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Evaluation of parameters and models of human thermal comfort: an overview

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Abstract

Thermal comfort and human well-being is a phenomenon that has been studied over the years because directly affects the entire population of the planet. Today, with the technological advances, there is a big number of objects and systems that are becoming more and more automated in terms of air conduction, ventilation and air conditioning, making comfortable conditions possible over time.

Although technology makes it possible to change indoor environmental conditions flexibly and instantaneously, these systems must know how, when and why they must change the environmental conditions.

This thesis is based on a literature review of the parameters that influence human thermal comfort and the methods and models found over the last few decades to quantify it. It reviews articles on the first static models, the first adaptive models, in order to study the hypothesis of our parameters, which historically were not considered to be influential, but from new techniques that allow technological advances, it has been possible to prove their importance.

Since there are many parameters that influence thermal comfort and these interact with others, it is very difficult to obtain expressions or models that describe human thermal comfort in a precise way. In addition, each person has different physiological characteristics which, together with psychological and behavioral characteristics, determine human comfort.

The aim of this thesis is to identify which factors influencing comfort have been considered over time and which ones have been discovered recently. Another objective is to identify how new technologies can be used for thermal comfort. The method for meeting these objectives has been the literature review.

As a result, a total of 20 factors that influence human thermal comfort and 5 new technologies that can help both the research of thermal comfort and its application in buildings have been identified.

As conclusions, the interaction between the user and the research element (both human and machine) is essential to evaluate comfort and to be able to research it. Another conclusion is that new technologies play an important role in the study of comfort. Although many are still under development, they have great potential.

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Introduction

Background

Definition of well-being

Throughout the history of humanity, human beings have always acted in such a way as to obtain the maximum possible comfort. For example, the prehistoric people lived in caves because instinctively, without being aware of it, they noticed that if they slept there they would be more comfortable. The first signs of discomfort that they carry with them when they lived in caves or build huts were either the sound, and therefore a feeling of warmth, or the feeling of shivering, which indicates a feeling of faith.

Socrates (400 BC) may be considered the first person to show a "scientific" interest in thermal comfort, since he "had some thoughts on the climatic suitability of houses, on how to build to ensure thermal comfort" (Auliciems & Szokolay, 1997) , followed by Vitruvius, but his writings did not have much influence on later architecture. For centuries, thermal comfort was not a subject of study in science and technology, but rather "heating technology improved from the late 18th century onwards and mechanical cooling became a possibility early 20th century. The impetus for comfort research came from engineers: it was now possible to overheat or overcool buildings, so it was necessary to establish design temperatures" (Auliciems & Szokolay, 1997) .

In the 1920s, Houghten and Yagloglou tried to define a "comfort zone" based on laboratory experiments, which is now obsolete.

Throughout the 20th century, the study of thermal comfort was motivated by the harsh atmospheric conditions suffered by manufacturers. And "during and after World War 2 research activity increased and many disciplines became involved besides engineering, from physiology and medicine to geography and climatology” (Auliciems & Szokolay, 1997).

Then, in 1970, P.O. Fanger published the first model to quantify thermal comfort, which was a static model and considered the occupants as passives. This model has a number of parameters to define thermal comfort and is currently the most widely accepted and used.

Later, in the 90s, Richard De Dear and Gail Brager proposed an adapted model, which they considered to have been transitory in the environmental conditions and that the occupants had an active attitude.

Nowadays, models are developed from the two previous ones and thanks to the computer, every time there are tools that make more complicated calculations, and therefore, it is possible to model better the thermal comfort.

Thermal comfort can be defined as ‘‘the condition of the mind in which satisfaction is expressed with the thermal environment’’ (ASHRAE, et al., 1966).

However, there are terms that are closely related and have similarities with the term comfort, but they should not be confused. These are the terms: satisfaction, health and well-being.

Satisfaction can be defined as “a composite state involving an overall response to a combination of stimuli that includes, other than objective physical factors, also subjective physiological and psychological dimensions” (Altomonte et al., 2019).

Otherwise, health is considered "merely the absence of disease or infirmity” (World Health Organization, 1948).

And finally, well-being is defined as “an even wider and overarching construct of physical, physiological, and mental aspects combining hedonic and eudemonic dimensions” (Huppert & So, 2013).

