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On The Link Between Energy Performance Of Building And Thermal Comfort: An Example

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Abstract. This paper investigates 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 IAQ and energy efficiency in a residential building located in centre-north of Italy, namely Ravenna. 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. In order to optimise energy performance of buildings have been proposed several methods, including exergy evaluation [1], also considering economic evaluation [2],[3].
The aim of the Energy Performance of Building Directive 2002/91/CE [4] 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 [5].
The standard EN 15251 [6] 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 ISO 8996 [7];
• clothing, measured in Clo, as in ISO 9920 [8];
• PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied), as in ISO 7730 [9].
The ISO 7726 defines the measurement procedures of all these parameters [10].

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 [11], [12] and [13].

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*" [14].

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 [15,16, 17] and standard [18,19] define some parameters: thermo-physical, lighting, acoustic and IAQ.

The Ashrae standard

The "Thermal Environmental Comfort" is as individual sensation but could be defined by standards.

The American Society of Heating Ventilation and Air-conditioning Engineers (ASHRAE) defines the thermal comfort in the ASHARE Standard 55 - "Thermal Environmental conditions for Human Occupancy" [20]. 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 behavior. 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 [21]. These standards aim to specify the conditions that provide comfort to a majority of healthy building occupants, including older adults [22].

THE 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 (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 [23], in this work a real dwelling building case (and not a models) has been evaluated, with on site measuring devices, in the framework of a multi scale analysis .that could link operation performance analysis, energy efficiency, demand side management and energy storage technologies [24], [25], [26]

All the measured parameters are referred to 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 and 2).

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 (λ = 0.031 W/mK) with wall transmittance U = 0.319 W/m^{2}K [27], 11.67 hours of thermal phase displacement and periodic transmittance YIE 0.03 W/m^{2}K [28]; The thermal variation of conductivity [29], even though important, has not been considered in this study.

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

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

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

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

The windows have high insulation performance with wooden frame and insulating glasses with transmittance U_w = 1.20 W/m^{2}K [30].

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^{2}year, evaluated with Italian standard UNITS 11300 part 1 and 2 [31]. The Italian standard is a national transposition of EN ISO 13790 [32] with monthly method and EN 15316 – 1 [33] and linked standards for HVAC and DHW plant.
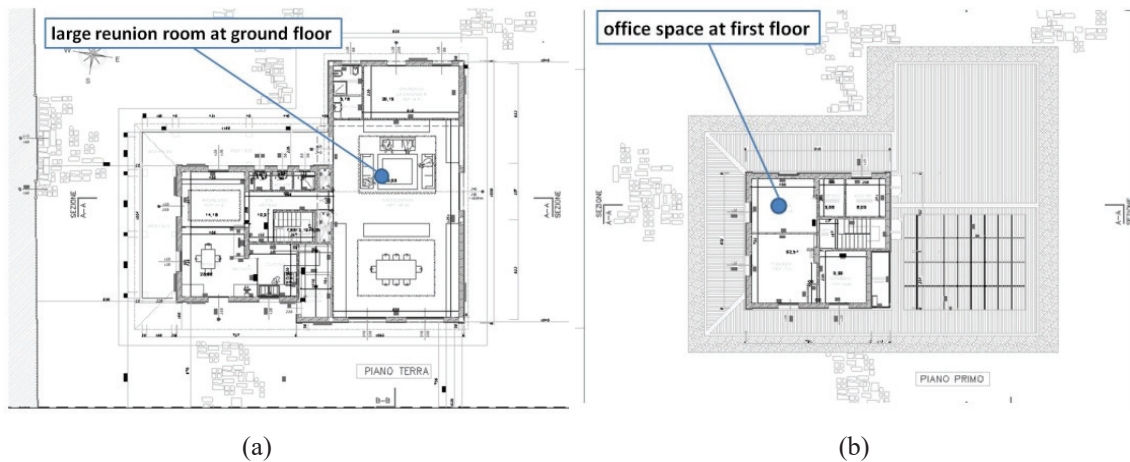

(a)   (b)

FIGURE 1 the case study – ground-floor (a) and first floor (b)

The building is in energy Class A, with respect to Emilia-Romagna regional Law DAL 156/2008 [34]. 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.

