than described above when some mechanisms included in the "static" approach in standards are duly taken into consideration, and we will show existing limitations in their use based on their current formulation.

We consider here the influence on PMV due to:

- a reduction of the value of the variable "total insulation" via e.g. the adoption of dress codes that allow or encourage to reduce the clothing resistance and/or an explicit choice towards chairs with low insulation value
- an increased air velocity to offset the warmth sensation caused by increased temperature.

The effect of chair insulation in the past has been underestimated in a number of studies, and it seems seldom explicitly considered in everyday design practice, even if it is now described and quantified in ASHRAE 55 and ISO 7730.
In order to explain the description of discrepancies between calculated PMV and sensation judgments from interviewed subjects in fields studies researcher (Schiller, 1990; Fanger and Wyon, 1990) suggested that the method of estimating clothing insulation might be systematically biased by omission of the thermal effect that chairs have on their occupants. Subsequently (McCullough and Olesen, 1994) by examining the effects of upholstered office furniture on the total thermal insulation of a heated manikin, concluded that a typical office chair adds approximately 0,15 clo to the value obtained by addition of individual garment values, as described in ASHRAE Standard 55-92 or ISO-7730: 1994. This change in clo value corresponds to a change of about one degree Celsius in the value of neutral temperature. ASHRAE RP-884 has systematically included a value of 0,15 clo in calculating total insulation values (defined in the study as one of the main variables of the database and corresponding to the insulation value due to both clothing and chair). ISO 7730 states that for sedentary persons, the chair can contribute an additional insulation of 0 clo to 0,4 clo.

We explore in this section the effect on the long term indexes produced by changes in total insulation (clothing plus chair) from the value of 1 clo assumed in previous sections to values of 0,85 and 0,65. Assuming an insulation value for the chair of 0,15, this means reducing clothing insulation from 0,85 respectively to 0,7 and 0,5 e.g by relaxing the requirements of explicit or implicit dress codes.

Reducing the clothing value of insulation means on average a higher percentage of skin exposed to air, and hence higher air velocities would have an effect in ameliorating thermal sensation of the building occupants. That is we get into a situation where, according to literature and standards, it is justified to use a "velocity correction" to comfort temperature calculated using the PMV index. It is particularly relevant for Mediterranean climates and summer conditions to discuss the effect on thermal comfort produced by air velocities higher than 0,2 m/s.

ISO 7730, ASHRAE 55 and EN15251 standards recognize the possibility to increase the indoor comfort temperature while maintaining comfort if a means is provided to also elevate the air velocity. The methods proposed are similar but some details and the description of the conditions of applicability are slightly different. We chose to use to the methods presented in ASHRAE 55-2004 since application conditions are presented in a more explicit and unambiguous way.

ASHRAE 55-2004 (point 5.2.3) proposes a more precise and unambiguous procedure. Use of the PMV model in this standard is limited to air speeds not greater than 0.20 m/s. The standard allows air speeds higher than 0,2 m/s to be used to increase the maximum temperature for acceptability if the affected occupants are able to control the air speed. The amount that the temperature may be increased according to ASHRAE 55 is shown in figure 12. The combinations of air speed and temperature defined by the lines in this figure result in the same heat loss from the skin. The reference point for these curves is the upper

temperature limit of the comfort zone (PMV = +0,5) and 0,20 m/s of air speed. This figure applies to a lightly clothed person (with clothing insulation between 0,5 clo and 0,7 clo) who is engaged in near sedentary physical activity (with metabolic rates between 1,0 met and 1,3 met).
According to ASHRAE 55, elevated air speed may be used to offset an increase in the operative temperature, but not by more than 3,0°C above the values for the comfort zone without elevated air speed; the required air speed may not be higher than 0,8 m/s and the elevated air speed must be under the direct control of the affected occupants and adjustable in steps no greater than 0,15 m/s.
We do not discuss here analysis which seem to indicate that air velocities higher than 0,2 m/s are preferred by people in neutral and slightly warm conditions even when their control over air velocity is limited (Zhang, 2007) and we rather concentrate on analysing how the air velocity correction can be incorporate in the optimization methodology we are discussing.

