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# Comfort Models and Building design in the Mediterranean Zone

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## Abstract

In the presence of renewed research and application efforts 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.

This paper discusses how the evolution of knowledge on comfort and its incorporation into international Standards, inter alia in the form of comfort categories for different types of buildings, can influence the design, operation and evaluation of buildings in the Mediterranean area.

We discuss some of the implications, obtained by the authors via dynamic simulation software complemented by pre and post processing tools purposely 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.

Critical analysis and results presented here have been developed partially under the IEE projects Commoncense and ThermCo.

**Keywords:** thermal comfort, building simulation, optimization procedure, natural ventilation.

## Comfort models and their areas of application

The data collected in laboratory and in the field on physical parameters and subjective comfort sensations and preferences have been interpreted and meaningful correlations between variables have been searched for, giving rise to what are generally called “comfort models”. 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, 1970) and the “adaptive” model (De Dear and Brager, 1997; Nicol and 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).

A number of researchers have observed that some buildings will not fall exactly into the two ensembles for which the Standards propose to use either the Fanger or the Adaptive model 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 and ThermCo report 2009). 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.

One of the aims of this paper is to show some of the ways in which these two models may be used in synergy for helping the design of low energy comfortable buildings.

## Comfort categories in relationship to comfort models in recent standards (Ashrae 55:2004, ISO 7730:2005 ; EN 15251:2007 )

ISO7730:2005 proposes, only for the Fanger model, three categories of comfort (A, B, C) defined by the ranges of PMV: ±0,2, ±0,5, ±0,7 and leaves open choice about to which buildings apply a certain category.

EN 15251:2007 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, in terms of temperature ranges (as a function of outdoor running mean temperature).

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 EN 15251-2007 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 | 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 1:** *Categories of comfort based on Fanger approach and hence defined in terms of PMV and PPD values.*

Comfort ranges are one of the basis inputs for design and assessment of comfort and energy performance of buildings. E.g. in EN 15251 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.

EN 15251 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.

## Long term comfort indexes (EN 15251) as design optimization functions. About their use and limitations in mediterranean climates

The authors have developed, partially under the IEE project ThermCo, (Thermco 2009) and Commoncense (Commocense 2009) a methodology for the application of the long term discomfort indexes suggested by EN 15251 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.”.

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) if the setpoint is explicitly set according to the definitions in the Standard.

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 2 as a prerequisite for approval of installation of an air conditioning system.

**Table 2**: *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 2).

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.

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 centre of the zone or from a specified point to the various surfaces.

We chose then 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$^2$K (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. Table 3 describes the characteristics of two standard office rooms.

**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$^2$K] 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 load densities and schedules typical of office buildings and daylight availability coherent with geographical position.

We have performed the analysis for the climate conditions of Milan, Palermo and Foggia. The simulations have been performed using EnergyPlus Weather File (EPW) produced from IWEC (International Weather for Energy Calculations format from ASHRAE).

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. We have hence considered all the long term evaluation indexes proposed by the Annex F of the Standard:

*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 $wf = \left|\Theta_{\mathrm{o}} - \Theta_{\mathrm{o,\,limit}}\right|$, which is the module of the difference between actual (calculated) operative temperature $\Theta_{\mathrm{o}}$ at a certain hour and respectively the lower or upper limit $\Theta_{\mathrm{o,\,limit}}$ 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. EN 15251 specifies that in the warm period the summation is extended only to the hours when $\Theta_{\mathrm{o}} > \Theta_{\mathrm{o,limit,upper}}$. Similarly for the cold period the summation is extended only to the hours when $\Theta_{\mathrm{o}} < \Theta_{\mathrm{o,limit,upper}}$.

