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On the necessities to analyse the thermohygrometric perception in aged people. A review about indoor thermal comfort, health and energetic aspects and a perspective for future studies

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ABSTRACT

This study wants to examine the current bibliography concerning the thermohygrometric perception in aged people living in industrialized countries and its socio-economic consequences. Nowadays the number of European people between 70 and 90 years old is increasing, thus causing an aging of the average population. A proper and modern planning of indoor environments in residential buildings requires the presence of a good thermohygrometric comfort together with a low energy consumption level. The most common comfort indexes are the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) provided by Fanger's studies. Aged people present different demands with respect to the planning values suggested by Fanger. In particular, old people tend to live alone with a lower basal metabolic rate than active subjects and they are usually affected by pathologies provoked by the age. Medical studies revealed that pathologies might even be determined by indoor environmental conditions. Hence in order to have actual indoor comfort conditions able to satisfy aged people (especially during winter) different thermohygrometric values are required. This is why a higher energy demand is required and an optimization process should be performed to reduce the costs. Such condition will affect the future welfare of different countries.

1. About the importance of studies dealing with the thermal perception of aged people

The thermal comfort sensation is a psychological and physiological condition expressing the thermohygrometric perception of the human being about the environment (both indoor and outdoor) surrounding her/him (Del Ferraro, Iavicoli, Russo, & Molinaro, 2015; ISO, 2005; Parsons & Kenneth, 2018).

The thermal comfort is a consequence of the thermoregulation that the human body performs with respect to the conditions characterizing the environment surrounding the subject (ASHRAE, 2013a). Part of the energy that the human body produces (M) is consumed by the muscles (W); the rest of the energy (M–W) is dissipated towards the environment through the body skin (Q_{sk}) and the breathing apparatus (Q_{res}) or it can be stored (S), thus causing an increase in the body temperature.

$$M-W = Q_{sk} + Q_{res} + S = (C + R + E_{sk}) + (C_{res} + E_{res}) + S_{sk} + S_c \quad (1)$$

The heat the body dissipates towards the environment occurs through different ways of heat exchange: the sensible heat exchanged through the skin (C + R) due to conduction, convection and irradiation phenomena, the latent heat due to skin evaporation (E_{sk}), the sensible heat affected by the breathing (C_{res}), the latent heat due to evaporation phenomena during the breathing process (E_{res}). The rest of the heat is stored in the skin (S_{sk}) and the body (S_c) (Goromosov, 1968; Ormandy & Ezratty, 2012). This type of energy balance, even though it might seem simple, is actually complex depending on objective data (environmental conditions) and personal or subjective ones as the perception of a sensation (thermohygrometric comfort of a human being) (Golasi, Salata, de Lieto Vollaro, Coppi, & de Lieto Vollaro, 2016; Pisello, Castaldo, Piselli, Fabiani, & Cotana, 2016; Salata, Golasi, de Lieto Vollaro, & de Lieto Vollaro, 2016), not easy to quantify (Hensen,

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1991; Djongyang, Tchinda, & Njomo, 2010; Lin & Deng, 2008).

While focusing our attention on indoor conditions, it must be taken into consideration the fact that the world population, which has been developing since after the IIWW, tends to concentrate in those urban areas with a high density population (UN stated that 70% of the world population will live by 2050 in this type of environment) (POPULATION REFERENCE BUREAU, 2015). In highly anthropized cities, people tend to spend their time in indoor spaces while they perform their daily activities (it is estimated that people spend between 80% and 90% of their time in indoor spaces) (Pérez-Lombard, Ortiz, & Pout, 2008).

After the technological and financial development, the indoor conditions of houses are even more affected by thermoregulation systems functioning according to environmental parameters meant to provide thermal and, when it is financially possible, even hygrometric comfort (Pisello, Castaldo, Piselli, & Cotana, 2017). It seems clear that the comfort issues in indoor environments are highly affected by the functioning of energy-wasting systems which influence the general energy consumption (the civil and commercial sector are responsible for the 16% of the world energy consumption) (Hoyt, Lee, Zhang, Arens, & Webster, 2009; Rupp, Vásquez, & Lamberts, 2015).

The objective factors used to describe the quality of the environmental conditions, besides the air temperature, are the mean radiant temperature of the surrounding surfaces, the relative humidity and wind velocity. However, before stating that an environment has a good comfort level, the air exchange caused by the ventilation (natural or mechanical) must be also taken into consideration (Kingma, Schellen, Frijns, & van Marken Lichtenbelt, 2012).

The thermohygrometric comfort does not depend entirely on the environmental conditions present (which can be defined through objective factors that can be quantified in numbers), but rather it is affected even by subjective elements changing from one person to another which are really difficult to weigh. It is also affected by the type of activity performed, or the type of clothing the subject is wearing (Fanger, 1973; Xiong, Lian, Zhou, You, & Lin, 2016), the general health condition of the person, the adaptation capacity to the local climatic conditions, gender and age (Karjalainen, 2012). This makes more difficult the possibility to have a unique definition of the thermohygrometric comfort. Hensen defined it as “a condition where we are not moved to change the environmental conditions through our behaviour” (Hensen, 1991). The ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) defines it as “the mental condition where we express satisfaction for the thermal environment” (ASHRAE, 2013a). The personal opinion about the thermal comfort is deeply connected to subjective cognitive processes involving variables which are affected by physical, physiological and psychological factors. As a matter of fact and according to the World Health Organization (Ormandy & Ezratty, 2012), the comfort characterizing indoor environments where we live in which highly affects human health (especially some ranges of the population as children and old people) (Sunwoo, Chou, Takeshita, Murakami, & Tochihara, 2006).

1.1. Demographic aging

What is happening is an aging of the world population (Trezza et al., 2015). This phenomenon is due to a longer life expectancy (hence a lower death rate) of those generations living in developed countries going through a baby-boom which started in the past, with a simultaneous decrease in the fertility rate of the newly industrialized countries with a high population level (as China or Brazil) (POPULATION REFERENCE BUREAU, 2015).

The proportions of this phenomenon, especially in those firstly-industrialized countries, became so important that institutions must take care of their consequences. Surveys reported that in 2015 8,5% of the world population was formed by 65-years-old people, with a developing trend able to increase up until 167% by 2050 (He, Goodkind, & Kowal, 2016). In this scenario, Europe will be the continent characterized by the highest number of aged people, who will increase their number from 40 million to 219 million (five times more) (POPULATION REFERENCE BUREAU, 2015), whereas the States by 2030 will have 72 million of over-64-years-old people (20% of the entire population) (Shrestha & Heisler, 2011). Asia, though it is a young continent if compared to Europe or USA (except for Japan which is the “eldest” country in the world), will be considered as the continent with the highest aging rate for the next decades (POPULATION REFERENCE BUREAU, 2015). Table 1 reports briefly the current percentages of over-65-years-old people with respect to the entire population and demographic projections for the next ten years.