Another definition of thermal comfort could be ‘‘a state in which there are no driving impulses to correct the environment by the behavior. Dissatisfaction may be caused by the body being too warm or cold as a whole, or by un- wanted heating or cooling of a particular part of the body (local discomfort)” (Van Hoof et al., 2010).

It can also be defined as "absence of thermal irritation or discomfort" (Givoni, 2010). This will define thermal comfort zones, which are defined by physiological functions and determined by a set of conditions for which the thermoregulatory mechanisms are in a state of minimum activity.

In this project there are articles about the study of thermal comfort, so, the absence of thermal discomfort, which in many ways is based on the non-intervention of the thermoregulatory mechanisms of the human body.

The study of thermal comfort is not new, like it has been said before, human beings have always been in search of maximum comfort. That's why, for many years in the history of humanity, people believed that this thermal comfort was based on several very evident meteorological parameters, such as air temperature and wind speed. Since a few decades, there has been a revolution in the quantification of thermal comfort, in which we have discovered more parameters or factors that influence human comfort and have also created different models and methods to quantify it.

In the last decades, it has appeared a big number of students of thermal comfort. Some people study some possible parameters to check whether it really influences comfort or not, others study techniques or models in order to be able to quantify comfort. This project is a collection of scientific articles related to these topics.

In recent decades, new technologies have emerged that play a major role in the study of thermal comfort and its application. Technologies such as Machine Learning and Artificial Intelligence are taking a leading role in the creation of models and applications in HVAC.

Another definition of thermal comfort would be that the person is not aware of the climate that surrounds them and allows them to concentrate on other things.

Therefore, the concept of comfort can be observed from three different points of view.

"From a "psychological" perspective human thermal comfort can be defined as the mental condition in which there is satisfaction with the thermal environment, the person does not prefer to be in a warmer or cooler environment. This is a difficult definition to conceptualize due to its subjective character; however, the psychological aspects are of significant impact on the outdoor spaces"(Höppe, 2002). For example, it is possible to talk about the comfort of a working environment, where it is considered a comfortable environment the one that allows people to carry out the tasks assigned in a natural way, without having to bother or feel uncomfortable with other people. One aspect that could be considered as comfortable would be the fellowship.

"From the physiological aspect, the definition of comfort is based on the activation of the thermal receptors in the skin and the hypothalamus, in this case the condition of comfort is associated with the minimum proportion of nerve signals from these receptors. If we take into account the energetic definition, based on the criterion of the energy balance between the human body and the environment, thermal comfort is achieved when the heat flows from and to the individual are balanced" (Enescu, 2017). From a behavioral point of view, this "includes all modifications a person might consciously or unconsciously make that in turn modify heat and mass fluxes governing the body's thermal balance" (de Dear & Brager, 1998).

Summary of literature review

This project tries to answer the following question: How is thermal comfort measured?

Many branches of science and technology have researched this answer and it has been of great interest over time. The different disciplines have a different view on the quantification of thermal comfort, since they approach this question from different points of view. It is certain that in order to answer this question, all points of view are necessary, because the answer is a mix of all points of view.

From the point of view of engineering and physics, comfort is measured from physical variables such as temperature, humidity, wind speed, etc. and the existence of the energy balance, so, the heat flow between the human body and the exterior.

From the point of view of psychology, comfort is achieved when the brain interprets that it does not need to change anything outside, since the body feels an absence of pain. There are several psychological factors that influence comfort, which is explained later.

From the biological point of view, thermal comfort is measured from the amount of signals that send the thermorecievers located in the skin that when heat, cold or changes in the environment begin to send neurological signals in greater or lesser frequency.

As it is explained in the project, it is not possible to study the thermal comfort only from a point of view, but it turns out to be a combination of all of them.

The first studies and models consider that the occupants were passive about the environmental conditions and that they were static. Later, it will be considered that "people have a natural tendency to adapt to changing conditions in their environment. This natural tendency is expressed in the adaptive approach to thermal comfort"(Nicol & Humphreys, 2002). "Man, like other living beings, has to adapt to the limits imposed by climatic conditions and to the various sensations that his organism has to endure. However, unlike animals, plants, etc., man has the ability not only to adapt to a wide variety of climates, but also to change the environmental conditions of his surroundings through clothing and housing" (Fernández García, 1994).

Objectives

Why quantify thermal comfort?

