Will naturally ventilated dwellings still be safe under heatwaves?

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ABSTRACT

Heatwaves are often responsible for many deaths due to high temperature indoors. Energy savings is a key element in building design and refurbishment works to reduce the impact of climate change. Natural ventilation is often promoted as an indoor space cooling solution thanks to its energy saving potential.

The paper deals with prediction of heat-related health risks situations in naturally ventilated dwellings.

In these spaces, indoor thermal conditions depend on windows opening and on difference between outdoor and indoor temperatures. The efficiency of temperature control also depends on especially building thermal inertia, solar gains and occupants' behaviour. Yet, meteorological variability and occupants' behaviour are difficult to predict. Thus, operating limits of technical solutions using natural ventilation are not totally reliable because of uncertainties on the variability of these parameters.

In order to decrease uncertainties in prediction of heat-related health risks and to secure building design, the first step of a science-based methodology is proposed to help building sector professionals. It links consensual indicators, including ergonomics of the thermal environment standards, to distinguish between a moderately warm situation from heat stress causing unhealthy indoor environment for occupants. Simulations are performed for a dwelling with different air flow rates under contrasting meteorological conditions to illustrate the methodology and the potential limits of natural ventilative cooling, according to health risks.

In tested dwelling, natural ventilation can reduce indoor temperature but doubt remains about providing comfortable conditions. According to ergonomics standards scopes, a gap occurs between "moderate thermal environment" and "heat stress" areas. Further investigations are needed to bridge the observed gap.

KEYWORDS

Thermal comfort, heat stress, natural ventilative cooling, health, climate change

1 INTRODUCTION

Once upon a time in Western Europe, during a conference about climate change[1], a naturally ventilated school[2] was presented as the paragon of adapted building to climate change. Later, supplement to CEN Guide 32 (2016), about climate change adaptation in standards, recommends to "give[s] preference to equipment that is not weather sensitive". The contrast is striking between both comments.

Indeed, usually passive energy constructions, mixing high thermal mass and night cooling ventilation, are supported according to climate change mitigation policies. These constructions are known to significantly reduce indoor temperature, if outside temperature is low enough at night. Thus which way should be followed?

Climate projections warn us about the return of even hotter heatwaves with several hot days. Cautiously CEN GUIDE 32 (2016) invites to "ensure building can […] provide thermal comfort in a changing climate." In practical terms, is natural ventilation reliable enough to avoid thermal stress and their dire consequences?

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[1] 11Th, The international weather and climate forum, april 2014.

[2] Ecole Saint Exupéry, Pantin (Paris suburb), Ademe et vous, n°73-Mars 2014

The long term goal of this work is to help professional to establish the running limits of these bioclimatic solutions. Dedicated to professionals, most of references are international standards, and used numerical models are strongly linked to them.

In this paper, an overall view of the methodology in process is introduced, before studying how to bridge the gap between thermal comfort and thermal stress. A tested situation helps to draw standards limits and to provide reasonable values of disruptive threshold from comfort to stress. Finally, it gives an idea of natural ventilation efficiency to keep dwelling safety with high thermal mass under a heatwave. First of all, heatwave hazards and climate change context are outline in order to highlight a way to design buildings to achieve both objectives: adaptation and mitigation to climate change.

2 METHODOLOGY

In this section are presented the health effects of heatwaves and the measures to limit their impacts. Then, the method is described step by step. Finally, it presents the results understanding keys as regards the question of mitigation and adaptation to climate change.

2.1 Heatwave hazards and climate change

Long-duration heatwaves and prevailing warmth for annual conditions are becoming increasingly likely because of a warming planet. Heatwaves represent a real risk to vulnerable population. Significant increases in the risks of extreme heat are projected under all scenarios of climate change. There is a well-established relationship between extreme high temperatures and human morbidity and mortality (The Lancet Commission, 2015; Koppe et al. 2004).

