THERMAL COMFORT AND EPB IN RESIDENTIAL BUILDING: A COMMENTED CASE STUDY IN RAVENNA, ITALY

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ABSTRACT

The aim of this paper is to investigate the relationship between Indoor Environmental Quality index (IEQ): thermal comfort index and indoor temperature trend in moderate thermal environments, in buildings that belong to the Class A with reference to the Energy Performance of Building Directive (EPBD).

The work consists of the measurement of IEQ and energy efficiency in a residential building located in centre-north of Italy. The results of the measurements, as well as the PMV-PPD indexes are presented and commented. These indexes could be a criteria to test if EPBD labelling building could be coherent with EN 15251 requirements.

INTRODUCTION

High-energy performance buildings are able to save primary energy and reduce CO_2 emission. The EU energy policy in buildings sector, including technical solution and legal procedures, aims to improve energy performance of building and to guarantee human comfort.

The aim of the Energy Performance of Building Directive 2002/91/CE is to reduce the energy consumption in building sector (responsible of the 40% of energy consumption in EU), by means of:

- minimum level of energy requirements in new building;

- energy performance requirements and energy retrofit of existing building;

- energy labelling: energy certificate of building, that should inform and influence the retail market operators.

Several solutions could be used to reduce energy consumption; the easiest would be to reduce the indoor temperature for saving energy for heating plant. However, this solution does not represent a proper solution because energy saving should guarantee a minimum level of indoor environmental input parameters (Yang K.H. et al., 1997).

The standard UNI EN 15251 defines indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

THERMAL COMFORT AND STANDARDS

The thermal comfort parameters fixed by law, in Italy, concern air temperature and relative humidity.

However, thermal comfort depends on several kind of parameter:

• metabolic activity, measured in Met, as in UNI EN ISO 8996;

• clothing, measured in Clo, as in UNI EN SO 9920;

• PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied), as in UNI EN ISO 7730.

The UNI EN ISO 7726 defines the measurement procedures of all these parameters.

The numerical simulation of environment (or energy) sin some specific cases allow to evaluate the trend of air temperature, radiant temperature, human body adaption and thermo regulation, in connection with geometrical and thermo physics data input. Some examples of thermal adaption standards and software are reported in Brager. et al, 1998; Stewart T. , 1995; and Olesen B.W.,1995.

The relations between health and comfort have been studied since 80s: "*The WHO (World Healthy Organization) concept of health, became significant for identifying the concept of a ''healthy building'' in terms of building performances (i.e., indoor air quality, thermal comfort, lighting quality and acoustics)"*. […] "*The health and comfort indicators available today can be looked up from: - The occupants or end-user: such as sick leave, productivity, number of symptoms or complaints, health adjusted life indicators, specific building related illnesses"* (Bluyssen P.M, 2010).

The studies and standards about Indoor Air Quality (IAQ) describe chemical and biological pollution of indoor air. In the other hand the Indoor Environmental Quality (IEQ) studies (Fisk W.J. et al. 2007; Adan O.C.G., 1994, European Commission, 2005) and standard prEN 15643 part 1 and 2, 2008; ISO/TS 21931-1, define some parameters: thermo-physical, lighting, acoustic and IAQ.

Ashrae standard

Thermal environmental comfort is as individual sensation, but could be defined by standard.

The American Society of Heating Ventilation and Air-conditioning Engineers (ASHRAE) define the thermal comfort in ASHARE Standard 55:2004 - "Thermal Environmental conditions for Human Occupancy" [17]. The comfort is defined "as the state of mind that expresses satisfaction with the surrounding environment".

In the specific, the indoor parameters that should be controlled and measured are:

- air temperature (dry bulb temperature);
- mean radiant temperature;
- relative humidity;
- air velocity.

The relationship between human body and indoor environment depends on energy and mass exchange, which is necessary in order to maintain homoeothermic balance without human effort. However, each people have a different metabolism rate and physiological behaviour. Therefore, the thermal comfort should be an acceptable approximation.