(a)   (b)

FIGURE 2 the case study – external view (a) and internal view (b) during the measurements

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}year. This is possible with energy efficiency of low temperature HVAC plant and use of energy renewable sources with solar collector and photovoltaic module. During the second period of measurement, from 16 to 25 October, the HVAC has stopped for maintenance. The measurement continued to verify building behaviors 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 1: 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 the following figures.

(a)   (b)
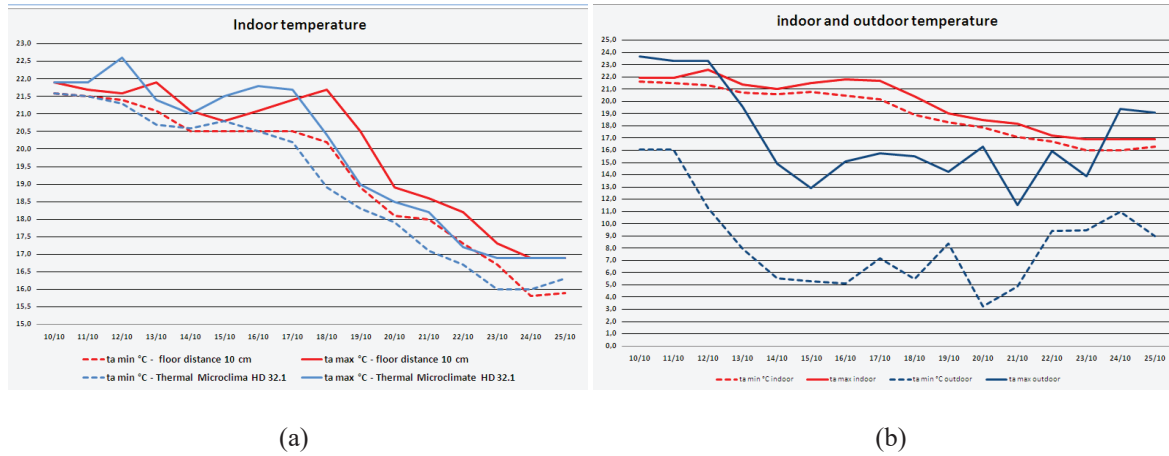
FIGURE 3 (a) indoor temperature (°C); (b) Indoor and outdoor temperature (°C) trends

The trend of temperature evidences differences and phase displacements between near floor air temperature to air temperature at 1.20 m.

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 4 are reported indoor and outdoor relative humidity (%), and correlated with rain precipitation (mm). The indoor relative humidity trends follow 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 EN ISO 13788 [35].

The range of relative humidity value is between 45% and 65% width.

(a)

(b)
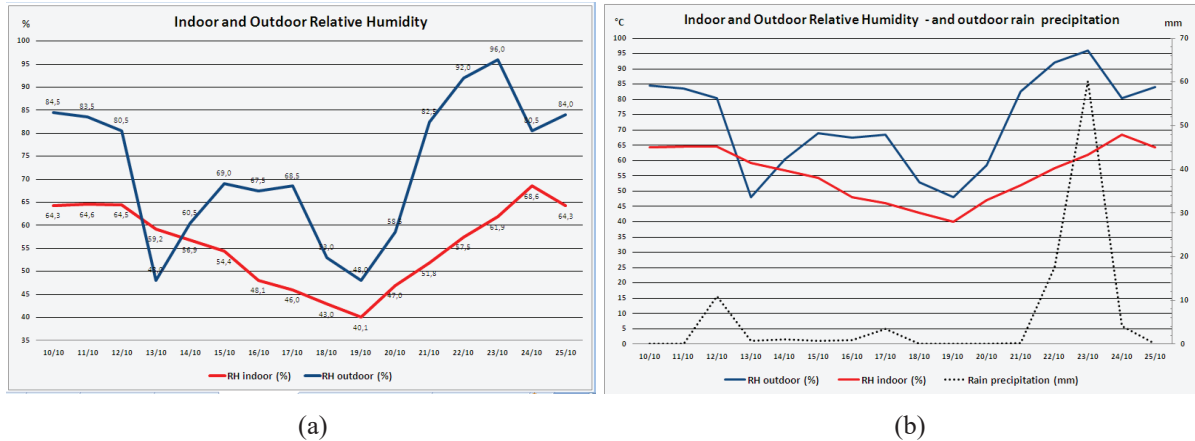
FIGURE 4 (a) Indoor and outdoor relative humidity (%) trends, (b) Indoor and outdoor relative humidity (%) trends with rain precipitation (mm)

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 [36].