Before starting to study how thermal comfort works or what parameters influence it, it is important to know why we are trying to quantify comfort in the most accurate way possible. First of all, one must be aware that there is not only interest in quantifying thermal comfort in indoor environments, as it would be evident. For public buildings or habitats, there is also interest in being able to quantify thermal comfort in outdoor environments.

The study of thermal comfort has mainly been addressed for closed areas such as offices, schools and homes. However, "many recreational and commercial activities, such as cultural and tourist events, take place in open spaces" (*J. Spagnolo, R. De Dear, Field Study to Calibrate... - Google Académico*, 2003). "The thermal comfort of people in open spaces is one of the factors that most influences the habitability of the spaces, given that the quantity and intensity of activities that the individual carries out is affected by the level of discomfort experienced when exposed to the climatic conditions of these open spaces" (Vale & Vale, 2009). In indoor spaces, the concept of comfort is increasingly significant, since, for example, if it is a question of a habitat, this will have an affected value if it has a high qualification in terms of comfort and the demand for this habitat will be greater, because people consider that thermal comfort is a very important factor in living in a space.

It is important for the occupants to be listened, their choices or how they find it in relation to the comfort of the indoor of the room.

Another important factor for studying comfort in indoor environments is that throughout history, and especially in the last century, a great deal of domestic energy has been devoted to obtaining what is considered to be comfort. This implies an energy waste that has to be studied to find out how it is possible to achieve thermal comfort with less energy than that used to condition a room, which would imply a high energy surplus that, for a minimum of time, if it is produced in each room, ends up creating a large amount of saved energy.

In public indoor environments, such as a shop, it is very important to study comfort, since it must be possible to create a climate that is as comfortable for the buyer as it is for the worker who finds himself in a space for more time, and without a break.

Another example would be public transport; many people have a sensation of being disturbed by the heat or the cold when entering a subway car. This climate, which is not pleasant for the passengers, normally produces a waste of energy that could be avoided.

In outdoor environments, it is not studied as much as in the case of indoor environments, since it is much more complicated to quantize and the body is much higher, because it involves a volume to be conditioned in a much bigger order than the case of indoor environments. However, a comfortable outdoor environment makes the inhabitants more likely to carry out activities in the open air. This is particularly interesting in urban areas, since different actions can achieve a more comfortable outdoor climate. In addition, there are many activities, cultural events, sports events... that are carried out in the exterior space of a city or out from the her, and to obtain a maximum possible comfort will make that city or space gain a reputation.

Outdoor environments, unlike indoor environments, can present great variations in daily and seasonal climate, which are more difficult to control and directly affect the energy balance between the inhabitants and the outside air, so, in the comfort.

In terms of urban planning, the study of thermal comfort in external spaces is also of great importance, since when building or constructing equipment (cultural, sporting...) the more comfortable the climate, the more the space will be used or demanded. Moreover, urban planning plays a fundamental role in the pursuit of this thermal comfort, since with different techniques or actions it is possible to influence on it.

1- *Which factors influence thermal comfort?*

Historically, thermal comfort has been related to air temperature and wind speed, so it is certain that these two parameters have a big influence on thermal comfort, but they are not the only ones, there is a large number of parameters that determine comfort, and that is why it is so complicated to model, and there are also many models that quantify the comfort that are explained after.

These parameters or factors can be divided into different types.

From one band there are the external environmental factors, which, as indicated, are the set of phenomena that have the outside and that can influence human comfort. These are very difficult to control or influence, since they are marked by the climatic conditions of each area of the planet, and moreover, there are great changes throughout the days and seasons of the year.

Another type of factor is the personal physiology and contribution, so, those factors that depend on the physiology of each person and the behavior and activities that he or she is going to carry out. These factors lead to variations in the sensations of comfort in the same space between different people. For the same climate and space, a person can feel warm or a different feeling of comfort depending on his or her activities and constitution.

The most difficult factors to study and therefore to quantify are the socio-cultural and psychological ones, which are the ones that vary the sensation of comfort depending on social (not only on the individual, but also on the group) and psychological relationships, that is to say, they are not directly related to physiology, but rather to behaviors or facts that condition the perceptions of the brain in terms of thermal sensation.

The factors which are easiest to influence and control are the indoor environmental factors, since in a closed area, with current technology it is very easy to modify the climatic conditions and it does not involve high body's, but it represents an energy waste which is sometimes avoidable.