The PMV model is adopted by the (inter)national standards ISO 7730, ANSI/ASHRAE Standard 55, and EN 15251 (Olesen B.W, 2007). These standards aim to specify the conditions that provide comfort to a majority of healthy building occupants, including older adults (Van Hoof J. et al., 2010).

AIM OF THE PAPER

In this paper a case study about a building in Ravenna, in centre-east of Italy will be described. The building has been built with respect to EBPD and belongs to the best Energy Certification (Class A) in order to promote owner entrepreneur. The design of the building included the use of renewable energy sources: photovoltaic panels and solar collector.

The aim of the paper to know**,** by way of an example, the relation between building energy rating (energy class A following EPBD transposition) and the IEQ classification (UNI EN 15251) which depend on in situ measurement of the indoor parameter.

Comparing other studies about relationship between human comfort, HVAC and building energy performance (Corgnati S.P et al., 2008), in this work a real dwelling building case (and not a models) has been evaluated, with on site measuring devices.

All the measured parameters are referred to UNI EN ISO 7730 and PMV, PPD indexes. They are related to energy performance of building certificate and outside climate data. The energy behavior of building was also evaluated considering two different reference periods, having the HVAC system switched on and off.

THE CASE STUDY

The object of case study measuring is a building realized in 1950 that belongs to a consortium of companies (CEIR) about energy retrofit in Ravenna. The building has two blocks: the first one is on a single level, with a large ground-floor and roof. The second one is on two levels: kitchen and living room on ground-floor and office and meeting room at the first floor (figures 1, 2 and 3).

The covered area is 245.7 m^2, the gross volume is 1111.3 m^3 (V) and the dispersing surface is 745.1 m^2 (S) with a ratio S/V of 0.67.

The load bearing walls could be described as in the following:

For one level ground-floor block wall is composed by: Porotherm™ wall (size 30 cm), 8 cm EPS insulation ($\lambda = 0.031$ W/mK) with wall transmittance U = 0.319 W/m^2K (UNI EN ISO 6946),, 11.67 hours of thermal phase displacement and periodic transmittance YIE 0.03 W/m^2K (UNI EN ISO 13786);

For the two level blocks, the wall is composed by: double brick with 8 cm EPS insulation ($\lambda = 0.031$ W/mK) with wall transmittance U = 0.336 W/m^2K, 7.30 hours of thermal phase displacement and periodic transmittance YIE 0.099 W/m^2K;

The floor pavement is based on soil with transmittance U = 0.254 W/m^2K, periodic transmittance YIE 0.014 W/m^2K.

The reinforced concrete floor on mansard, for two level block, has a transmittance U = 0.250 W/m^2K, periodic transmittance YIE 0,043 W/m^2K;

The roof in wooden structure with 10 cm of insulation has a transmittance U = 0.286 W/m^2K, periodic transmittance YIE 0.483 W/m^2K;

The windows have high insulation performance with wooden frame and insulating glasses with transmittance U_w = 1.20 W/m^2K (UNI EN ISO 10077-1).

The heating and cooling plant are:

- A plan solar collector for domestic heat water (DHW) and space heating;
- A photovoltaic module for electrics production with an incentive rate;
- A heating rate (air-water) cooling power 80.9 kW, EER 2.55 COP 2.85 for heating and cooling;
- A natural gas boiler for heating and DHW;
- Water storage to joint three kinds of energy generation and energy distribution network;
- A radiant heating floor.

The activation of energy generation is in cascade: firstly, one solar collector; if it won't suffice, a heating pump with photovoltaic module, and last a condensing boiler.

After energy retrofitting the building have a energy performance index (primary energy) EP 33.01 kWh/m^2year, evaluated with Italian standard UNITS 11300 part 1 and 2. The Italian standard is a national transposition of UNI EN ISO 13790 with monthly method and UNI EN 15316 part 1 and linked standards for HVAC and DHW plant.