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 $\mathrm{PMV}_{\mathrm{limit,lower}} < \mathrm{PMV} < \mathrm{PMV}_{\mathrm{limit,upper}}$ where $\mathrm{PMV}_{\mathrm{limit}}$ 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: ∑wf· time for $\mathrm{PMV} > \mathrm{PMV}_{\mathrm{limit,upper}}$,
and for a cold period only on the lower side: ∑wf· time for $\mathrm{PMV} < \mathrm{PMV}_{\mathrm{limit,lower}}$.

For our purposes (optimization of the parameters during the design of a new building) we are guided by EN 15251 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.
In our analysis the summations have been done during the working hours, from 15 May to 15 September. With EnergyPlus we calculated the mean hourly values of air temperature, mean radiant temperature, air velocity and relative humidity, for each typical office room.
We have developed some pre-processing and post-processing tools to achieve calculations not yet or not fully included in EnergyPlus. 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 e.g. 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 tool produces the hourly comfort temperature profile for each climate, through the correlation with external running mean temperature defined in EN 15251.

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 5. 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 5), 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.

**Table 5**: *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 | $W/m^2K$ |
| | | | Wall | 0.32 | $W/m^2K$ |
| | | | Basement | 0.36 | $W/m^2K$ |
| | | | Window | 2.4 | $W/m^2K$ |
| | | | Air Permeab | 5 | $m^3/h/m^2$ |
| | **+** | SIA Refurbishment: target values | Roof | 0.2 | $W/m^2K$ |
| | | | Wall | 0.2 | $W/m^2K$ |
| | | | Basement | 0.2 | $W/m^2K$ |
| | | | Window | 1.2 | $W/m^2K$ |
| | | | 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 | $Wh/m^2K$ |
| | | | Ceiling | 11.0 | $Wh/m^2K$ |
| | | | Floor | 4.1 | $Wh/m^2K$ |
| | | | Internal Wall | 2.3 | $Wh/m^2K$ |
| | | | TOTAL | 20 | $Wh/m^2K$ |
| | **o** | Medium Internal Thermal Mass | External Wall | 15.4 | $Wh/m^2K$ |
| | | | Ceiling | 18.6 | $Wh/m^2K$ |
| | | | Floor | 12.7 | $Wh/m^2K$ |
| | | | Internal Wall | 8.9 | $Wh/m^2K$ |
| | | | TOTAL | 50 | $Wh/m^2K$ |
| | **+** | High Internal Thermal Mass | External Wall | 15.4 | $Wh/m^2K$ |
| | | | Ceiling | 22.1 | $Wh/m^2K$ |
| | | | Floor | 22.4 | $Wh/m^2K$ |
| | | | Internal Wall | 18.8 | $Wh/m^2K$ |
| | | | TOTAL | 80 | $Wh/m^2K$ |
| **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 the following long term discomfort indexes and referring them to category II (to be used for new buildings according to EN 15251):

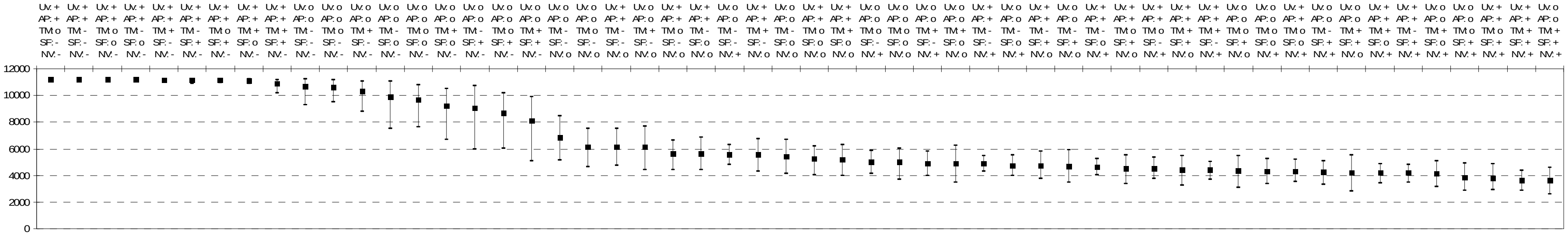
- PPD weighted criteria (method C),
- Adaptive degree hours criteria (method B),
- percentage of hours outside the Fanger comfort range (method A, Fanger),
- percentage of hours outside the Adaptive comfort range (method A, Adaptive).