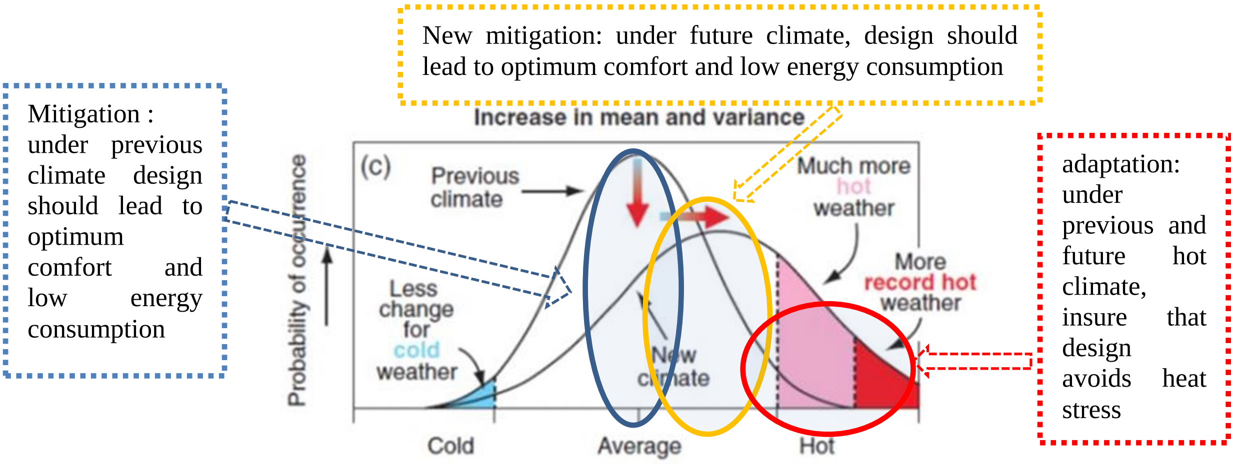
The effects are worsened by the urban heat island effect, which results from greater heat retention of buildings and paved surfaces, compared with transpiring, shading, and air-flow promoting vegetation-covered surfaces. Today, a quarter of the French population is aged over 60, and three-quarters of the population live in urban areas. In next decades, ageing population and urban life will increase, leading to an increased risk of heat-related death.

The 2003 heatwave in Europe killed up to 70 000 people (Kovats and Hajat 2008). It is estimated that it caused 14 800 excess deaths in France (Hémon and Jougla, 2004). The 2006 heatwave in France caused 2 000 excess deaths in a 18-day period, the 2015 heatwave caused 3 300 excess deaths in a 26-day period. Today, French people are better prepared to deal with significant heatwaves. Despite the prevention measures, the impact of heatwaves remains significant and demands the continuation of all the work achieved.

Five kinds of heat-related health factors are considered in literature (Laaidi et al., 2015): environmental factors (urban density, building construction quality,…), socio-demographic factors (age, specific population, …), health factors, social factors, behaviour factors (inadequate clothing, reduced mobility,…).

Following the 2003 heatwave, a case-control study has shown that for people who lived at the top floor of an uninsulated block of flat, the risk factor was multiplied by 4 (Ribéron et al., 2006). Other factors, such as window number and the inability to create draughts by cross ventilation were associated with increased death rates (Vandentorren et al., 2006).

This history explains strong apprehensions about climate change. But to understand consequences on thermal comfort and heat stress in buildings, average annual temperature on a national or world scale is not comprehensive enough. Indeed, to estimate comfort or energy consumption, to design or to define operating limits, different weather sequences must be selected based on probability of occurrence. The following figure shows a probability distribution of outside daily temperatures during a nowadays typical year, called previous climate, and a projection of a future one, called new climate.


Mitigation : under previous climate design should lead to optimum comfort and low energy consumption

New mitigation: under future climate, design should lead to optimum comfort and low energy consumption

adaptation: under previous and future hot climate, insure that design avoids heat stress

Figure 1: schematic showing the effect on extreme temperatures when both the mean and variance increase for a normal distribution of temperature (Folland, 2001)

Long term objective aim is to link two areas from average to hot weathers:

- The average one, with a high frequency, concerns notably mitigation. Indeed, buildings under it should lead to optimum indoor thermal comfort with low energy consumption.
- The hot one, with a low frequency, concerns mostly adaptation. It is too rare to be used for building design. Should these hot weathers happen, which occurs more often in urban heat islands, estimating indoor thermal conditions would be necessary to avoid danger.