Table 1
Incidence of the percentage of the 65-yeras-old population in the world (Population Reference Bureau, 2015).

Region	Population [%]		
	2015	2030	2050
Africa	3,5	4,4	6,7
Asia	7,9	12,1	18,8
Europe	17,4	22,8	27,8
Latin America and Caribbean	7,8	11,8	186
North America	16,1	20,7	21,4
Oceania	12,5	16,2	19,5

In particular, in Italy the aging process is constantly increasing, even though over the past years it has been reported an increase in deaths due to old age and a slight decrease in life expectancy. 22% of the Italian population is formed by people who are older than 65-years-old while, if the attention is focused on over-75-years-old people (a part of the population presenting several issues in terms of health), the percentage is 112% (Demographic indicators, 2016).

This phenomenon will cause deep social changes, both financial and health related (Jay Olshansky et al., 2011; Miller, Vine, & Amin, 2017). It seems inevitable that an increase will occur in the number of subjects affected by chronic pathologies due to age and they will be institutionalized in health-care, structures, with a resulting increase in health expenses (Gerland et al., 2014). Hospitals and nursing homes will be structures destined to give service to bad cases only; hence guaranteeing comfort conditions to aged people in their own houses will be essential, since 65-years-old people tend to spend most of their time in closed environments or similar familiar spaces (Caley & Sidhu, 2011; Mendes et al., 2015). It seems evident that indoor thermohygrometric conditions of those areas will be adjusted according to their needs (Damiani et al., 2009), which are usually different if compared to younger subjects (Ahrentzen, Erickson, & Fonseca, 2016; Basu & Samet, 2002).

1.2. The thermohygrometric perception in aged people

The perception of the same environment variables (which affect the comfort or discomfort in the subjects) can determine different physiological and psychological responses in subjects with different habits, gender, age or geographic origin (Djongyang et al., 2010). The thermohygrometric comfort is deeply connected to a combination of so many factors that trying to find conditions common to every subject would inevitably lead to a high percentage of people experiencing a discomfort (Kuchen & Fisch, 2009). If the goal is to examine the needs of a part of the population, to determine the ideal environmental conditions, the analysis must be performed on subjects with common characteristics. Hence it is important to understand how the body of the aged subject, which statistically presents health issues due to old age, is different from the normotipo which represents (valid from a statistical point of view) transversally the entire population (Hwang & Chen, 2010).

Such normotipo in normal conditions (defined as “resting conditions”) and with a nutritional balance, generates metabolic heat as a consequence of the cellular activity. This will determine an oxygen consumption (O_2) of 186 l h^{-1} (assessed thanks to the hour rate of the air inhaled and to the difference of concentration of the air inhaled and the air exhaled). In these conditions, the normotipo generates about 104 W, that is 58 W m^{-2} (1 met, with a standard surface of the heat exchanged through the body surface area of 1,8 m^2, while sitting with a clothing which is thermally neutral without any other external affecting factor) (ASHRAE, 2013a; Hashiguchi, Tochihara, Ohnaka, Tsuchida, & Otsuki, 2004; Kingma, Schellen et al., 2012).

Different studies show that among aged people these values do not represent a standard subject which is statistically valid due to variations in the metabolism during the aging process (Collins & Hoinville, 1980; Ormandy & Ezratty, 2012). The World Health Organization in 1982 stated that while investigating among the different groups of the population, it was possible to notice a specific touchiness characterizing each group with respect to the range of the temperature values considered as comfort conditions for the normotipo (Hwang & Chen, 2010; Mendes et al., 2013b). In 1986, Collin stressed the different temperature intervals used to define the comfort among those aged people he examined, finding some connections between the increase in the risk of breathing problems and the increase in the temperature of the environment; he also noticed a higher blood pressure in those old subjects standing in spaces they considered to be cold (Collins, Exton-Smith, & Doré, 1981).

Hence it is necessary to investigate deeply in the thermohygrometric preferences of the aged population, in order to determine those ideal environmental features specific for an average subject used as a model for this part of the population (van Hoof, Kort, Duijnstee, Rutten, & Hensen, 2010; Wong, Fong, Mui, Wong, & Lee, 2009). It will be possible to provide specific information (to those working in the field, to engineers and architects) useful to plan indoor environments considered as having a good thermal comfort for aged people (Ahrentzen et al., 2016; Miller et al., 2017; Schellen, van Marken Lichtenbelt, Loomans, Toftum, & de Wit, 2010), while always complying with the regulations about energy saving in buildings.

2. Consistency of the bibliographic research useful for a substantial review on the topic

This study was carried out to investigate, in the field of indoor comfort (main set), which studies analysed deeply the problems concerning the thermohygrometric perception of the population in old age (specific subset) while keeping into consideration the problems it involves, as: how their health responds to spaces with a low comfort level (Roelofsen, 2013; Xiong et al., 2016) and the energy consequences in the buildings to make them more healthy (Salonen et al., 2013; Trezza et al., 2015; van Hoof, Kort, Hensen, Duijnstee, & Rutten, 2010).

The bibliographic research was carried out through the main scientific search engines on the Internet: Scopus (Scopus search, 2018), PubMed (Home-PubMed, 2018), (Google Scholar 2018) and Science Direct (ScienceDirect.com, 2018), because the authors wanted to understand a first numeric impact and the importance on the international studies of the specific subset with respect to the main set. Hence those search engines were first used to search through keywords as “indoor thermal comfort” and then “(elderly / older people) + indoor thermal comfort”. Table 2 reports briefly the quantitative results of the documents available in the four search engines according to the parameters set.

It can be noticed how in the main set (formed by a consistent number of scientific articles, hence it is an interesting topic to the eyes of the scientific international community), the subset here examined concerns about 7,8% of the total of the works produced (Fig. 1). This provides a first sign for what concerns the possibility to analyse this matter with results which might be important to the subset as well.

Among the commonly used search engines, PubMed and Science Direct do not allow to list the search based on the number of citations, but rather it presents a relevance-based research (where the order depends on how many times the keyword is present in the article). Where the order of the results in output, is set according to the relevance or number of citations, the first scientific paper for each database is reported in Table 3.