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.

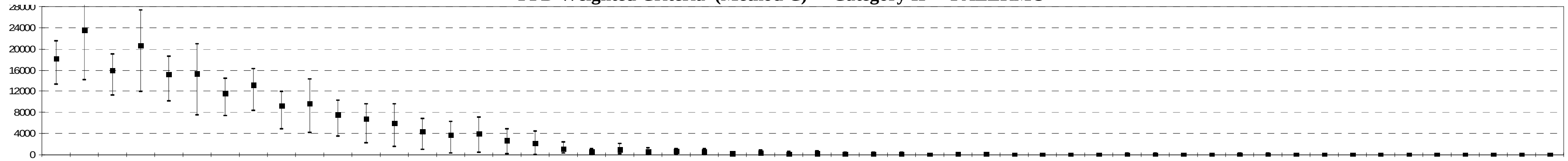
Based on the results of the dynamic simulation (air and radiant temperature in the zone, air velocity, humidity) and on assumptions on clothing and metabolism, we calculate PMV via our post processing tool.. In the results presented below, taking into account that we are focusing on an office in Italy, 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 (de Dear, Brager & Cooper 1997). A value of 0,15 clo is assumed in the database for average office chairs, based on previous measurements and analysis (Schiller, 1990; McCullogh and Olesen, 1994 and others).

Each building model is described with the combination of variables and the symbolic code that is shown in Table 5. The results are ordered by decreasing PPD weighted index (method C), for each climate location. We show in figures 1 how the results may be presented (for one climate example: Palermo).

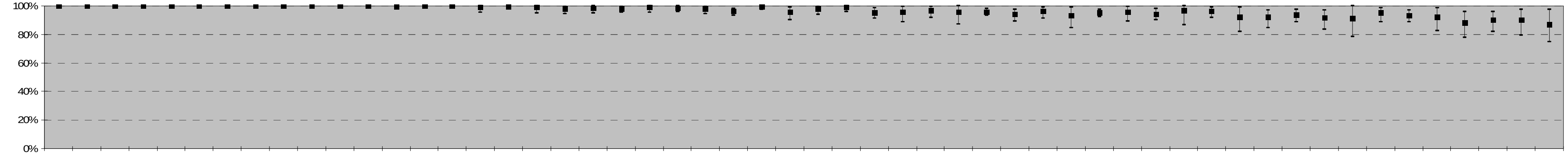
For each building model, 6 office rooms were considered, in order to check the fulfilment of EN 15251 request about 95% of space for the assessment of categories. In the following graphs one can read, for each configuration, the average value over the six office rooms of the discomfort index, together 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.



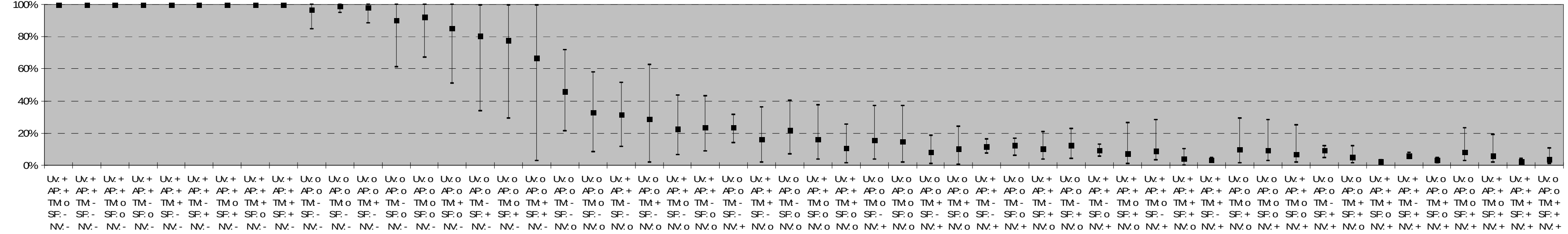
PPD Weighted Criteria (Method C) - Category II - PALERMO