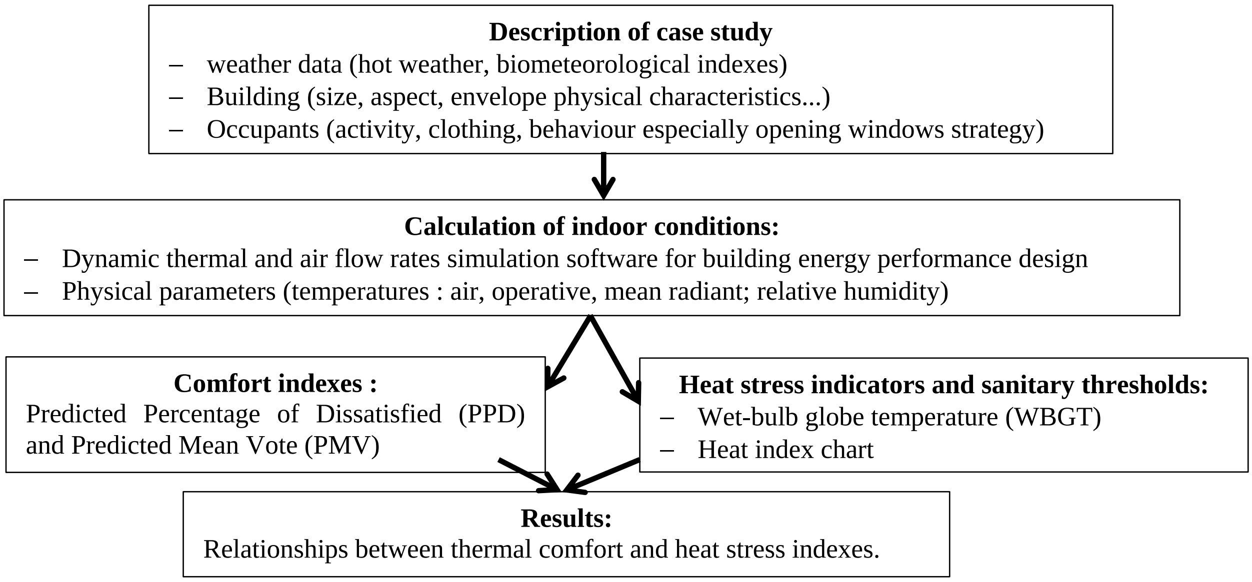
Selected weather is previous extreme hot climate, in the pink area. It also gives an idea of future design conditions. As stakes, objectives and study boundaries are known; an overall overview of the methodology can be drawn.

2.2 Methodology main steps

They are introduced in figure below. According to the long term goal, available tools for building designs are mainly standards related to:

- energetically performant building for meteorological data and calculation methods,
- ergonomics of the thermal environment for comfort and heat stress.

ISO 15265 (2004), deals with risk assessment strategy for the prevention of stress or discomfort, but it cannot be used because, firstly, it concerns usual situations not designed ones. But recommendations from this standard are used when possible.


Description of case study

- weather data (hot weather, biometeorological indexes)
- Building (size, aspect, envelope physical characteristics...)
- Occupants (activity, clothing, behaviour especially opening windows strategy)

Calculation of indoor conditions:

- Dynamic thermal and air flow rates simulation software for building energy performance design
- Physical parameters (temperatures : air, operative, mean radiant; relative humidity)

Comfort indexes :

Predicted Percentage of Dissatisfied (PPD) and Predicted Mean Vote (PMV)

Heat stress indicators and sanitary thresholds:

- Wet-bulb globe temperature (WBGT)
- Heat index chart

Results:

Relationships between thermal comfort and heat stress indexes.

Figure 2: chronological sequence with basic steps of the methodology

2.3 Biometeorological indicators IBM

In order to improve the heatwave response, the French Minister of Health developed a National Heatwave Plan (NHP) in 2004. The NHP defines actions aimed at preventing the health impact in episodes of extreme heat. It includes recommendations for different stakeholders: health professionals, key actors in the social sphere, etc. The NHP includes a Heat Health Watch Warning System (HHWWS) (Laaidi et al., 2013). HHWWS has classified NHP actions according to four levels:

- Seasonal vigilance, continuously activated from 1st of June to 30th of September,
- Warning level, when the thresholds are to be reached within three days. Preparation for staggered implementation of the preventive measures detailed in the NHP,
- Heatwave alert, when the thresholds are reached. Implementation of the appropriate sanitary and social measures,
- Maximum mobilization level, when the thresholds are reached and when the heatwave tends to last or when exceptional conditions are met.

The HHWWS was developed on the basis of retrospective analysis of mortality and meteorological data in fourteen pilot cities representative of the different climates of mainland France (Laaidi et al., 2013). Several heatwave indicators were tested in relation to levels of excess mortality. An indicator that mixes minimum and maximum temperatures was chosen. Excess mortality levels were set at 50% for Paris, Lyon, Lille and Marseille and at 100% for the other smaller cities. The indicator is therefore the pair (IBMin, IBMax) where IBMin is the sliding mean over three days of minimum temperatures, and IBMax the sliding mean over three days of maximum temperatures. The HHWWS is regularly assessed, and updated annually (Pascal et al., 2006).