Table 2
General results of the bibliographic research carried out in different databases.

	Scopus	PubMed	Google Scholar	Science Direct
Research Option	No specific	Search: Title, abstract and keywords	Search: Title, abstract and keywords	Search: Title, abstract and keywords
Keyword: “indoor thermal comfort”				
Number of Results	4.571	167	65.000	11.999
Keywords: “(elderly / older people) + indoor thermal comfort”				
Number of Results	93	18	9.100	502

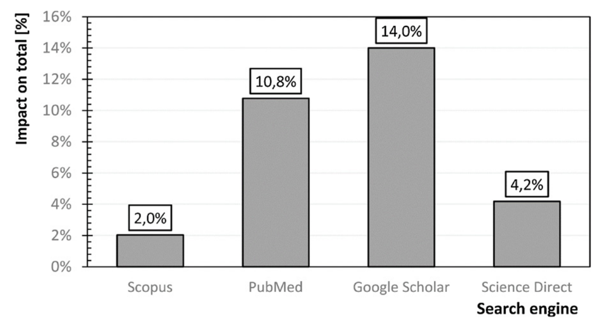

Fig. 1. Incidence of scientific searches concerning the aged population with respect to the total number of researches on the indoor thermal comfort.

It can be noticed the high number of citations and this proves the interest of the scientific community in this topic.

While focusing the attention on the thermohygrometric comfort of the aged people and analyzing the data provided by Scopus only, this search engine gives the possibility to draw further considerations.

Examining the results (taking into considerations just those published articles written in English without paying attention to other types of studies as conferences, books, thesis, etc…) there is an increasing trend highlighting a deep interest into this matter (Fig. 2).

Among the articles found in Scopus, the 5 keywords presenting a higher occurrence are those reported in Table 4. It can be noticed that this topic is surrounded by words as buildings, systems and energy efficiency.

Table 5 reports the scientific areas having a major interest into this matter.

Once the bibliographic analysis was performed it was possible to state that the origin of the researches based on aged people was in Fanger’s studies (Fanger & Toftum, 2002; Fanger, 1973; Fanger, Östberg, Mc, Breum, & Jerking, 1974) carried out in 1970 to define the normotipo on a transversal population of subjects. The analysis was useful to determine the parameters used to set the indoor comfort range in air-conditioned environments (the experimental part of those studies was carried out on subjects interviewed in enclosed air-conditioned spaces). Fanger’s stationary model was based on the body heat balance useful to predict the thermal sensation of a group of people through the PMV (Predicted Mean Vote) and the PPD (Predicted Percentage Dissatisfied) (ASHRAE, 2013a, 2013b; ISO, 2005). The expressions of these indexes are respectively Eqs. 2 and (3):

$$PMV = (0.30e^{-0.036 \cdot M} + 0.028) \cdot L \qquad (2)$$

where:

Table 3
The first 5 common documents (ordered according to their relevance) in the 4 search engines.

	Title	Authors	Year	Published in	# quotes
Parola chiave: "indoor thermal comfort"					
Scopus	The physiological equivalent temperature - A universal index for the biometeorological assessment of the thermal environment (Höppe, 1999)	Höppe P.	1999	International Journal of Biometeorology	500
PubMed	Perceived Indoor Environment and Occupants' Comfort in European "Modern" Office Buildings: The OFFICAIR Study (Sakellaris et al., 2016)	Sakellaris I.A., Saraga D.E., Mandin C., Roda C., Fossati S., de Kluizenaar Y., Carrer P., Dimitroulopoulou S., Mihucz V.G., Szigeti T., Hänninen O., de Oliveira Fernandes E., Bartzis J.G., Bluyssen P.M.	2016	International Journal of Environmental Research and Public Health	–
Google Scholar	Different aspects of assessing indoor and outdoor thermal comfort (Höppe, 2002)	Höppe P.	2002	Energy and Buildings	363
Science Direct	Thermal comfort of heterogeneous and dynamic indoor conditions - An overview (Mishra, MGLC, & Hensen, 2016)	Mishra A.K., Loomans M.G.L.C., Hensen J.L.M.	2016	Building and Environment	–
Parola chiave: "(elderly / older people) + indoor thermal comfort"					
Scopus	Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations (Indraganti & Rao, 2010)	Indraganti M., Rao K.D.	2010	Energy and Buildings	51
PubMed	Indoor air quality and thermal comfort-results of a pilot study in elderly care centers in Portugal (Mendes et al., 2013b)	Mendes A., Pereira C., Mendes D., Aguiar L., Neves P., Silva S., Batterman S., Teixeira J.P.	2013	Journal of Toxicology and Environmental Health, Part A	–
Google Scholar	Low indoor temperatures and morbidity in the elderly (COLL INS, 1986)	Collins K.J.	1986	Age and Ageing	150
Science Direct	The influence of seasonal characteristics in elderly thermal comfort in Korea (Yang et al., 2016)	Yang J., Nam I., Sohn J.R.	2016	Energy and Buildings	–

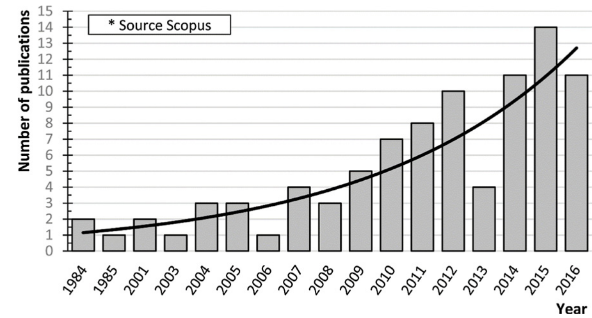

Fig. 2. Number of articles published per year (source: Scopus).

Table 4
Short report with the Nations where the research was carried out.

#	Keywords	Occurrence
1	Thermal comfort	55
2	Air conditioning	22
3	Buildings	22
4	Indoor air pollution	20
5	Energy efficiency	17

Table 5
Scientific areas with a higher interest in the thermal comfort concerning aged people.