Degree Hours Criteria - Adaptive (Method B - Adaptive) - Category II - PALERMO



Percentage outside the range (Method A - Fanger) - Category II - PALERMO



Percentage outside the range (Method A - Adaptive) - Category II - PALERMO

**Figure 1:** *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.*

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 EN 15251. 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. 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, don’t show a good performance 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. We note here that the results presented in the following refer to a case where night ventilation ends at 7am and calculation of the discomfort indexes starts at the same hour.

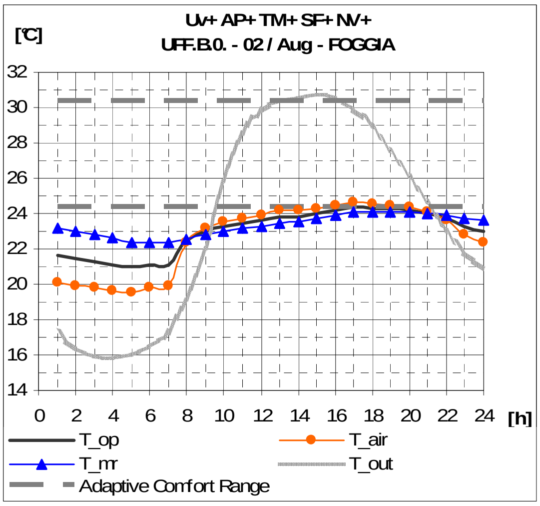


**Figure 2**: *Evolution of temperatures when the building is situated in the climate of Foggia and night ventilation is set at high values. In the morning hours operative temperature can be below the comfort range (which in itself is shifting from day to day due to changes in the outdoor running mean temperature; here calculated for category II )*

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 suggested in EN 15251. 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 3. An earlier discussion on the implication of considering symmetrically the departure from the Comfort range is presented in previous studies (e.g. Pagliano, Zangheri 2005).