Finally, there are architectural factors of adaptability of space, which are based on the architecture, usually of an indoor environment, can influence the feeling of thermal comfort of people who are in it.

Within these types of factors there is a long series of parameters that modify thermal comfort, many of which are obvious, but which are not so easy to qualify and whose relationship with thermal comfort has been discovered through studies and experiments. Therefore, it cannot be said that they are all the factors that influence comfort since, as it is a subject that is being studied and researched, they can identify new factors and parameters that are not considered to be influential nowadays.

2- What are the new technologies that will influence the field of thermal comfort?

The HOME Project proposes a series of new technologies that have emerged over the last few years, related to computer advances. The aim is to identify what these technologies are and how they can influence the field of thermal comfort. What are the aspects that can help the investigation of the comfort and how they can help the application of the air conditioning operation of the building.

Research questions

Considering the objectives and title of this thesis, the research questions to be answered are:

What are the factors that influence human thermal comfort?

What are the new technologies that can play an important role in the field of thermal comfort and how they can help in this field?

The questions are related with which are the parameters that influence the thermal comfort and which are the methods and models to find them.

Summary of tools of thermal comfort study

The different factors that influence thermal comfort are announced below and will be explained in more detail later:

- Temperature of the outside air.

- Outside radiant temperature.

- Indoor relative humidity.

- Indoor air speed.

- Sex.

- Age.

- Weight.

- Metabolism tax.

- Light.

- Thermal history.

- Length of stay.

- Types of clothing.

- Expectations of comfort.

- Interpersonal relationships.

- Visual contact with the outside world.

- Indoor air temperature.

- Indoor radiant temperature.

- Indoor relative humidity.

- Indoor air speed.

-Thermal asymmetry.

Structure

The structure of the work is based on the synthesis of several articles that help to answer the question of How is thermal comfort measured?

The thesis consists of 4 chapters in that order: Introduction, Methodology, Literature review and Conclusions.

1- **Introduction:** This chapter is divided in three parts: Background (there is a general definition of the comfort and a summary of the literature review), Objectives and Structure.
2- **Methodology:** Here is an explanation of the methodolgy realised in the thesis, the literature review. It's divided in four parts: Introduction to the methodology, Specific methodology, Research focus and Limitations of the methodology.
3- **Literature review:** It's an overview of the selected articles, they are separated. Here is also a list of factors or parameters related with thermal comfort and a list of methods to found the behaviour of the thermal comfort.
4- **List of factors:** It's a compilation of the parameters of the thermal comfort.
5- **Conclusions:** It's an answer to the research question.

The articles are based on research work, each with its aim, the context, what does the report present, the explanation and methodology and the relevant results. It is important to note that most of them are not based on answering the same question as in this project, but from hypothesis and results obtained in each of them we have just obtained useful information to answer the question.

Methodology

Introduction to the methodology

Definition of literature review

This project bases its methodology on literature review.

The literature review is a method of study and development of projects that is based on the management of information, so, to look for, to select and to consult the bibliography that can be useful in the field that is to study or that has a deep relation that helps to understand ideas that serve for the investigation. Literatures reviews are designed "to provide an overview of sources you have explored while researching a particular topic and to demonstrate to your readers how your research fits within a larger field of study" (Fink, 2014).

The fact that we find ourselves in a time when there is a big deal of information, which is available to anyone with a computer, that anyone can share information without being verified, without being filtered, and that there is a constant appearance and diffusion of this information, makes it even more complicated to identify what is the most relevant information related to the field of study.

Literature review is defined as the documentary operation of recovering a set of documents or bibliographic references that are published in the world on a specific topic, author, publication or work. It is retrospective and provides information that is limited to a specific period of time. Furthermore, a good review critically evaluates the results and questions raised in previous works, thus providing a justification for the research and demonstrating a broad knowledge of the conceptual basis of the study or subject.

We must also know how to differentiate between a review and an original work, and the latter is differentiated in the unit of analysis and not in the scientific principles applied.

The following steps have been followed to realize this literature review:

1- Use the keywords "comfort", "thermal comfort", "thermal comfort methods" and "thermal comfort parameters" on Google Scholar and analyse the title of the ten first results.