#	Scientific area	Occurrence
1	Engineering	57
2	Environmental sciences	28
3	Energy	22
4	Social sciences	15
5	Medicine	8

- M: metabolic rate;
- L: body thermal load (defined as the difference between the internal thermal heat generated and the heat the subject releases towards the environment).

$$PPD = 100-95e^{-(0.03353\cdot PMV^4+0.2179\cdot PMV^2)} \quad (3)$$

These studies were then extended going deep into this problem. It was indeed defined the adaptive model for the thermal comfort (Rupp et al., 2015). This approach towards the definition of thermal comfort is based on the idea that if the state of the thermal comfort changes, people (as active subjects rather than passive ones) have a reaction trying to restore the previous state of comfort. Nicol and Humphreys (1973); Auliciems (1981); de Dear and Brager (1998), studied the adaptive model by changing the paradigm with respect to Fanger's theory and introducing the idea that the comfort of an indoor environment also depends on the climatic conditions of the outdoor environment. The adaptive model takes into consideration even psychological factors (addictions to microclimatic conditions), behavioural (reacting to the discomfort by opening windows or screening with shutters) and physiological (acclimatization to new conditions). From those recent studies what emerged was also the concept of alliesthesia suggested by (Cabanac, 1971) and studied by de Dear (2011, 2009). The alliesthesia states that a certain external stimulus coming from the outside can be perceived as pleasant or unpleasant according to warnings sent from the body and it must be kept in mind that people tend to avoid unpleasant stimuli in search of pleasant ones. This means that a state of thermal neutrality might not correspond to a pleasant thermal sensation; hence it is important to understand how different parameters balance each other while determining the thermohygrometric comfort.

Then new scientific researches were carried out specifically for the

Table 6
Short extract reporting those Nations where the research was carried out.

Authors	Nation
Loughnan M., Carroll M., Tapper N.J. (Loughnan, Carroll, & Tapper, 2014)	Australia
Miller W., Vine D., Amin Z. (Miller et al., 2017)	Australia
Glass K., Tait P.W., Hanna E.G., Dear K. (Glass, Tait, Hanna, & Dear, 2015)	Australia
Alves C.A., Duarte D.H.S., Goncalves F.L.T. (Alves, Duarte, & Goncalves, 2016)	Brazil
Trezza B.M., Apolinario D., Sanchez de Oliveira R., Busse A.L., Gonçalves F.L.T, Saldiva P.H.N., Jacob-Filho W. (Trezza et al., 2015)	Brazil
Mourshed M., Zhao Y. (Mourshed & Zhao, 2012)	China
Wong L.T., Fong K.N.K., Mui K.W., Wong W.W.Y., Lee L.W. (Wong et al., 2009)	China
Hashiguchi N., Tochihara Y., Ohnaka T., Tsuchida C., Otsuki T. (Hashiguchi et al., 2004)	Japan
Sunwoo Y., Chou C., Takeshita J., Murakami M., Tochihara Y. (Sunwoo, Chou, Takeshita, Murakami et al., 2006)	Japan
Del Ferraro S., Iavicoli S., Russo S., Molinaro V. (Del Ferraro et al., 2015)	Italy
Yang J., Nam I., Sohn J.R. (Yang et al., 2016)	Korea
Jeong W.S. (Jeong, 1999)	Korea
van Hoof J., Kort H.S.M., Hensen J.L.M., Duijnstee M.S.H., Rutten P.G.S. (van Hoof, Kort, Duijnstee et al., 2010)	Holland
van Hoof J., Kort H.S.M., van Waarde H., Blom M.M. (van Hoof, Kort, van Waarde et al., 2010)	Holland
Roelofsen P. (Roelofsen, 2013)	Holland
Schellen L., van Marken Lichtenbelt W.D., Loomans M.G.L.C., Toftum J., de Wit M.H. (Schellen, van Marken Lichtenbelt et al., 2010)	Holland
Mendes A., Bonassi S., Aguiar L., Pereira C., Neves P., Silva S., Mendes D., Guimarães L., Moroni R., Teixeira J.P. (Mendes et al., 2015)	Portugal
Burholt V., Windle G. (Burholt & Windle, 2006)	United Kingdom
Chard R., Walker G. (Chard & Walker, 2016)	United Kingdom
Collins K.J., Hoinville E. (Collins & Hoinville, 1980)	United Kingdom
Hwang R.L., Chen C.P. (Hwang & Chen, 2010)	Taiwan
White-Newsome J.L., Sánchez B.N., Parker E.A., Dvonch J.T., Zhang Z., O'Neill M.S. (White-Newsome et al., 2011)	USA
S., Erickson J., Fonseca E. (Ahrentzen et al., 2016)	USA

study of the indoor comfort among aged people. The setting of those studies was represented by Countries affected by the issue of old age. Table 6 reports a short extract showing how this problem has been an interesting topic to the eyes of the international scientific community.

3. Current international standards for the thermohygrometric comfort

Thanks to Fanger's studies the thermal neutrality was associated to the state of comfort. This allowed to define the ideal environmental conditions for the normotipo comfort and to determine the ranges of air temperature, relative humidity and mean wind velocity that might fulfil most of the occupants of an environment (Schellen, Loomans, Kingma et al., 2013).

For what concerns the planning of thermotechnical systems used in buildings, the results obtained gave the possibility to outline the standards set by international regulations (that are the basis of the system planning, from the definition of a scope statement to the final test). In particular the ANSI/ASHRAE Standard 55 (ASHRAE, 2013b) defines the thermal comfort and the minimum requisites for the conditions in indoor environments that might be considered as acceptable by the occupants (Kingma, Frijns, & van Marken Lichtenbelt, 2012). Such regulation must take into consideration the environmental conditions together with personal factors as the activity performed and the type of clothing the subject is wearing and it can be applied to all those healthy subjects staying in enclosed environments for at least 15 min in buildings constructed at a height lower than 3.000 m. The thermal comfort expressed in PMV (whose numerical value is based on a 7 values scale ranging from -3 (cold) to +3 (hot)) characterizes the ISO 7730 (ISO, 2005), where the values of the metabolic rate (expressed in met, 1 met corresponds to 58.2 W/m2) of people who are between 20 and 65 years-old are defined. On such scale, number 0 represents the thermal comfort. Being a mean index referring to a group of subjects, if the PMV is 0 does not mean that the state of thermal comfort has been achieved for all the occupants.

The adaptive model was included in the EN 15251 (2007) in 2008, in the Dutch guide lines ATG (Boerstra, van Hoof, & van Weele, 2015) and the Brazilian regulation suggested for the thermal comfort (Cândido, Lamberts, de Dear, Bittencourt, & de Vecchi, 2011).