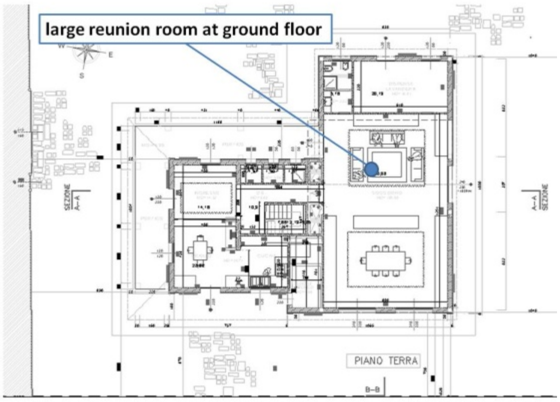

Fig 1 Case study – ground-floor

The building is in energy Class A, with respect to Emilia-Romagna regional Law DAL 156/2008.
In order to evaluate thermal comfort and energy performance of building, it is necessary to explain difference between: "*energy use for space heating and cooling*" and "*primary energy*" results.
The energy use for space heating (Q_h) is 51.20 kWh/m^{2}year, and energy performance index (primary energy) EP 33.01 kWh/m^{2}anno. This is possible with energy efficiency of low temperature HVAC plant and use of energy renewable sources with solar collector and photovoltaic module.

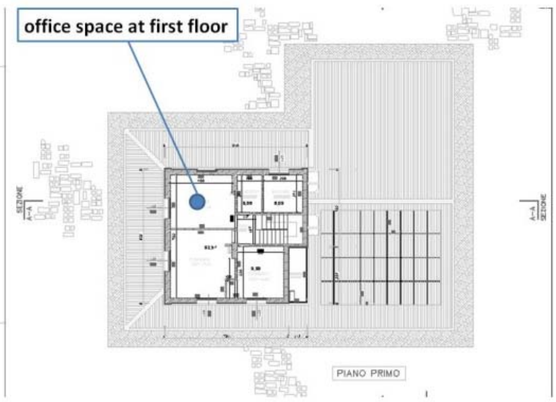

Fig 2 Case study – first-floor

Fig 3 Case study – external view

Fig 4 Measurements with HD32 thermal microclimate.

During the second period of measurement, from 16 to 25 October, the HVAC has stopped for maintenance. The measurement continued to verify building behaviours without energy plant, with respect to the outside weather variations.

DATA RESULT: PMV PPD INDEX

In order to evaluate PMV and PPD, this user data input has been adopted:

- clothes (by ISO 9920):

- Case 1, light dress clothes with: slip 0.04 Clo, cotton shirt 0.1 Clo, long socks 0.03 Clo, shoes 0.05 Clo, cotton trousers 0.18 Clo, long-sleeved shirt 0.29 Clo;
- Case 2, average dress clothes with: slip 0.04 Clo, cotton shirt 0.1 Clo, long socks 0.03 Clo, shoes 0.05 Clo, trousers 0.18 Clo, long-sleeved shirt 0.29 Clo, golf acrylic necklace 0.29 Clo.

- activity (by ISO 8996):

- Case A: sedentary activity 1.33 met (low metabolic rate)
- Case B: normal activity 1.89 met (moderate metabolic rate)

The results are reported in table 1 and 2
The results are refereed at specific case, but we could see the relationships between building wrapped with low energy use for heating (51.20 kWh/m^{2}year), good thermal mass of walls and insulation, and guarantee comfort also without HVAC plant (during 15-25 October).