(a)

(b)
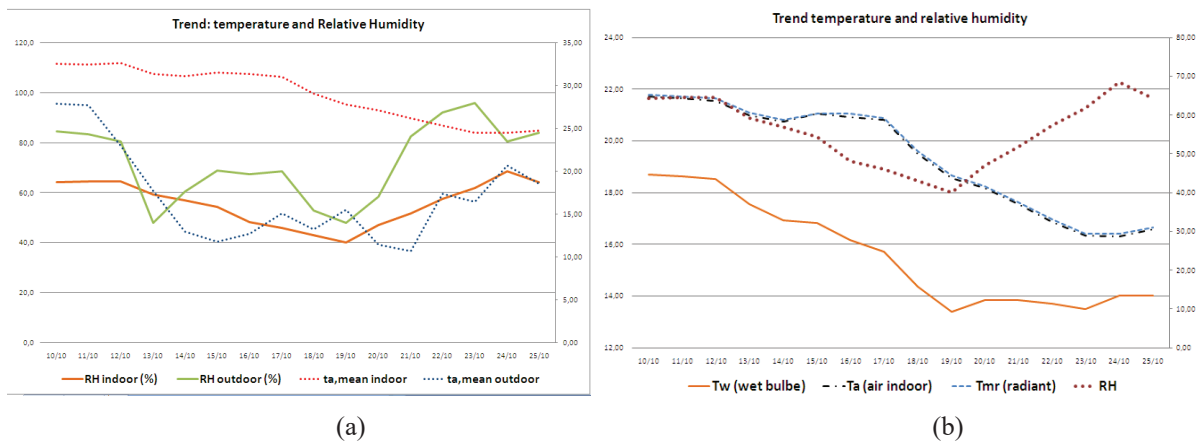
FIGURE 5 (a) Indoor temperature (°C) and relative humidity (%) trends: (b) Indoor parameter trends: wet bulb temperature (°C), air temperature (°C), main radiant temperature (°C) and humidity RH (%)

(a)   (b)
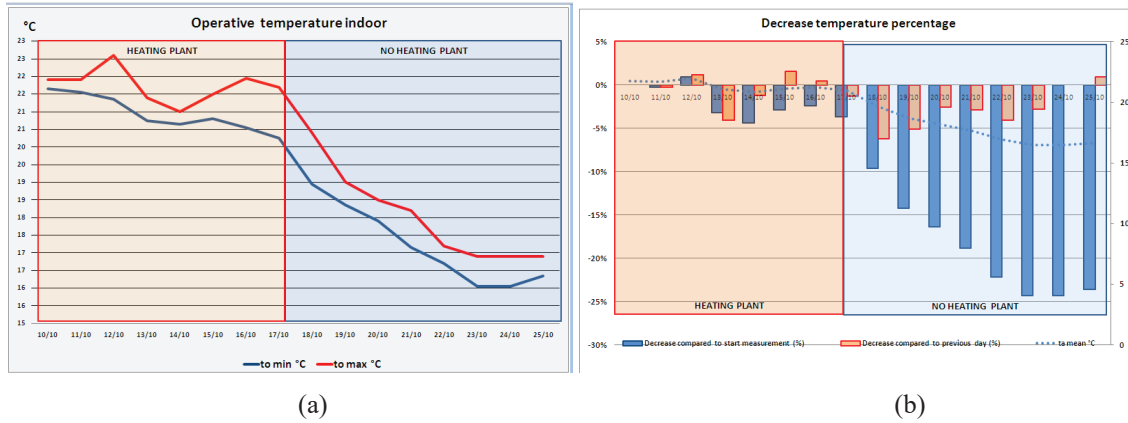
FIGURE 6 (a) Indoor minimum and maximum operative temperature with HVAC on (10-16 October) and off (17-25 October): (b) Graphics 8 Decrease temperature percentage

In figure 6 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 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)**	Slightly warm		Slightly warm	
	Cat.IV	**Cat.IV**	**Cat. III**	**Cat. III**
office space at first floor during 16 – 25 Oct. **(HVAC off)**	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.