4. The thermohyhrometric comfort and old people health

4.1. Physiological mechanisms for the thermal comfort

The assessment of the PMV determined through Fanger's studies, based on tests and interviews performed on a sample of college students generally in good health, does not take into consideration the different needs of those subjects who are not part of that statistic sample (who also present different physical features and necessities) (Van Hoof, 2008). Generally, the systems in indoor spaces are set on parameters provided by the current regulations hence the present conditions will not satisfy subjects with different metabolic necessities (depending on the activity performed and health conditions). Fanger went through some further studies (ASHRAE, 2013a; Fanger, 1973) focusing his interest on a sample characterized by aged people, though those studies were not taken into considerations by those regulations about the planning of indoor comforting spaces (Van Hoof, 2008). This problem was stressed thanks to a study carried out in an Italian hospital where the different needs of the staff and patients were examined (Del Ferraro et al., 2015). The data collected during this study showed that in order to have a thermal neutrality for the patients, the staff felt hot and often some patients, though in conditions of thermal neutrality (PMV), stated they felt cold anyway. These researches, even if carried out in peculiar places as hospitals, show that in a society, whose population progressively gets old, it is important to adjust the setting of the systems used in buildings in a more specific way according to its occupants (Havenith, 2001).

Old people, even if in good health, present more difficulties with respect to younger people over their body thermoregulation, because their basal metabolic rate declines with the aging (Salata et al., 2017; van Hoof, Kort, Hensen et al., 2010). 20% of aged people show problems of vasoconstriction in the cutaneous blood vessels, this means that the body temperature decreases hence an environment with higher temperatures is required. Medical and physiological studies showed that old people generally present a mean hourly body temperature which is lower than the conventional 37 °C (Fox et al., 1973). It is important to specify that this temperature in people who are in good health is stable with maximum variations of the order of 0,5 °C. The skin temperature can range between 31 °C and 36 °C (ordinary environments), according to the activity performed (Gomolin, Aung, Wolf-Klein, & Auerbach, 2005; Vandentorren et al., 2006) and the part of the body where the temperature is measured (with higher variations in hands and feet) (Miller et al., 2017; Tsuzuki & Iwata, 2002).

The mechanisms regulating the body temperature are complex (Ahrentzen et al., 2016; Gomolin et al., 2005). The section of the brain managing the body temperature is the hypothalamus (Yochihara, Ohnaka, Nagai, Tokuda, & Kawashima, 1993). It is formed by sensors useful to perceive the temperature of the arterial blood. Since human blood flows quickly, without having the time to release heat, and the blood flowing will be mixed in the heart before going back to the body, the temperature of the arterial blood is a good representation of the mean body temperature. Moreover, the hypothalamus receives information from some organs as skin perception, spinal marrow and intestines. Thanks to this information, the hypothalamus is able to control the different physiological processes meant to regulate our body temperature (managing the hormonal secretions through the autonomous and somatic nervous system acting on the heart, lungs and blood vessels) (Winslow, Herrington, & Gagge, 1937). The hypothalamus acts in a way which is directionally proportional to the variation in the temperature with respect to its set-point value. The most important process that manages the temperature is the regulation of the blood flowing through the blood vessels positioned in the skin. When the internal temperature increases, what occurs is a vasodilation that can determine a blood stream which is 15 times higher than the normal one, in this way it allows the heat to be released. If this is not enough the sweating will occur: sweat glands generate sweat that, with the proper environmental conditions, will evaporate through the skin taking out the latent heat provoked by the change of state (Gwosdow, Stevens, Berglund, & Stolwijk, 1986). This mechanism usually occurs in our body, without the perception the skin is sweating. If the skin sweats, it means there is a thermal discomfort. For a human being, having a strong sweating process means a decrease in the salts which the endocrine system emitted together with the sweat generated. On the other hand, if the internal body temperature decreases, what happens is a skin vasoconstriction that preserves the heat (Arens, Gonzalez, & Berglund, 1986). If this is still not enough, the tension of the muscles will get higher to generate extra heat (that is when the body shivers, which is able to double up the heat generated by a resting body) (Cannistraro & Cannistraro, 2016; NIELSEN, BERGLUND, GWOSDOW, & DUBOIS, 1987).

These thermoregulation processes hardly occur among old people: 20% of them cannot have a vasoconstriction of the cutaneous blood vessels, whereas the rest 80% reports a general decrease in the capacity to control the body temperature (Collins & Exton-Smith, 1983). As a matter of fact, some studies report that the metabolic heat generated by old people who are resting is about 4,7 W m^{-2} lower than the *normotipo* based on a sample of the younger population (Hwang & Chen, 2010). In particular, among old men there is a decrease in the ability to activate the sweating process with respect to younger people. Even old women present a higher set-point that if exceeded the sweating process will start. During the old age, all those physiological mechanisms allowing the thermal homeostasis are less responsive to the external stimuli and usually are the cause and consequence of breathing and cardiovascular problems (Foster, Ellis Doré, Exton-Smtth & Weiner). The lack of a proper response to the heat determines (if the internal body temperature is still too high) a heat stroke. Moreover thermal stresses can provoke other physical problems as muscular spasm, excessive physical effort, anxiety, fatigue, and confusion (White-Newsome et al., 2011). The worst conditions are not generated by the effect of the single case of thermal discomfort that occurs sporadically, but rather the problem is if the body is forced to perform constant thermoregulation processes due to temperature fluctuations that are too high. This is provoked by a constant stress that can lead to a hypertension (Sunwoo, Chou, Takeshita, Murakami et al., 2006). Less worse effects caused by "uncomfort" values of temperature and humidity in environments with old people can lead to dry skin, hence itching (Sunwoo, Chou, Takeshita, Murakami et al., 2006; Sunwoo, Chou, & Takeshita, 2006; van Hoof, Kort, van Waarde, & Blom, 2010); this might be determined by a low level of sweating with a simultaneous low production of cutaneous sebum. These have some negative effects on the eyes as well: aged people usually have a low lacrimal production which is important to keep humid the ocular surface (Yochihara et al., 1993).

This is due to the aging process and those physiological aspects that it implies. While the human-being gets old, the body starts having some difficulties dealing with the strong fluctuations of the temperature (especially if it tends to extreme values). The peripheral nervous system starts getting worse and its ability to be a primary communication system between the body and brain and the peripheral organs diminishes (Cacioppo & Tassinary, 1990; Vente, De, Olff, Amsterdam, & Van, 2003). This decline in the thermoregulation phenomenon is caused by the delay neural messages informing the organism about the perception of hot and cold temperatures. The resulting regulation of the heart frequency, the vasodilation and sweating are subject to a slowdown (Trezza et al., 2015; Xiong et al., 2016). Hence the human-being is not able to activate its thermoregulation process (physiological and/or behavioural) based on the outdoor environment (Kenney & Munce, 2003; Verdú, Ceballos, Vilches, & Navarro, 2008). Moreover the thermoregulation process can be worsened by chronic diseases due to aging (diabetes, obstructive lung diseases, hypertension, etc…) that increase the risk of hyperthermia (provoked by a body temperature which is higher than 42 °C) thus blocking the regular blood stream towards the epidermis (Kan, London, Chen, Song, & Chen, 2007; Minson, Wladkowski, & Cardell, 1998; Tam, Wong, Chair, & Wong, 2009).