2.4 Occupants' behaviours

Indoor thermal environment is strongly impacted by occupants. Metabolic water vapour and heat production depend on activity. Moreover, opening window strategy, solar shading running and the way appliances are used are deeply linked to occupants' behaviours. Thus, building occupation is needed to predict indoor temperature and humidity. Behaviour scenarios are better reliable when done in cooperation with building project stake holders. In this paper, given scenarios are close to those used in French thermal regulation (J.O., 2013).

2.5 Thermal and air flow rates models

Indoor environmental conditions are calculated with a dynamic thermal model linked with a mass air flow balance one, including large opening windows, so called COMETh (Videau et al., 2013). This integrated model is used by French thermal regulations since 2000 (Da Silva et al., 2016a; Da Silva et al., 2016b), first for summer thermal comfort then for heating, cooling, ventilation, sanitary hot water and lighting consumptions. It is acquainted to thermal design engineers at a national scale. COMETh can calculate indoor environment conditions for different occupants' behaviours and under different climates.

Thermal model has been successfully compared to EN 15265 standard (2008) and to ASHRAE 140 Standard (ASHRAE, 2001). Thermal balance is computed with a 5RC equivalent electric representation of the building components, similar to ISO 13790 (2013) simplified model. It gives air (T_a), mean radiant (T_{rm}) and operative temperatures (Top) at each hourly time step. Radiant internal heat exchanges are based in the Walton radiation model (Walton, 1980). Solar radiations are absorbed by walls, which is in accordance with black globe temperature. Then Top is obtained with usual equation:

$$\text{Top}= \frac{Ta+Trm}{2} \qquad (1)$$

The air change rate is calculated according to the De Gids and Phaff air flow model through large openings (De Gids and Phaff, 1982). It gives a general expression for the ventilation rate

Q through an open window as a function of, ΔT, temperature difference between inside and outside, U_{wind}, wind velocity and fluctuating terms:

$$Q = \frac{A}{2} \times \sqrt{C_1 U_{wind}^2 + C_2 H \Delta T + C_3} \tag{2}$$

Where A is area of the window opening, H is height of the opening, C_1 is a dimensionless coefficient depending on the wind, C_2 is buoyancy constant and C_3 is turbulence constant. This model has been used for the IEA Annex 20 research works especially for single-sided ventilation studies (IEA, 1992). It has been used in the calculation method for the French thermal regulation since 2000 (J.O., 2013) and in the European standard dealing with calculation methods for the determination of air flow rates in buildings EN 15242 (2007). For humidity balance, in and out dry air flow rates are supposed equal. Without cooling systems absolute humidity variation is given by next equation.

$$\frac{dw}{dt} = \frac{\sum Q_{in}(w_{in} - w_{ex}) + internal\ Latent\ loads}{V\rho_{indoor}} \tag{3}$$

Q_{in} is incoming air flow rate, w_{in} is incoming air absolute humidity, w_{ex} is absolute humidity exhausting from dwelling, internal latent loads (kg/s), V is dwelling volume and ρ_{indoor} is indoor air density. w_{ex} is assumed to be equal to absolute humidity within dwelling.

A Cranck Nicholson method is used to link thermal and air flow models. Time step result is the average between end and beginning time step solutions. Solution at the end of previous time step is assigned to beginning of next time step. Thus temperature beginning value is used to calculate air flow rate through windows and humidity balance at time step end.

Models assume indoor temperature and humidity are spatially homogenous and each wall has isothermal surfaces. Radiation balance is done for a cube with same absorption and emissivity for walls. To linearize radiation equation inside wall temperatures must be close. According to these assumptions only whole thermal feeling can be assessed, effects of draught, vertical air temperature difference or radiant asymmetry are not checked.

2.6 Thermal comfort and thermal stress indexes

ISO 11399 (2001) is used to select two main standards with adjacent scopes:

- ISO 7730 (2006) for moderate thermal environment with predicted mean vote (PMV),
- ISO 7243 (1994) for hot thermal environment with wet bulb globe temperature (WBGT).

Both indexes are consistent with a hourly time step.

Predicted percentage of dissatisfied (PPD) can be obtained from the predicted mean vote (PMV). In this study T_a, T_{rm} and relative humidity (RH) are calculated by the model, while air velocity (V_a), metabolic rate, and clothing insulation are given data.