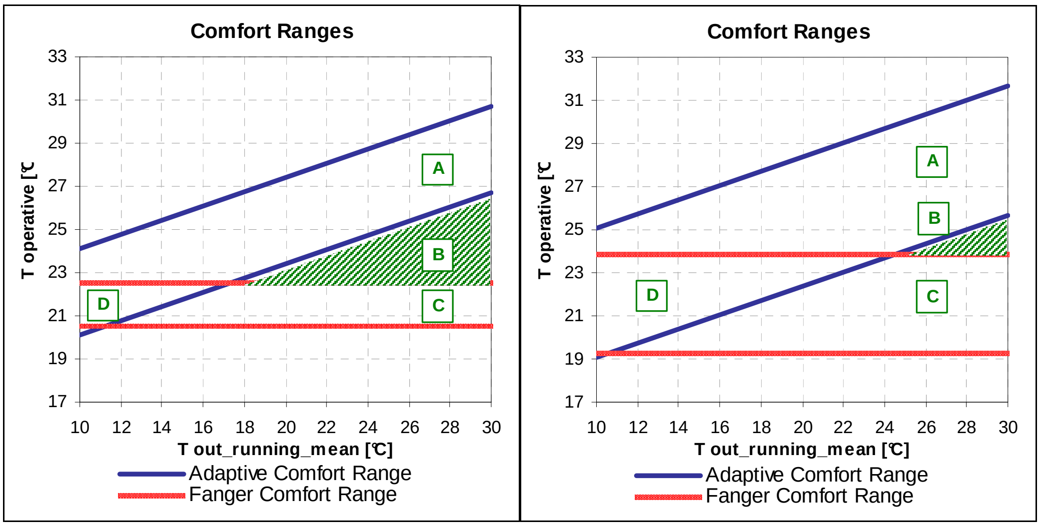


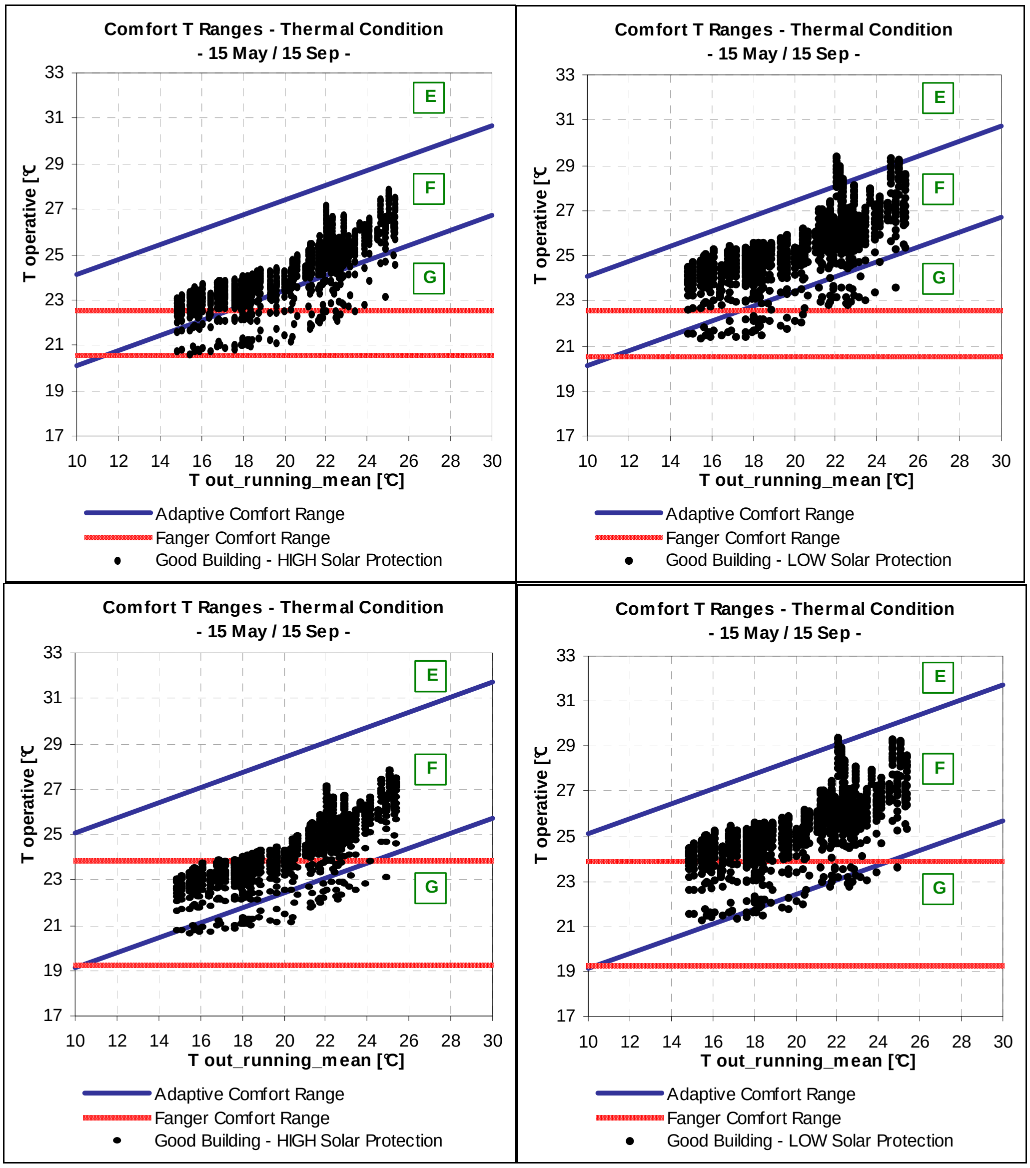
**Figure 3**: *Comfort ranges for category I (also called category A according to ISO7730 terminology) and II (also called category B) for the Fanger and Adaptive models. PMV is calculated with the assumptions: metabolic activity 1,2 met, total (clothing + chair) insulation 1,0 clo, relative humidity 50%, air velocity 0,1 m/s.*

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 perceived 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 obviously 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 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 is 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 4. 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.