Then the administration of some types of medicines to aged people to prevent bad diseases can have negative effects on the body thermoregulation. Psychiatric drugs are connected to an increase in the hospitalizations due to hyperthermia, whereas non-steroidal anti-inflammatories (used to prevent myocardial infarction) block the production of prostaglandin, which controls the blood pressure and body temperature (Carmichael & Shankel, 1985).

Moreover, due to aging, what occurs is a decrease in the cognitive functions as the velocity to elaborate information, general attention, executive functions, memory, learning and episodic memory. All those factors affect the capacities of old people to judge their own thermo-hygrometric comfort and tend to be more easily subject to health risks. Unfortunately old people are not fully aware of the dangers determined by the lack of proper behaviour that might allow an easy adaptation to the climatic conditions (Fox et al., 1973).

Actually some studies focused on that subset of the old population affected by mental dementia (van Hoof, Kort, Hensen et al., 2010). It has been estimated the presence of 6 million people in Europe with this pathology. Most of them live at home where they depend on the cures provided. The dementia implies serious cognitive dysfunctions which in turn have negative effects on the sensitivity (in terms of environmental conditions) of those living with this pathology. This sensitivity is altered and some people might be particularly sensitive to external sensory stimuli (as the perception of thermal comfort) that can lead to social and behaviour issues. This is why there is the long-term hospital institutionalization of these patients. If those people had the possibility to live in properly thermoregulated environments fulfilling their own needs, rather than be hospitalized, this might determine financial savings for the healthcare system (Roelofsen, 2013; van Hoof, Kort, Hensen et al., 2010).

4.2. Incidence of the domestic environment

After what has been said, it seems evident that improper indoor conditions where the occupants are old people might highly affect their comfort and health conditions. Moreover, many over-65-years-old people lifestyle is generally staying at home most of the day (performing sedentary activities with a low production of metabolic heat, without forgetting that aged people have a lower basal metabolic rate) (Sunwoo, Chou, Takeshita, Murakami et al., 2006). Hence an

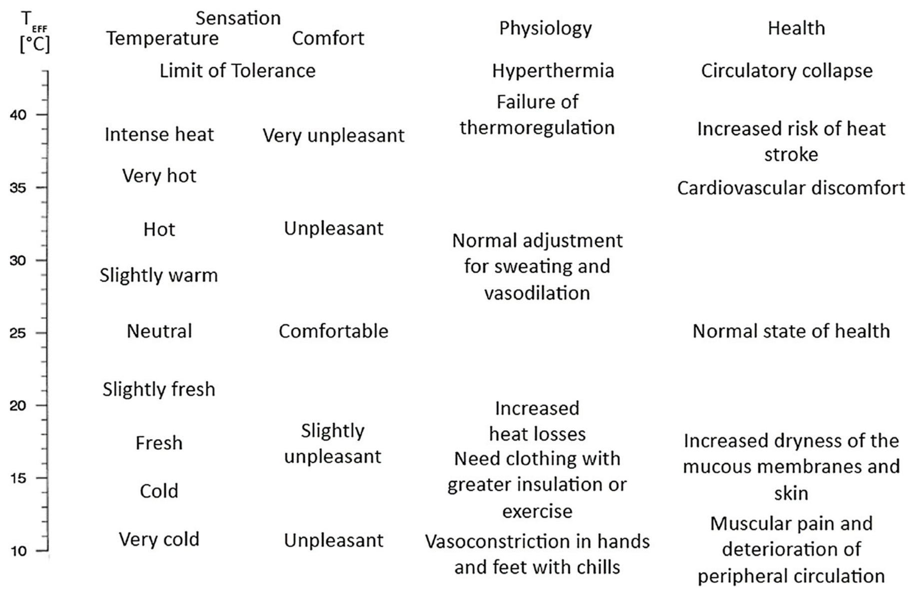

Fig. 3. Relation concerning sensation, physiology and human health with respect to temperature.

environment characterized by a discomfort can cause a higher unsatisfaction than younger people who are more dynamic during the day going to different places with respect to their home (Ahrentzen et al., 2016).

Although comforting spaces help aged people since they can feel better, healthy and independent (Hwang & Chen, 2010; Mendes et al., 2015).

Outlining questions about the thermohygrometric issue are important to those experts dealing with the regulations considering the incidence of the environment on over-65-years-old people. The comfort range of this age and the minimum temperature necessary to the thermal balance of the body of an aged person should be considered (Cena, Spotila, & Ryan, 1988; Dalip, Phillips, Jelinek, & Weiland, 2015; Haghighat, Megri, Ahmed, Donnini, & Giorgi, 2000; Hashiguchi et al., 2004; Natsume, Ogawa, Sugenoya, & Ohnishi, 1992; Ormandy & Ezratty, 2012).

Some studies discovered that the thermal comfort zone (between 20 °C and 24 °C for adults not involved in any activity, Fig. 3) might not be warm enough for aged people, whose thermal comfort is characterized by higher temperatures with a neutral temperature of 2 °C higher than the functioning temperature set for the systems (Miller et al., 2017). Hence during winter, keeping a proper relative humidity can be difficult without some technical expedients which in turn make traditional heating systems insufficient (able to regulate the temperature only). As a matter of fact it was observed the behaviour of old people (in Baltimore, USA) who wanted to find a solution (wear a different clothing, drink, turn on the air-conditioning or fans, take a shower, etc…) to improve the thermohygrometric comfort (White-Newsome et al., 2011). In a similar study carried out in Detroit (USA) a group of old people did not perform any action to change the environmental conditions in order to ensure a better thermal comfort as long as the temperature did not exceed 29.4 °C (White-Newsome et al., 2011), a temperature that was considered too high for the normotipo. Even in a study performed in London, old people did not have any active behaviour that might change and improve the environment as long as the temperature did not exceed 322 °C (White-Newsome et al., 2011, 2012).