WBGT index is a weighted sum of natural wet-bulb temperature (t_{nw}) and globe temperature (t_g). For indoor conditions, WBGT formula, without sun loads, is used:

$$WBGT = 0.7\ t_{nw} + 0.3\ t_g \tag{4}$$

WBGT is to be measured. Thus ISO 7726 (2002) is used to establish the link with the thermal model. t_g can be assumed to be equal to Top calculated with the model. To obtain t_{nw}, natural wet-bulb temperature, Malchaire (1976) formula is used:

$$(t_{nw} - t_{wb}) = \frac{0.16(t_g - t_a) + 0.8}{200}(560 - 2RH - 5t_a) - 0.8 \tag{5}$$

He specifies that a good accuracy is obtained for V_a below 0.15 m/s. As before, Top is assumed to be equal to t_g. All parameters are calculated by the model except t_{wb}, psychrometric wet-bulb temperature. According to psychrometric chart, t_{wb} is the cross section of continuous enthalpy curve and air saturation one. Enthalpy is calculated with t_a and RH, given by the model.

2.7 How to read results

The aim is to find a design running the limits of naturally ventilated dwellings. It also includes balance between mitigation building design and solutions for adaptation to climate change. The figure below presents increasing health risk versus increasing discomfort. Safety indoor environment is on the left and unsafe one on the right. Blue arrows show the way proposed to design building in order to save energy and provide occupants health.

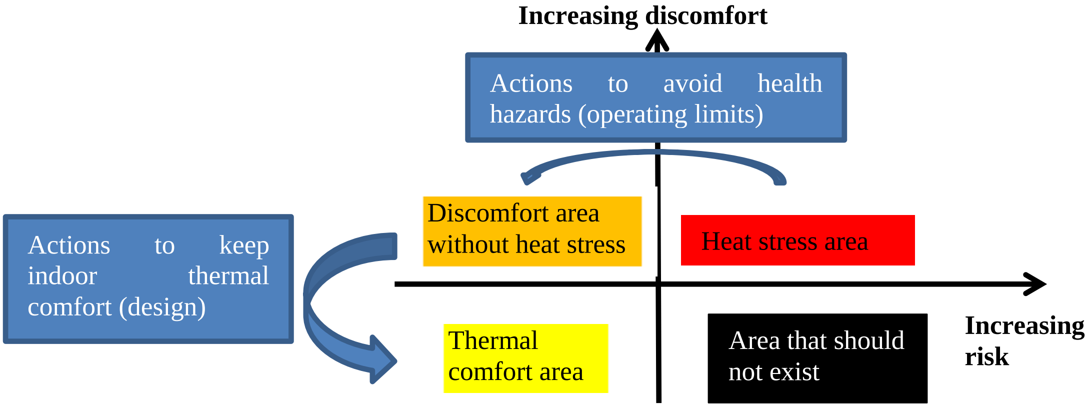


Figure 3: arbitration between thermal comfort and health risk

In reference to automotive segment, after a crash test occupants are expected to be safe. On the same idea, under a heat stress test, dwelling is supposed to protect people from health hazards. Thus attempted indoor thermal conditions are not the same under extreme and common weathers. Solutions, which guarantee comfort under usual circumstances – from the top left area to the bottom left one - should also protect occupants from health hazards under extreme events, from top right area to top left one. The crossing dot, at the border between thermal comfort and heat stress, is needed to apply the methodology. A practical approach through a specific situation is used to find it.

3 CASE STUDY AND RESULTS

Dwelling characteristics, climate conditions and occupants' behaviours selected for numerical simulations are given as following.

3.1 Simulation conditions

Without future climate data available for the numerical model (a set of 8 meteorological parameters with an hourly time step), a real heatwave episode is chosen according to HHWWS (§2.3). The chosen 7-days period is during July 1999 in Hautes-Alpes district in France. Table below sums up IBM thresholds and daily values.

Table 1: IBM thresholds and daily values during selected heat wave

IBM	Thresholds	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
IBMin (°C)	18	20	20	19	18	18	19	20
IBMax (°C)	33	33	33	33	33	33	34	36

Internal heat loads and humidity production are given according to people activity. Three occupants are supposed present in the dwelling all day long, awake from 8AM to 11PM. At each hourly time step, appliances loads range from 8 to 12 W/m² during waking time. Clothing insulation is equal to 0.6 clo. Metabolic data are selected in order to match with ISO 7730 (2006) and ISO 7243 (1994) scopes. A 1.2 met is selected for occupant assuming a sedentary activity. In the model, body's water vapor losses are not indoor temperature dependent. For each occupant, a 85 g/h metabolic vapor production is used. It matches with a sedentary activity under a 28°C (Recknagel, 1995).