Table 1 Case 1: results

Activity	Sedentary activity (1,33 Met)			
Clothes	Light dress (0,69 Clo)		Average dress (0,98 Clo)	
Comfort index	**PMV**	**PPD**	**PMV**	**PPD**
large reunion room at ground-floor during 10 – 16 Oct.	- 0.2	5,9	+ 0.2	6.1
	Neutral		Neutral	
office space at first floor during 16 – 25 Oct.	- 1.2	37.5	- 0.6	13.6
	Slightly cool		Slightly cool	

Table 2: Case 2: results

Activity	Normal activity (1,89 Met)			
Clothes	Light dress (0,69 Clo)		Average dress (0,98 Clo)	
Comfort index	**PMV**	**PPD**	**PMV**	**PPD**
large reunion room at ground-floor during 10 – 16 Oct.	+ 0.6	11.6	+ 0.9	20.3
	Slightly warm		Slightly warm	
office space at first floor during 16 – 25 Oct.	- 0.2	5.9	+ 0.2	5.9
	Neutral		Neutral	

DATA RESULTS: MICROCLIMATE MEASURING TRENDS

The results of measuring campaign are reported in figure 2 – 7.

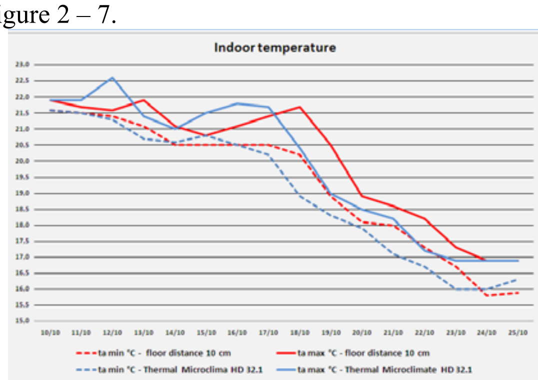

Figure 5 –indoor temperature (°C)

In figure 5 the indoor temperature trends are reported: air temperature (t_a), minimum and maximum day indoor temperature, expressed in °C at 1.20 m and 0.1 measured of distance from floor.
The trend of temperature evidences differences and phase displacements between near floor air temperature to air temperature at 1.20 m.

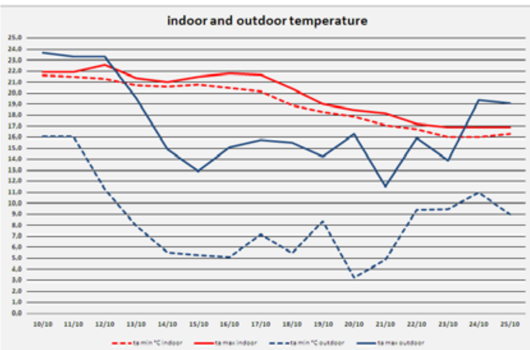

Figure 6 –Indoor and outdoor temperature (°C) trends

During HVAC activation (from 10 to 16 October) the indoor air temperature at 1.20 m increases faster than near-floor-air-temperature, near radiant heating floor. In HVAC deactivation (from 17 to 25) the indoor air temperature trend decreases faster than near-floor-air-temperature. That depends on thermal inertia and phase displacement of heating radiant floor.
In figure 7 and 8 are reported indoor and outdoor relative humidity (%), and correlated with rain precipitation (mm). The indoor relative humidity trends follows outside humidity and precipitation rain. The relative humidity is an important parameter for thermal comfort and PMV PPD index. This comparison evidences the utility of a good airtight of windows frame and a hydro-thermal performance of wall and roof. The internal surface temperature is verified for all structures to avoid critical surface humidity and interstitial condensation with UNI EN ISO 13788.
The range of relative humidity value is between 45% and 65% width.