Further studies discovered that aged people have more difficulties than young people for what concerns their body thermoregulation if they are in an environment that tends to have conditions changing quickly. During these time intervals with transitory temperature, old people show a higher peripheral vasoconstriction (Schellen, Van Marken Lichtenbelt, Loomans, Toftum, & De Wit, 2010, 2013a; Schellen, Loomans, de Wit, & van Marken Lichtenbelt, 2013).

All those factors determine higher installation and exertions costs for the systems meant for the comfort of old people.

However old people present a lower income than active workers. Researches showed that usually houses inhabited by aged people have an indoor temperature which is lower than what is actually necessary according to the standards. This issue afflicts mostly Northern Countries where heating costs during winter are high. In England, during winter (from December to March), there is an increase of about 25.000 dead people than the rest of the year (Jevons, Carmichael, Crossley, & Bone, 2016). A cold and humid climate, together with a low energy efficiency, combined with other factors (as the “fuel poverty” and health inequalities) are the reason of the high number of deaths during winter in England if compared to the rest of Europe. The first victims are aged people.

Another cause is that with the aging of the population, in those Counties where this phenomenon is more present and there is a general welfare, the demand of special structures dealing with the treatments and recovery for old people who are not independent is higher (Yang, Nam, & Sohn, 2016). Those social residential structures present expensive management costs that have a heavy influence on the costs of the social politics (Mendes et al., 2013a, 2015). For example, in South Korea there are 72.000 of those structures giving a shelter or a place to spend some time providing medical treatments. The number of these structures increase with the increasing of the aging of the old population. The National Health Service must be able to manage, financially speaking, this condition and one possible solution could be making the house of old people healthier and more comforting by using more smart technologies available thus helping this range of the population (Caley & Sidhu, 2011; Korhonen, Parkka, Gils, & Van, 2003).

5. Energy implications and social costs

Indoor conditions determined through the thermal comfort analysis affects the energy consumptions of a building. The energy necessary to make indoor environments more comforting usually implies the exertion of non-renewable sources (responsible for the emission of climate-changing gases) (Djongyang et al., 2010; Kwok & Rajkovich, 2010). Improving the energy efficiency has been one of the challenges set over the past few years to reduce carbon dioxide emissions and promote energy cost savings, while always keeping in mind the thermal comfort of the occupants (World Health Organization, 2007). Hence provide a proper acclimatization in some environments whose occupants are old people, in order to satisfy their peculiar thermohygrometric necessities (complying with the standards set), will inevitably affect the energy consumptions of the building involved (Kawashima, Tochihara, Gotoh, & Uryu, 1993; Wong, Mui, & Shi, 2008, 2009). All these factors set a hard task for those planners dealing with constructions or building refurbishment (Burholt & Windle, 2006).

The mitigation of the thermohygrometric conditions, that are the cause of the thermal stress, is important to preserve their health (since aged people tend to spend most of their time at home). Moreover old people usually present financial problems that make them more vulnerable to the phenomenon of "fuel poverty" (Ahrentzen et al., 2016; Burholt & Windle, 2006). A family is considered to be in poor-energy conditions if they spend more than 10% of their income to heat and light their house, cook food and use appliances (Burholt & Windle, 2006). Energy poverty, especially when the heat is necessary, is the cause of a high indoor discomfort in those houses affected by financial issues, with resulting negative consequences on the health of the occupants. If to obtain the standard thermal comfort conditions during winter it must be maintained a minimum temperature of 18 °C (World Health Organization, 2007), the house inhabited by old people should report a temperature of 21 °C (Healy & Clinch, 2002, 2004). If it is not possible to heat a house properly, it will inevitably force old people to spend more money to preserve their health. Hence what occurs is the so called vicious cycle which generates a reduction in the financial possibilities of the occupants leading them to a state of poor-energy condition. As a matter of fact living in a non-energy efficient house implies not having good financial conditions (Burholt & Windle, 2006) and old people represent a high percentage of this part of the society (Sefton, 2005). The necessity to have a heated house is an important matter among old people because they spend there more time during winter, hence the functioning hours of the heating system (cost) are higher than other ranges of age (Baltes, Mayr, Borchelt, Maas, & Wilms, 1993; Baltes, Maas, & Wilms, 1999; Gabb, Lodl, & Combs, 1991; Healy & Clinch, 2002). All those factors require certain regulations providing help to old people who are not in a good position financially and socially speaking (Chard & Walker, 2016). Some studies carried out in the United Kingdom estimated that this issue can be the cause, during winter, of a 10% increase in the death rate with respect to the mean (Hills, 2011, 2012; Hitchings & Day, 2011).

Performing building refurbishment (Hoyt et al., 2009; Pisello & Rosso, 2015; Pisello, Castaldo, Rosso, & Piselli, 2016), incentivized by financial deductions or public assistance, can make the effort of keeping comfort conditions in houses belonging to old people less expensive (Coppi, Quintino, & Salata, 2013; D'Orazio, Fontana, & Salata, 2011; Salata, Alippi, Tarsitano, Golasi, & Coppi, 2015), thus guaranteeing good health conditions (Hitchings & Day, 2011). Structures suiting both the demand and costs are vital to guarantee the life quality and the active and independent life of old people thus diminishing the need of being assisted (Oswald et al., 2007). This, besides improving their life-quality, can also improve, financially speaking, public health infrastructures (Chard & Walker, 2016; Hovmand et al., 2012; Salata, Golasi, di Salvatore, de Lieto, & Vollaro, 2016).

Government institutions must consider the necessities of aged people in order to realize proper political choices, given the fact that population will keep aging (Stimson & McCrea, 2004). Commercially speaking the aging of the population can represent a new opportunity both for products and services (Pinnegar, 2012).

6. Necessities and future developments: an outlook for the research

As previously said, it is clear that the stakeholders (politicians, doctors, specialists, authorities, economists, sociologists and so on) must focus on these topics in order to govern the aging phenomenon in industrialized countries. This topic is characterized by many interesting crossing aspects, and from an engineering point of view they concern those issues related to the systems necessary to ensure thermal comfort conditions for aged people. The last step will be the analysis of the social aspects concerning the new necessities of welfare and the social and economic choices that the govern should make.

In order to have an attentive analysis of the technical aspects, it is very important to identify the necessity to realize air-conditioning systems able to ensure the thermohygrometric comfort in those environments characterized by aged people. This issue is related to the judgment provided by a normotype (defined based on the statistics) in a way that it might represent the normalized demands of a specific population. The next step is to define and quantify the planning parameters which will be the base of the planning phase, future energy optimization, social policies and so on. Therefore this study wants to define a correct procedure to experiment and define a normotype that can represent the demand of the aged population in terms of thermohygrometric conditions in those environments where they usually spend time.