2- Download the articles with the titles with more relevance or related with the thesis topic.
3- Read the abstract of the downloaded articles and analyse which of them would be useful for the thesis and remove those which wouldn't be useful.
4- Read the articles and summarize it highlighting the most relevant information of it.
5- Compare the information found on the different articles.
6- Make a list of methods and parameters related with the thermal comfort found in the articles.
7- Write another summary of the articles only with the relevant parts for the literature review and sort them.
8- Write the conclusions related with the research question enunciated above.

Type of literature review

There is no specific classification of literature review, traditionally it can be classified in three general types, which are the following:

- Exhaustive: An article on commented bibliography, usually consisting of long and very specialized texts. They do not offer accurate information for professionals to answer specific questions.

- Description: It is in charge of updating the reader on the concept in which he or she is interested. They are used very much as a teaching method and also by people who study related fields.

- Assessment: This type answers a specific question, offering answers based on scientific evidence.

Therefore, they can also be classified in a more specific way into three types being defined by Snyder on 2019, which are:

- Systematic: It can be explained as a research method and process for identifying appraising relevant research and to collect data related with the topic of the thesis. It identifies all empirical evidences that support an answer to a question or hypothesis. It is used to synthesize research findings in a systematic, transparent, and reproducible way and have been referred to as the gold standard among reviews.

- Semi-systematic: Because every single article related with the topic can't be reviewed, it takes a different strategy. A semi-systematic review often looks at how research within a selected field has progressed over time or how a topic has developed across research traditions. In general, the review seeks to identify and understand all potentially relevant research traditions that have implications for the studied topic and to synthesize these using meta-narratives instead of by measuring effect size. It also like it's designed for topics that have been conceptualized differently and studied by various groups of researchers within diverse disciplines and that hinder a full systematic review process".

- Integrative review: It’s related to the semi-systematic review but it has a different purpose, it wants to “assess, critique and synthesize the literature on a research topic in a way that enables new theoretical frameworks and perspectives to emerge”(Torraco, 2005). It’s used when the person wants “to overview the knowledge base, to critically review and potentially reconceptualize, and to expand on the theoretical foundation of the specific topic as it develops” (Snyder,2019).

Specific methodology

Type of methodology used

This project is about understanding and collecting what thermal comfort is and which parameters can influence it. It is clear that over the years many studies have been made on this subject and many experiments have been carried out to find out and verify which these parameters are. Therefore, this work is intended to be a collection of information on this subject.

As it has been commented, this topic is not remote, there are many articles and researches about it that have made it impossible to reach, analyze and comment a great part of the existing articles. However, there have been some articles that are considered to be closely related to the issue of thermal comfort.

According to the classification of types of revisions of Snyder on 2019, commented on the previous section, this is a systematic literature review, because it includes only quantitative, experimental studies and many times only randomized controlled trials. On integrative reviews there are both quantitative and qualitative studies, so it's not the case.

It's also known that, systematic reviews "are based on pre-defined eligibility criteria and conducted according to a pre-defined methodological approach as outlined in an associated protocol" (Moher et al., 2016).

It's important to define a plan of how to make the research and to follow it, according to PRISMA-P Group, "the preparation of a protocol is an essential component of the systematic review process; it ensures that a systematic review is carefully planned and that what is planned is explicitly documented before the review starts, thus promoting consistent conduct by the review team, accountability, research integrity, and transparency of the eventual completed review" (Moher et al., 2016).

As the recommended checklist of items to make a systematic review that shows PRISMA- P Group, there is an adapted checklist of this thesis literature review. This list is comprised of six items shown below:

Eligibility criteria:

There are no restrictions on the years of the studies or publications or studies designs. The research is done all around the world, so there's not any geographical location restriction. The language of publications is Spanish, English and Italian.

The searching keywords are "thermal comfort", "comfort", "thermal comfort methods", "thermal comfort parameters", "comfort measures", "factores confort térmico", "historia del confort térmico". The entries considerated are the first ten.

Information sources:

The research has been focused on Google Scholar and articles received from Progetto HOME before. Most of the information has been found on scientific articles found through Google Scholar research.

Search strategy:

Only articles specifically declared as thermal comfort studies were considered, without publication year restrictions, the languages searched were only in Spanish, Italian and English.

Data management:

The articles downloaded have been those of the ten first entries that had the more relevant title related with the well-being or comfort. After this selection, the next step has been reading the abstract of those and analyses which of them would be useful for the thesis.

Selection process:

The articles that once read one time is confirmed that are related with the thermal comfort or bring useful information related to them, would be selected to next summarizing them.