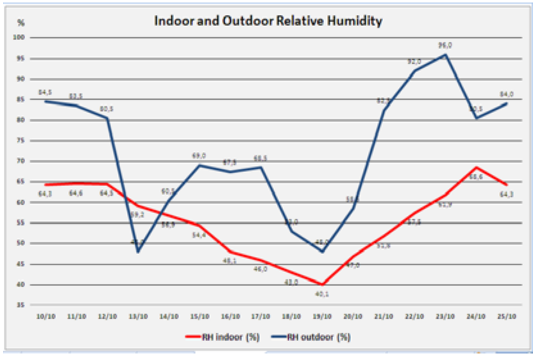

Figure 7 –Indoor and outdoor relative humidity (%) trends

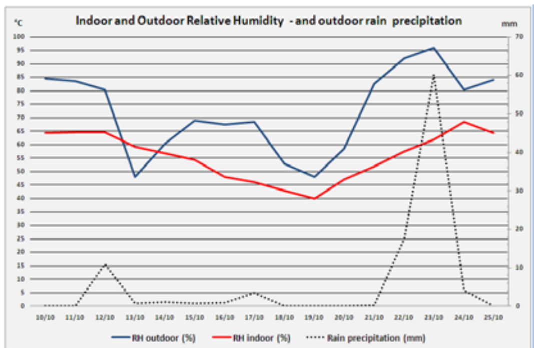

Figure 8 – Indoor and outdoor relative humidity (%) trends with rain precipitation (mm)

The graphics trend evidences the importance of relationship between indoor and outdoor air temperature and time period. The results of index comfort reported in table (1) and (2) are compared to HVAC activation, especially the time variation of microclimate parameters adaption when HVAC is switched off. The time of adaptation of thermal comfort and the indoor microclimate measures represent an important factor, which has an important incidence (J.F. Nicol J.F., et al., 2002).

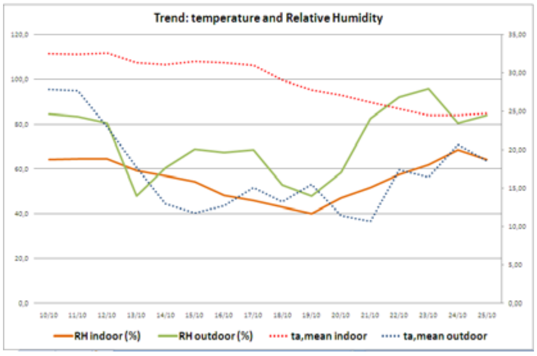

Figure 9 –Indoor temperature (°C) and relative humidity (%) trends

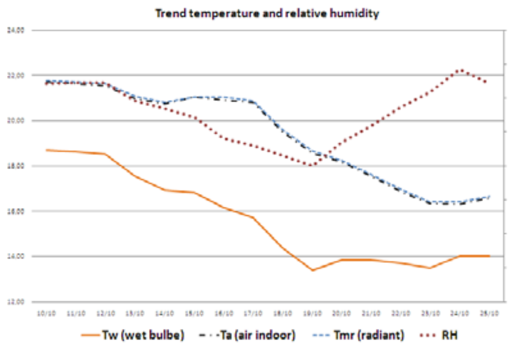

Figure 10 – Indoor parameter trends: wet bulb temperature (°C), air temperature (°C), main radiant temperature (°C) and humidity RH (%)

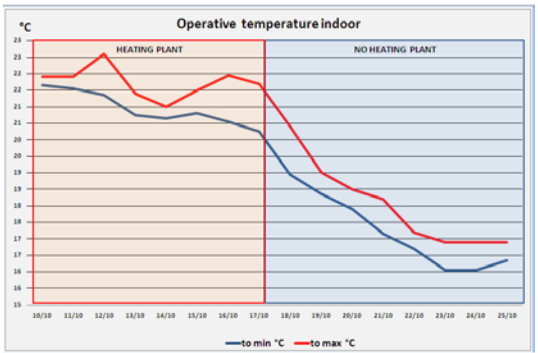

Figure 11 – Indoor minimum and maximum operative temperature with HVAC on (10-16 October) and off (17-25 October)

In figure 11 the indoor operative temperature trends are reported. The operative temperature is defined as the average of air temperature and globe-thermometer temperature, and it is a set-point temperature for HVAC.