The conditions characterizing the thermohygrometric comfort were previously determined through indexes developed in the North of Europe according to a statistical sample of young people. This is why, environmental conditions that can represent the thermohygrometric comfort for that specific sample might not have the same results if applied on the aged population, whose biological modifications can lead to a different thermal perception.

The necessity to redefine the parameters characterizing the thermohygrometric comfort in indoor environments depends on the adaptive models able to take into consideration the physiological and clinical needs of people in old age living in a certain climatic area. This is something that can be done if Fanger's researchers were updated and a new index, replacing in the regulations the PMV and PPD, was determined. Hence the old energy exchange models of body-environment would be replaced. Thus, future researches should focus on, through a new specific index, the identification of the correct temperature conditions, relative humidity, mean radiant temperature and wind velocity while keeping into consideration the psychophysical and physiological factors affecting the population. Indoor climatic conditions which do not correspond to the values expected, might determine health issues and compromise the results of possible rehabilitation treatments of the subjects.

Determining a new thermohygrometric index adjusted for aged people can represent an important instrument to obtain a physical, cognitive and emotional wellbeing. The interaction between microclimate and health (in aged people) could mean a decrease in the number of people with a worsening of their chronic pathologies. Since the institutionalized subject stands for the paradigm of the fragile patient, it might be interesting to apply the results on some healthcare structures. This can lead to a more precise measurement and regulation of the microclimate in those contexts where subjects at risk live.

The research should consider the realization of a new empirical index for the comfort of aged people and it can be determined through the elaboration of some questionnaires complying with the ISO 10,551 and filled during an annual field survey. This will be possible if the field survey is performed in an environment that allows a precise setting of the variables affecting the thermal perception (air temperature, relative humidity, mean radiant temperature of the walls, wind velocity). Indeed, it is necessary that a series of tests will be set with all the possible combinations of the afore mentioned variables' values.

The interviewees should not be less than 1000 old people in health ($>$ 65 years) and they will be asked to judge their thermal perception according to the ASHRAE scale (cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm ($+1$), hot ($+2$) very hot ($+3$)). While collecting the subjects, each interviewee should be evaluated through a multidimensional geriatric evaluation. This transversal sample statistic should also question about personal information (age, gender, level of the activity performed, etc…). At the same time, some micro-meteorological measurements should be performed for the air temperature, mean radiant temperature, relative humidity and wind velocity. This would create a correspondence between the vote of the interviewees and the measured values of the variables (both environmental and operative). The next step was to apply statistical methods (Best Subsets Analysis, multicollinearity, VIF, etc.) to the results obtained to define the new comfort model and new planning parameters for the air-conditioning systems related to the old age population.

This research project can be represented as follows:

- Phase 1: plan all the different experimental measurements in a thermostated room. Draft the questionnaire that will be used to investigate the thermal perception and personal information concerning the aged population. Perform the Multidimensional Validation. Realize the thermostated room and set the experimental environment that will be tested.
- Phase 2: collect the questionnaires about thermal perception answered by aged people. It must be specified that the process of collecting the questionnaires should take one year, in order to take into consideration a wide variety of outdoor climatic conditions which in turn affects the indoor thermal perception. Preliminary statistical analysis and comparison of the results obtained with those determined through commonly used thermohygrometric comfort indexes as the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD).
- Phase 3: statistical elaboration of the results obtained through the questionnaires. Development of the basic model of the new thermal comfort index meant for aged people living in the Mediterranean area. Final comparison with some indexes as Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). Technical draft of the developed projects.
- Phase 4: define the indoor comfort conditions for what concerns the aged population living in the Mediterranean area.
- Phase 5: energy consumption evaluation determined by the setting of new environment values considered as being representative of the comfort conditions.

Being able to achieve the aforementioned goal would mean: i) on a clinical level, to study the interactions between environment and physical, psychological and cognitive wellbeing of the aged person focusing on the measurement and regulation of the microclimate for therapeutic/rehabilitating reasons; ii) on an engineering level, the assessment of the planning parameters for the systems that want to fulfil the needs of the aged population, thus redefining the values set by the regulations.

Deeper studies about these matters would enrich, from a scientific point of view, a field which over the past few years has been characterized by a vivid activity that wanted to improve the regulations concerning the planning of air-conditioning systems. This might affect the way the systems are used during the different periods of the year, hence influencing the energy demand of the building to save both energy and money. This can represent an entirely new approach willing to reduce the energy consumptions acting on the climatic conditions demanded, rather than on the system efficiency (which over the past few years, thanks to the efforts of the research, achieved a good technological status). In this way, most of the energy waste would be avoided, since the problems would be solved from the beginning.

New scientific studies might lead to the definition of the planning conditions both of the indoor environments occupied for a long time and the spaces occupied for shorter periods of time, defining the comfort of the aged population with the possibility to control the energy demand of the present systems. While examining the comfort of the occupants, with the adaptation capacities in a dynamic regime, it is possible to define those planning conditions of the systems in areas where the occupants do not spend much time, but they are rather a transition zone between outdoor and indoor conditions.

All these factors might become interesting for both the building and systems industry through the realization of smart electronic devices meant for houses characterized by adaptive domotic and modern systems. The planning of personalized air-conditioning systems represents a promising solution both to have personal comfort conditions (fulfilling specific demands) and obtain high energy performances in buildings (without being necessary high energy consumptions to have a thermal comfort in the entire building, even where it is not required or necessary). These highly automated systems create a microenvironment suiting every type of user (Cannistraro & Lorenzini, 2016). Hence, every single demand concerning the thermal comfort can be fulfilled thanks to a higher efficiency with respect to more traditional systems (Vesel, Molenaar, Vos, Li, & Zeiler, 2017).

The results of this kind of study would have vertical consequences (thanks to the exertion of the results provided by the medical field), and horizontal consequences thus spreading a know-how knowledge and the skills acquired in similar fields different from the medical sector (as the energy efficiency in the building sector).

The possibility to realize specific systems according to the demand of the aged population in buildings where they live in, must become a topic examined in the field of legislation and regulations concerning buildings hosting those people. In future studies, once the correct planning procedure able to fulfil the indoor comfort for aged people is defined, the optimization of the energy demand and the adoption of solutions able to determine energy savings will be topics that every designer is asked to take into consideration. Once those necessities are defined, it will be possible to carry out social and economic studies concerning the necessity to provide thermohygrometric comfort to this range of the population and the consequences that those issues will have on a future aging society asking for attentions and care.

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