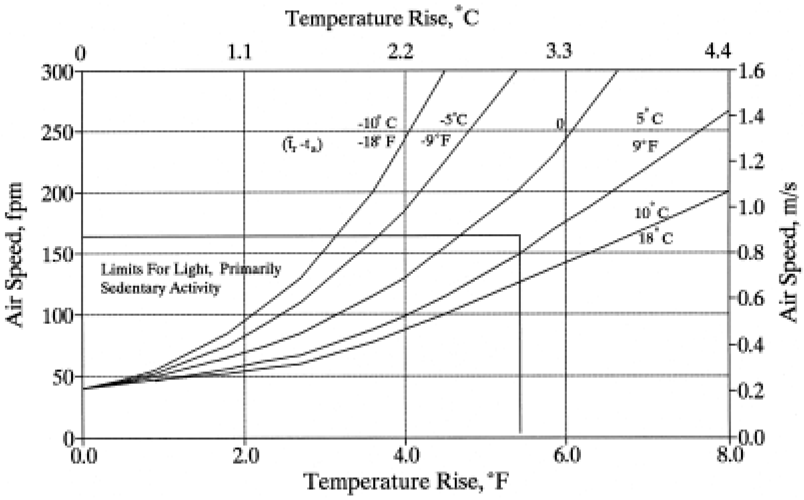


Figure 12: *Increase of the upper temperature limits of the comfort zone when air velocity is increased above 0,2 m/s, according to ASHRAE 55- 2004 (Figure 5.2.3) . The curves describe conditions of equal heat loss from the skin, and have as a parameter the difference between mean radiant temperature and air temperature.*

The fact that this correction is a correction to temperature (the upper limit temperature of the comfort range) implies that it can be included only into one of the long term indexes proposed in EN15251, that is method B: degree hours criteria. Method A (percentage outside (PMV) range), and Method C (PPD weighted criteria) both require the calculation of PMV and the method proposed in figure 12 does not propose a way to correct PMV and PPD to take into account elevated air velocities.
We have considered the climate of Palermo and four good configurations of envelope parameters and high level of night ventilation for our prototypical building which resulted by the previous optimization step, and used them as base cases for the next improvement step (see figure 13). The base cases are further characterised by the common assumptions that total insulation value (considering clothing and chair) experienced by occupants is 1,0 clo, metabolic activity level is 1,2 met, mechanical work negligible, air velocity is 0,1 m/s. Relative humidity is calculated by means of energyplus each hour .
For each of the base cases we calculate the degree hours index (method B). Then we consider a few scenarios:

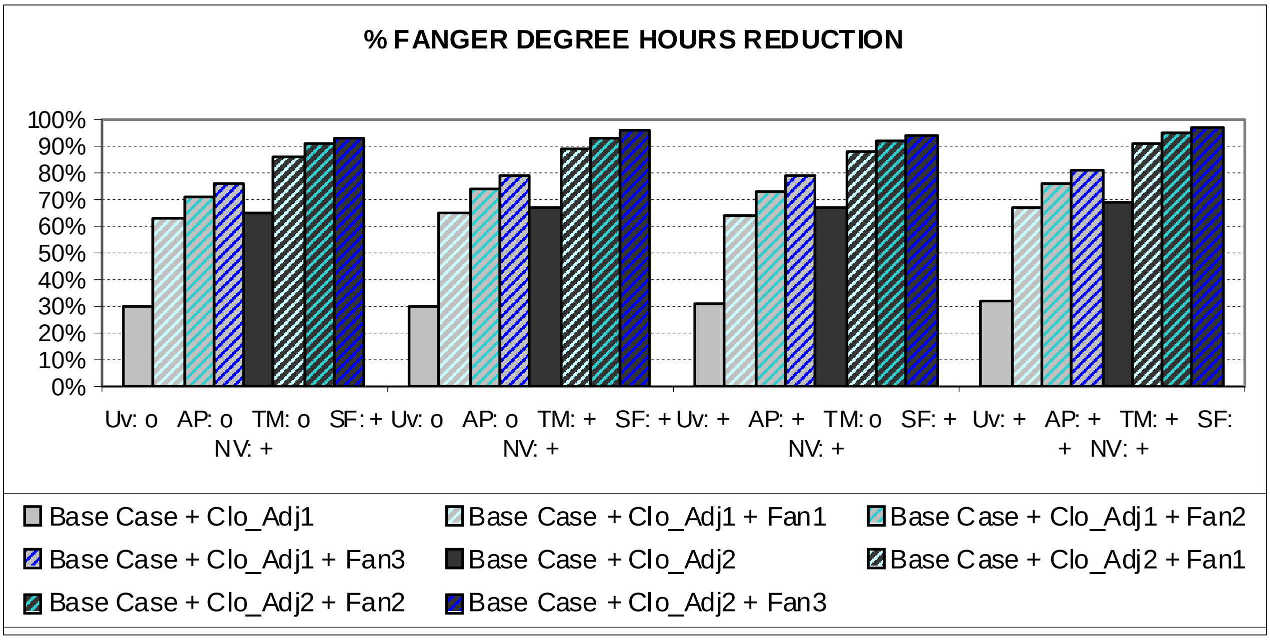
- a reduction of total insulation value from 1,0 to 0,85 clo (clo_adj1), or from 1,0 to 0,65 (clo_adj2)
- an increase of air velocity from 0,1 to 0,4 m/s (fan1), or to 0,6 m/s (fan2), or to 0,8 m/s (fan3)

and combinations of the above.

The effects of air velocity increase on the upper temperature limit of the comfort zone are calculated following the ASHRAE 55 method: up to 2 m/s normally with the PMV formula of ISO 7730 and from 0,2 onward using the graphic method of figure 12.
The results (see figure 13) show that the reduction of total insulation from 1,0 clo to 0,85 and 0,65 alone are able to reduce the hours outside range by about 30% and 60% respectively, compared to the base cases. If

additionally to these changes to insulation air velocity is increased to a level of 0,4 m/s, hours outside range are reduce by about 60% or 85% compared to the base cases (65 and 95% in the best envelope conditions).
The result suggests that the optimisation processes done using the static or adaptive variants of the indexes in EN15251 might present a much reduced discontinuity when the "static" model is used to its full extent and clo and air velocities adjustments are allowed and accounted for.

Figure 13: *Calculated reductions from case bases in the value of the index degree hours (method B) in the Fanger variant, as a consequence of changes in total insulation value (from 1,0 to 0,85 and 0,65 clo) and of air velocity (from 0,1 to 0,4, 0,6 and 0,8 m/s)*



Even assuming that the gap between the optimization paths along the adaptive and "static" routes may be reduced to manageable values, there is the further problem due to the fact that the "static" model is comprised of subsequent steps, one of which is graphic, and hence a complete explicit optimisation procedure based on explicit objective functions to be minimised is not possible. Furthermore, the air velocity correction is expressed in terms of correction to the comfort temperature (or to the upper temperature of the comfort range) and therefore is not suited to be incorporated into the long term indexes of methods A and C, which rely on PPD or PMV calculations.
In order to move towards a fully fledged and reliable optimisation procedure, applicable with all the EN15251 indexes, one step would be to incorporate the effects of increased air velocity during hours with warm conditions as explicit reductions of PMV rather than as increases in operative temperatures (at comfort or upper range conditions). We present a PMV correction graph obtained by modifying the ASHRAE-55 graph calculating the effects on PMV of air velocity increases over a suitable range of variation of the input variables. We assumed clothing values of 0,5, 0,6 and 0,7 clo in order to be within the range of applicability according to the standard; relative humidity 50%; air velocity 0,2 m/s since it is the reference point for this graph; external work has been set to zero; air temperature and radiant temperature are assumed to be equal and to vary between 26 and 30°C. Based on these inputs values of PMV are calculated at the above temperatures and at temperatures reduced by the amount considered in the steps of figure 12; negative values of PMV are eliminated, and differences calculated. In figure 14 we report the PMV corrections (averaged over the combinations described above) corresponding to each temperature rise step.