A three-room middle floor dwelling, without air conditioning system, is selected. It has a 68 m² area and a 170 m^3 volume. It is a one single-sided ventilated dwelling mainly south orientated. Insulation and airtightness levels, recommended in Effinergie guidebooks (2008) are used. A 0.19 W/(m².K) U value is used for walls and for stairwell partition wall a 0.3 factor is applied. External insulation and concrete structure lead to heavy inertia. Each wall thermal capacity is calculated with ISO 13786 (2008). Th-I, French professional rules (CSTB, 2012) is used to obtain dwelling thermal capacity, i.e. the C value of the thermal model. For a square meter living space it reaches 264 Kj/(K.m²). Windows characteristics are selected with Th-S French professional rules (CSTB, 2012). Solar shadings are always used. Details are presented in table below.

Table 2: walls size and thermal charateristics

Orientation	Area (m²)	Uw (W/(m².K)	Solar factor		Description
			Sw1	Sw2	
South	8.26	1.6	0.08 short wave radiation	0.05 long wave radiation	4/16/4 double glaze, low emissivity glass, argon filled gap, outside clear color solar shading, 0,2 solar transmission rate
North	2.73				

The mechanical ventilation system provides an air renewal of 0.3 air change per hour (ach). Building envelope airtightness leads in calculation to an infiltration air flow rates lower than 0.1 ach. Southern windows are open when outside temperature is below indoor one, which is supposed to be cooling optimal strategy. Northern windows are never open. Air flow rates through windows are calculated according De Gids model (1982) with a 1.5m height of the opening and 3 opening windows areas of 0, 1 and 5 m².

3.2 Results

Table below gives air flow rates and indoor temperatures during the last three days of the heatwave, when outside night temperature is above 20°C.

Table 3: indoor temperatures and air flow rate during the last three days of a heatwave

Opening windows airing	Opening windows area (m²)	ach max	Top min-max (°C)	Outside T min-max (°C)
No	0	0.4	39 - 41	20 - 37
Low	1	2	30 - 34	20 - 37
High	5	10	26 - 31	20 - 37

In these simulations, opening windows, at relevant time, is needed to avoid heat stress. Wide opening window increases ventilation rate. Then maximal and minimal Top can be lowered, respectively, by 10°C and 13°C. To understand better interaction between natural ventilation and indoor environment, indoor temperatures courses are represented in figure below Green round spots represent Top for a high flow rate (black line) and purple crosses concern Top for a low flow rate (dotted purple line).

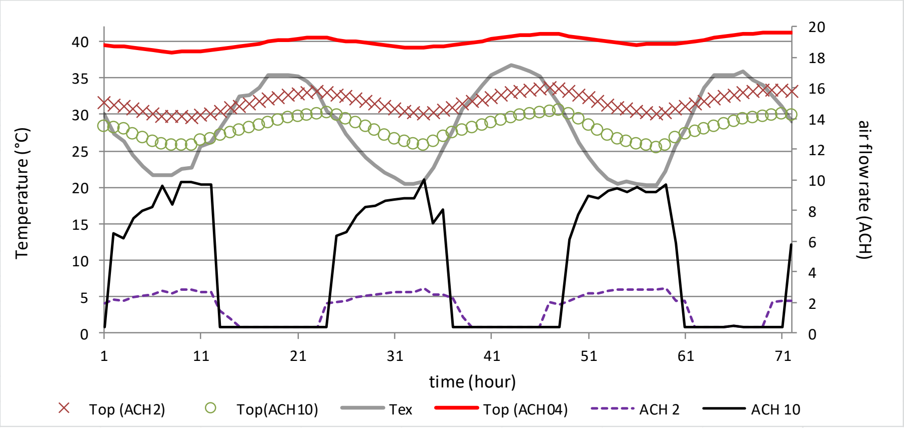


Figure 4: air change rate (ACH) and outside temperature impact on indoor temperatures under the last 3 days of a heatwave.

High and low ventilation rates, lead to the similar temperatures course. In tested situation, a 10 ach air change rate reduces Top by about 4°C as compared to the one reached with 2 ach. High ventilation reduces the gap between indoor and outside night temperatures (full grey line). Then heavy inertia sustains Top 6°C below outdoor maximal temperature. In this case, natural ventilation is efficient to reduce temperature. Nevertheless is indoor environment comfortable or does it cause a heat stress?

Main parameters run in recommended ranges of ISO 7730 (2006). Assumptions to calculate PMV are: V_a under 0.1 m/s, 1.2 met and 0.6 clo. A 0.1 m/s V_a may underestimate effective velocity in a high ventilated dwelling and thus over estimate PPD in this situation. This protective value is used, since indoor V_a profiles is not estimated. These assumptions are also used to select threshold proposed for WBGT; for not acclimated people ISO 7243 (1994) recommends not to exceed a 29°C WBGT. Each index is then calculated during waking period. Table below resumes main results relative to thermal comfort and heat stress. At several times, T_a and T_{rm} exceed comfort standard recommended limits. When it happens letters O.R. are added after concern PMV and PPD values in table below.