(a) (b)

**Figure 4**: *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.*

## Use of insulation adjustments and increased air velocities within the optimization

We consider here the influence on PMV during the cooling season 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.

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 in warm weather periods.

ASHRAE 55:2004 proposes an unambiguous procedure. Use of the PMV model in this standard is limited to air speeds not greater than 0,2 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 correction 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.

The fact that this correction is a correction to temperature (the upper limit temperature of the comfort range) implies that it can be directly included only into one of the long term indexes proposed in EN 15251, 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 by ASHRAE does not propose a way to correct PMV and PPD to take into account elevated air velocities. A reformulation of the correction in term of PMV is being developed by the authors.

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 5). 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)

The effects of air velocity increase on the upper temperature limit of the comfort zone are calculated following the ASHRAE 55 method.

The results (see figure 5) 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 EN 15251 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.

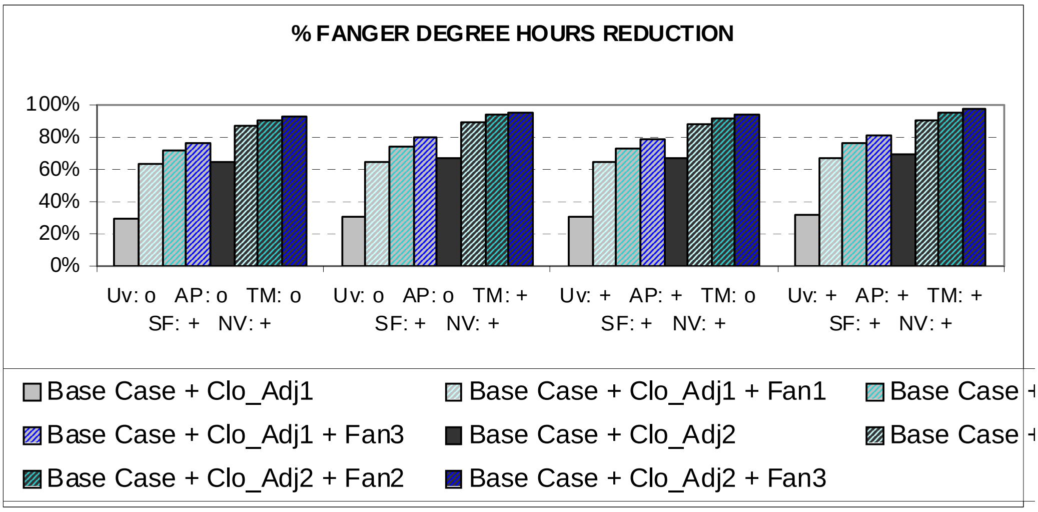


**Figure 5**: *Calculated reductions from case bases in the value of the index degree hours (method B) in the Fanger variant, as a consequence of changes in total insulation value (from 1,0 to 0,85 and 0,65 clo) and of air velocity (from 0,1 to 0,4, 0,6 and 0,8 m/s)*

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.

## Conclusions

Starting from the definitions of comfort categories and long term indexes as proposed in the international Standards, we discuss their effect of on the design of energy efficient and comfortable buildings, particularly in the Mediterranean area, via analysis performed via dynamic simulation software complemented by pre and post processing tools purposely prepared to ameliorate and speed the treatment of comfort data. We present an optimization methodology and some results in a choice of Mediterranean climates.

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 the Fanger model and below the range for adaptive one. 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 would be useful to e.g. guide controls that operate the openings for night ventilation in summer. 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.

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