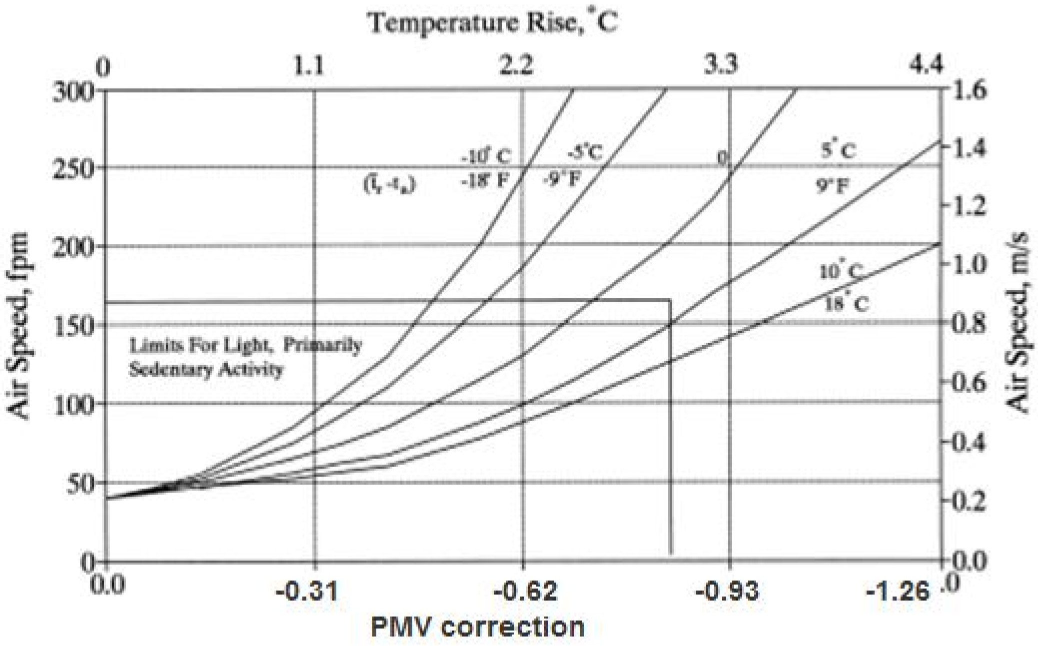


Figure 14: *A proposal for a graph for PMV correction compared to base case calculated with PMV formula at 0,2 m/s, as a function of air speed over 0,2 m/s, as an elaboration to graph 5.2.3 of ASHRAE 55.*

Using this version of the graph, long term indexes of methods A and C may be calculated. Still the graphical method presented has limitations in that it is an approximation based on averages over a range of variation of input variables, and it still requires manual calculations. Hence in order to include it into an explicit analytic optimization algorithm, in a next step it should be translated into analytical terms (which also would allow a finer calculation rather than an averaged one).

[a]CONCLUSIONS

We have presented a review of the evolution of knowledge about thermal comfort and of how the formulation by which these advances are incorporated into standards can influence the design, operation and assessment of buildings in the Mediterranean area.

Efforts are ongoing in order to systematize the wealth of data produced in the last decades; further work is needed in order to produce larger scientific and technical consensus on the criteria of acceptability and sometimes also on the scales of subjective judgment to be used for assessment of acceptability. Reference to ISO 10551 or similar systematization of terminology about scales and their careful linguistic transposition in the various languages is a prerequisite for further advancements to be based on sound comparability of data.