ACKNOWLEDGMENTS

REFERENCES

1   L. Tronchin K. Fabbri, International Journal of Exergy, 5 (**5-6**), 605-625 (2008)

2   L. Tronchin, M.C. Tommasino, K. Fabbri, International Journal of Sustainable Energy Planning and Management **3**, 49-62 (2014)

3   K. Fabbri, L. Tronchin, V. Tarabusi, , Energy Procedia, **45** 379-384 (2014)

4   European Union, Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, Official Journal of the European Communities, January 4, 2003

5   K.H. Yang, C.H. Su, , Building and Environment 32 (**1**) 25–30 (1997)

6   EN 15251 "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics"

7   ISO 8996: "Ergonomics of the thermal environment - Determination of metabolic rate"

8   ISO 9920: "Ergonomics of the thermal environment — Estimation of thermal insulation and water vapor resistance of a clothing ensemble"

9   ISO 7730 - "Moderate thermal environments. Determination of the PMV and PPD indices and specification of the conditions for thermal comfort"

10   ISO 7726 - "Ergonomics of the thermal environment - Instruments for measuring physical quantities"

11   G. S. Brager, R. J. de Dear, Energy and Buildings **27,** 83-96 (1998)

12   T. Stewart, Applied Ergonomics 26(**4**), 271-274 (1995)

13   B. W. Olesen, Applied Ergonomics 26(**4**) pp 293-302 (1995)

14   P.M. Bluyssen, Building and Environment **45** 808–818 (2010)

15   W.J. Fisk, Q. Lei-Gomez, M.J. Mendell, Indoor Air 2007;17(**4**) 284–296 (2007)

16   O.C.G. Adan "On the fungal defacement of interior finishes" PhD thesis. Technical University of Eindhoven: The Netherlands; (1994)

17   K. Fabbri, L. Tronchin, Energy Procedia, **78** 2778-2783 (2015)

18   ISO. ISO/TS 21931-1: "Sustainability in building construction framework"

19   EU. M/366: Development of horizontal standardized assessment methods for harmonized approaches relating to dangerous substances under the construction products directive (CPD), Emission to indoor air, soil, surface water and ground water. Brussels, Belgium: European Commission; 2005

20   ASHRAE. ANSI/ASHRAE standard 55-2004, "Thermal environmental conditions for human occupancy. Atlanta, GA, USA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc; 2004.

21   B. W. Olesen, Energy and Buildings **39** 740–749 (2007)

22   J. van Hoof, H.S.M. Kort, J.L.M. Hensen, M.S.H. Duijnstee$_d$, P.G.S. Rutten "Thermal comfort and the integrated design of homes for older people with dementia", Building and Environment 45(**2**), 358-370 (2010)

23   S.P. Corgnati, E. Fabrizio, M. Filippi, Energy and Buildings **40** 627–636 (2008)

24   L. Tronchin, M. Manfren, P.A. James, Energy **165** 26-40 (2018)

25   L. Tronchin, M. Manfren, L.C. Tagliabue, Sustainable Cities and Society 27(**1**) 296-306 (2016)

26   L. Tronchin, Acta Acustica United Acustica **99(1)**, 91-97 (2013).

27   EN ISO 6946 "Building components and building elements - Thermal resistance and thermal transmittance - Calculation method"

28   YIE periodic thermal transmittance calculated by EN ISO 13786 "Thermal performance of building components - Dynamic thermal characteristics - Calculation methods"

29   R. Shimokura, L. Tronchin, A. Cocchi, Y. Soeta, Journal of Sound and Vibration, **330(14)**, pp. 3526-3537

30   EN ISO 10077-1 "Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Simplified method"

31   UNI TS 11300 part 1 "*Prestazioni energetiche degli edifici – Parte 1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale*" (*Energy performance of buildings- part 1 Calculation of Energy use for space heating and cooling*) and UNI TS 11300 part 2 "*Prestazioni energetiche degli edifici – Parte 2: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale e per la produzione di acqua calda sanitaria*"(*Energy performance of buildings- part 2 Calculation of Energy Primary and energy performance for heating plant and domestic hot water production*)

32   EN ISO 13790:2008 "*Energy performance of buildings – Calculation of Energy use for space heating and cooling*"

33   UNI EN 15316-1: 2008 "Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 1: General"

34   DAL 156/2008 Regione Emilia-Romagna "Atto di indirizzo e coordinamento sui requisiti di rendimento energetico e sulle procedure di certificazione energetica degli edifici" (Act of addressing and coordinating the Energy performance requirements and building Energy Certificate procedure – Emilia-Romagna Region Law)

35   EN ISO 13788:2003 Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods

36   J.F. Nicol, M.A. Humpreys, Energy and Buildings, **34,** 563-572 (2002)