Table 4: indoor thermal comfort and heat stress indexes during last three days of a heatwave

ach	**PMV**	**PPD (%)**	**WBGT (°C)**	**Globe T (°C)**	**T_{nw} (°C)**	**RH (%)**
max	**Min - Max**	**Min - Max**	**min-max**	**min-max**	**min-max**	**min-max**
0.4	>2(O.R.) - >2(O.R.)	100(O.R.)-100(O.R.)	29 - 31	39 - 41	24 - 26	23 - 32
2	1.3 - >2(O.R.)	42 - 96 (O.R.)	23 - 26	29 - 34	19 - 24	25 - 47
10	0 - 1.7	5 - 60	20 - 25	24 - 31	17 - 23	32 - 57

For 0.4 ach, indoor environment conditions are strongly deteriorated and WBGT awareness limits are exceeded. With wide opening windows case (10 ach max), indoor conditions are kept, most of time, in moderate thermal environment according to standards. Calculated WBGT is significantly lower than standard proposed limits. In those both contrasted situations ergonomics standards indexes are reliable. In order to study boundaries between comfort and heat stress, PPD is plotted versus WBGT for the low ventilation test case on the figure below. Both indexes are calculated during the seven days heatwave.

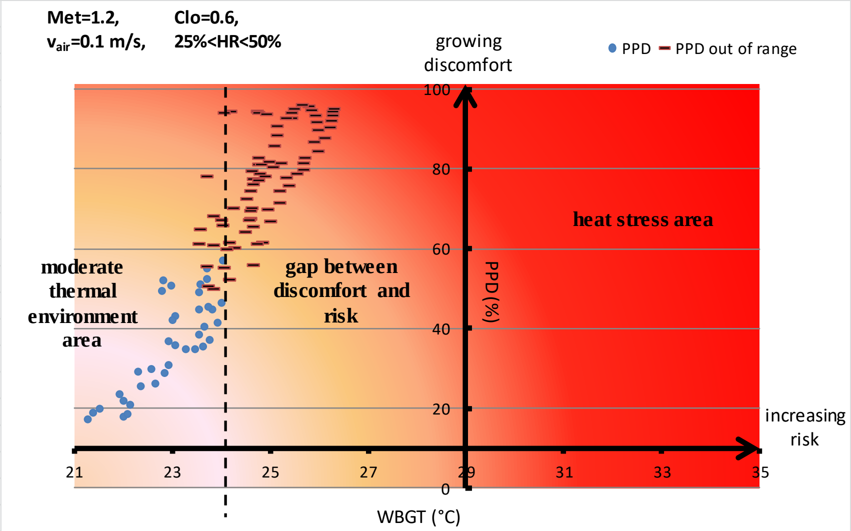


Figure 5: PPD versus WBGT calculated for a low natural ventilated building (2 ach) under a 7-days heatwave

Red dashes mean that PPD is calculated out of standard recommended range. According to ISO 7730 (2006), situation is never comfortable. Indeed, PMV is always above +0.5 with a percentage of dissatisfied over 10%. For a PPD above 50%, according to our assumptions, moderate thermal environmental area is exceeded. Numerous red dashes mean that indoor environment is often over moderate thermal environment limits. But it is also below heat stress according to 29°C WBGT limit and thus no specific supervision is required. There is a gap between areas for moderate environment and heat stress. With a 34 °C t_g (Table 4), it is hopeful to say that situation is healthy. When 32°C is exceeded, ISO 15265 (2004), in its observation scale, recommends preventive steps. Thus in this particularly situation the gap, between both standard indexes, is too large to check if indoor environment is safe.

3.3 How to bridge the gap between thermal comfort and heat stress?

Excepted human factor - WBGT was invented in the 1950s to avoid heat illness in US Army (Budd, 2008) -, two physical parameters, V_a and RH, are striking. G.M. Budd (2008) explains that evaporation impact increases with temperature. Yet, t_{nw} weight factor is set at 0.7 in WBGT. Under quite dry environment (25-47% RH) studied, at the border of moderate thermal climate, dry temperature weight factor (set at 0.3) should increase and lead to increase WBGT in the tested situation. WBGT gives no indication of air velocity reduction effects. Because it was developed for outside environment, V_a that led to set WBGT safety thresholds were probably higher than those in our study. Yet, heat resilience is strongly reduced at low V_a because of reduction of air potential evaporation (Budd, 2008). For indoor environment without wind, existing WBGT limits might be reduced.