At the same time uniform protocols for in field measurement of physical parameters, estimates of chair and clothing insulation values, description of the type of building, plants and controls available to individuals will enhance reliability and comparability of data needed e.g. to clarify the open issues about which comfort model is to be applied in which conditions. The categorization of buildings to be analysed via one or the other of the models is not clearly described in literature and standards, partly because of the limited number of surveys in the overlapping area of hybrid buildings, but also for the conceptual difficulty to sharply assign buildings to two different, separated sets, given that the number of variables involved in characterizing envelope, plants, availability of individual local controls and time-varying conditions (conditioned vs free floating) within a certain building.
The formulation of the concept of acceptability in terms of comfort categories in the standards and the issue of how fine can be the discrimination among those categories is subject of research and we reviewed some of the findings and interpretation of available data.

Starting from the de facto present situation as codified in the standards, we address then the relevance of the previous concepts on the design of energy efficient and comfortable buildings. For the design of new buildings or assessment of long term comfort performances of existing buildings, EN15251 proposes a series of long term indexes, based on both the Fanger and adaptive comfort models, and certain choices about acceptable ranges of conditions. We discuss some of the implications particularly for the design of buildings in the Mediterranean area, obtained by the authors via dynamic simulation software complemented by pre and post processing tools prepared to ameliorate and speed the treatment of comfort data. We present an optimization methodology, some results in a choice of Mediterranean climates.

EN 15251 requires that 95 % of the occupied space is for e.g 97% (or 95%) of occupied hours inside a certain comfort range in order to assign a building to the corresponding comfort category. Hence implicitly requires that the methodology consist of simulations carried out with sufficient detail (e.g. sufficient number of thermal zones) to evaluate local room parameters rather than building averages and to be able to detect disuniformities; in this respect it is more demanding than simulations oriented only to estimate yearly energy consumption where sometimes less detail may be considered sufficient (or apparently sufficient, since comfort conditions are less explicitly defined).

We show that using some of the indexes proposed by EN 15251 (e.g Method A: percentage outside the range) and their intended use (start with its adaptive variant and, if comfort conditions for the chosen category can't be met, switch to Fanger variant) implies the presence of discontinuities in the procedure. This is due to the fact that with common assumptions on met and clo certain conditions will be above the comfort range for Fanger and below the range for adaptive. More generally the sharp change from zero to non zero values in the weights when crossing the threshold between one comfort category and the other can be the source of discontinuities. Even with these limitations, the indexes can be useful as objective functions to be minimized in an optimization procedure to guide design, particularly for the building envelope and passive features. In passive buildings the use if these indices (in their adaptive variant) would be useful to e.g. guide controls that operate the openings for night ventilation in summer. In fact the comfort operative temperature to be reached depends from the recent history of external temperatures, hence the temperature set point (for operative or mean radiant temperature) at which night ventilation should be reduced/stopped cannot be set at the same level for the entire season, but it should be calculated each day based on the previous history and on the building characteristics which determine its dynamic response. It would also be useful to adapt simulation tools in such a way that they can handle directly such control algorithms and calculate their effect.

Part of the discontinuities between the two variants (Fanger and adaptive) arising in the optimization procedure with use of the long term indexes may be reduced when considering the large influence that certain variables like clothing (and total) insulation and air velocities have on the calculated values of PMV. Ensuring that clothing insulation is under 0,7 (e.g. by appropriate relaxation of explicit or implicit dressing codes) enables the use of the ASHRAE correction (in augmentation of the value calculated via PMV formula) to operative comfort temperature when velocities higher than 0,2 m/s are experienced by the occupants. These two changes have the effect of reducing the ambiguous zone between the two comfort ranges.

The correction as it is proposed is applicable directly only to temperature, hence only within method A (hours outside range), but not in method B and C which rely on PMV and PPD values for the weighting, plus being in graphic form is not implementable/implemented in simulation or optimization tools. We calculated and propose here a modified version, where increased air velocities effects are described in terms of PMV in graphic form. Further work is ongoing in order to incorporate it into analytic/numeric procedures for optimization.

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