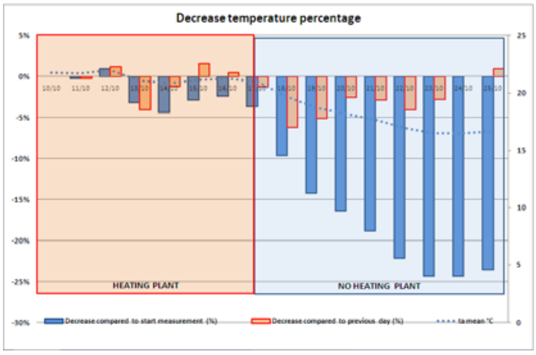

Figure 12 – Graphics 8 Decrease temperature percentage

In figure 12 and in Table (3) we can observe the decrease temperature percentage with HVAC switched off. The decrease respect to initial start measuring operative temperature is 23% but the decrease day-by-day is just 2 - 5%.

Table (3): measurements: results

DATA	t_a mean °C	Decrease compared to start measurement (%)	Decrease compared to previous day (%)
10/10	21,8	0,0%	0,0%
11/10	21,7	-0,2%	-0,2%
12/10	22,0	0,9%	1,2%
13/10	21,1	-3,2%	-4,1%
14/10	20,8	-4,4%	-1,2%
15/10	21,2	-2,9%	1,6%
16/10	21,3	-2,4%	0,5%
17/10	21,0	-3,7%	-1,3%
18/10	19,7	-9,6%	-6,2%
19/10	18,7	-14,2%	-5,1%
20/10	18,2	-16,4%	-2,5%
21/10	17,7	-18,8%	-2,9%
22/10	17,0	-22,2%	-4,1%
23/10	16,5	-24,3%	-2,8%
24/10	16,5	-24,3%	0,0%
25/10	16,6	-23,7%	0,9%

Table (4): IEQ Category following EN 15251 in Case 1

Activity	Sedentary activity (1,33 Met)			
Clothes	Light dress (0,69 Clo)		Average dress (0,98 Clo)	
Comfort index	**Cat.I**	**Cat.I**	**Cat.I**	**Cat.I**
large reunion room at ground-floor during 10 – 16 Oct.**(HVAC on)**	Neutral		Neutral	
office space at first floor during 16 – 25 Oct. **(HVAC off)**	**Cat.IV**	**Cat.IV**	**Cat. III**	**Cat. III**
	Slightly cool		Slightly cool	

Table (5): IEQ Category following EN 15251 in Case 2

Activity	Normal activity (1,89 Met)			
Clothes	Light dress (0,69 Clo)		Average dres (0,98 Clo)	
Comfort index	**Cat.I**	**Cat.I**	**Cat.I**	**Cat.I**
large reunion room at ground-floor during 1(– 16 Oct.**(HVAC on)**	Slightly warm		Slightly warm	
office space at first floor during 16 – 25 Oct. **(HVAC off)**	**Cat.I\'**	**Cat.I\'**	**Cat. III**	**Cat. III**
	Neutral		Neutral	

CONCLUSIONS

The measurement campaign confirms the relationship between thermal comfort condition and high energy performance (energy use value Q_H 51.20 kWh/m^{2}year), therefore a good building insulation with radiant heating floor and also a small-scale o net volume heating, guarantees also a high value of comfort index (“*neutral*” or “*slightly cool*”) also when HVAC is off.

The building evaluation, made following EN 15251 categories and reported in table (4) and (5) assigns Category I “*High level of expectation*” when HVAC is switched on (HVAC-on). This means that energy class A (low energy consumption) could guarantee a high level of comfort.

When the HVAC system is switched off (HVAC-off), the building insulation allows to assign Category III “*Acceptable, moderate level of expectation*” also in case of “*average dress*” condition; whereas in case of “*light dress*” the comfort condition will result not acceptable (Category IV).

The dual evaluation, i.e. energy classification and thermal comfort categories, demonstrate how they are correlated in order to express building quality.

In this case the measurements have confirmed low energy consumption and satisfactory IEQ.

Therefore IEQ could be a useful tool to promote good building in Real Estate market like as energy labeling.

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