Many of detailed relationships between indoor thermal climate and human health are poorly understood in epidemiological terms. Goromosov (1968) investigated influence of indoor climate on human health. He proposed to use a combination of methods, including study of indoor climate, physiological investigations, and statistical study of thermal conditions. He carried out studies in apartments under hot climate (outdoor temperatures ranged from 35°C à 38°C). Outcomes suggested that people feel ”comfortable” for 25°C indoor temperature associated to a 65 beats/min heart rate (HR). They feel ”warm” for 27°C (HR=68 beats/min), “hot” for 31°C (HR=72 beats/min) and “hot and oppressive” for 34°C (HR=74 beats/min).

Weihe reviewed health impacts of adverse thermal conditions. A 17°C to 31°C acceptable range for thermal comfort neutrality without impacts on health is defined. Then symptoms of discomfort and health risks are listed; such as fatigue, inappetance, hyperthermia, for temperatures higher than 31°C, health effects are heat stroke and heart failure for temperatures significantly higher than 31°C. (WHO, 1987, WHO, 1990).

The Heat Index Chart (HIC) developed by the US, National Oceanographic and Atmospheric Administration (NOAA, 1985) gives, according to temperature and humidity, physiological disorders in case of prolonged exposure to heat. Health effects are classified in four levels: caution level (fatigue), extreme caution level (muscle cramps, physical exhaustion), danger level (heatstroke possible), extreme danger level (high risk of heat stroke). For a sedentary activity (circa 1.2 met) and a light clothing (circa 0.6 clo), thermal comfort indexes show that comfort requirement is met as far as Top does not exceed circa 26°C. Arrow below draws continuum from thermal comfortable area to severe conditions with adverse health effects.

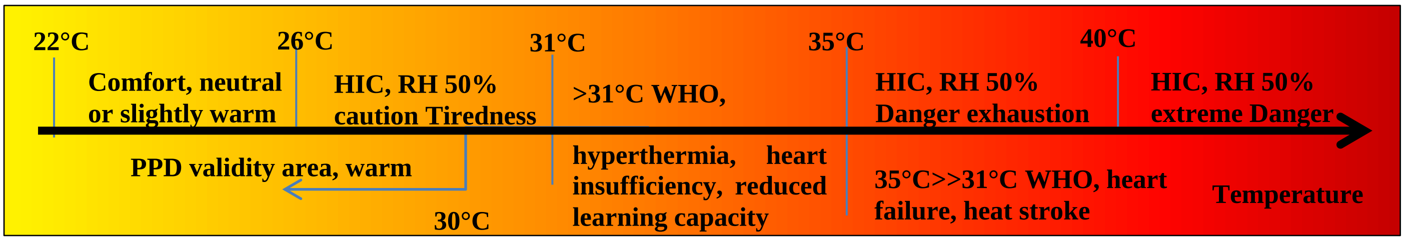


Figure 6: comfort and health continuum in warm and hot climates

For a given thermal stress physiological responses are variable, thus it is difficult to predict with accuracy an individual response.

4 CONCLUSIONS

Air temperature can be significantly reduced with natural ventilative cooling at relevant period, which occurs mostly at night, if outside temperature is below indoor one. In case study, natural ventilation avoids health risk upon ISO 7243 (1994), but doesn’t meet moderate comfort requirement upon ISO 7730 (2006). Strong air flow rate makes it possible to turn from hot to warm situation upon ISO 7730 (2006) with a PMV below 2. WBGT is attractive because it can be obtained with environment physical parameters. But a gap exists between ISO 7730 (2006) legitimate domain, for PPD calculation, and WBGT thresholds, proposed in ISO 7243 (1994). It can be explained by discrepancies between standard experimental conditions to quantify indexes. Indexes concern healthy people but WBGT was invented for US Army for probably more resistant people. Humidity weight given in WBGT seems too strong to match with moderate thermal environment limits. Moreover, WBGT thresholds appear too high for low air velocity. The observed gap attests difficulties to match indoor physical parameters and body physiological ones.

Standard indexes, consistent with building thermal models and literature thresholds, help to build a first step toward a continuum between thermal comfort and heat stress. But only healthy people under sedentary activity have been selected to bridge the gap. Investigations could be enlarged to vulnerable people and different metabolism. Moreover, situations could be tested under milder climate conditions at the HHWWS “warning level”, to check ability of naturally ventilated dwelling to protect people from thermal stress.

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