Articles that are not published on scientific magazines or universities would be excluded from the thesis because its veracity.

Data collection process and Data items:

The method is to extract data form the publications independently.

One of the most used tools is the search of the word desired (i.e. Temperature) on the articles and comparing on other articles what does the article say about it, if it is in order to the others it's important to collect the data about it to next compare them all.

One other used method is to search parameters of thermal comfort on the article. If there is a new parameter found, then search more information about it to verify.

Research focus

Which articles have been chosen and why?

For the realization of this thesis, there has been chosen a serie of articles, then they are analyzed and it is commented what has made them be chosen for the realization of this summary or revisions:

- **Assessment of man's thermal comfort in practice** (Fanger, 1973)**.**

This article announces possible improvements of the model that was be published by the same author years before, announcing possible hypotheses that over time have been raised by other authors and in many cases have been verified. The author of the static model, in order to quantify the thermal comfort, is aware that it is incomplete and announces why. In addition, he proposes other parameters, all related to the tax of metabolism that influence the thermal comfort.

- **Developing an Adaptive Model of Thermal Comfort and Preference** (de Dear & Brager, 1998)**.**

This article is a literature review about a big number of experiments that shows that it is necessary to study the behavior of the occupants of a building considering them active, separating it from the old vision of considering the occupants to be passive. In this way, new factors are found that influence thermal comfort, since the theory of the adaptive model is proposed, in which new factors such as thermal history and other psychological, physiological and behavioral factors are pronounced.

Thermal comfort: Research and practice (Van Hoof et al., 2010)**.**

This articles offers a general point of view of the two main types of thermal comfort models, commenting on their strong points and weak points and showing how the two models are included in the main thermal comfort standards, especially the PMV model. It also comments on how computer science can influence and donate tools to advance in the research of this field.

-**Thermal comfort and visual interaction: a subjective survey** (D'Ambrosio Alfano et al., 2019).

This article focuses on the study of how light can influence thermal comfort. From a study carried out in a laboratory room with bright and warm light, it will be possible to analyze if this possible factor is significant, so it is interesting to check the existence of a new factor that influences thermal comfort.

-Thermal Comfort and the Heat Stress Indices (Epstein & Moran, 2006)**.**

This article explains what are the indices of thermal stress currently used to define the conditions of safety in industry, what are the sporadic events... It also explains how the expressions of these have been arrived at and what are the parameters that influence them.

-**Practical evaluation of the thermal comfort parameters** (Markov, 2002)**.**

This article focuses on the study of another factor that influences thermal comfort: thermal asymmetry. It explains that the main phenomena are that cause a sensation of discomfort and how they are modelled.

-**Thermal comfort models: A review and numerical investigation** (Cheng et al., 2012).

This article explains how, starting from Fanger's model, we have been trying to arrive at models that try to simulate a series of assimilated and transient conditions, that is, real ones. There are also two models that can be simulated, and this article focuses on explaining one of them, the University of Berkeley.

-A method to weight three categories of adaptive thermal comfort(Cheng et al., 2012)**.**
This article proposes a method for quantifying the different parameters proposed in the adapted model of comfort, by following hierarchical structures and with the qualification of importance of different experts from the UK and China. Above the conclusion that which are the most influential parameters in adaptive comfort.

- Impact of Social Network Type and structure on modeling normative energy use behavior interventions (Anderson et al., 2014)**.**

This article was initially intended to locate whether the social relationships within a group increase or reduce the demand for energy to condition a habitat or indoor environment. This is extremely related to thermal comfort and its relationship with social relations, which is of great interest in identifying whether this parameter influences the thermal comfort of people.

- **Heritage buildings and energy performance: Mapping with GIS tools** (Fabbri et al., 2012)**.**

This article is based on how the architecture of urban buildings is influenced, and according to five types of buildings and the period in which they were built, it is possible to observe and map the energy class of each building. The fact of having studied the energy efficiency in function of the type of building also contributes to respect the thermal comfort.

- **Characterizing the household energy consumption in heritage Nanjing Tulou buildings, China, A comparative field survey study** (Li et al., 2012).

This is a comparative study of the energy consumption and thermal comfort between normal rural buildings and the Tulou buildings (a type of rural building located in China). This consisted of a survey of consumption data of the respective buildings, an observation of the habits of the population and a subsequent survey on the thermal comfort of the different buildings. From the collection of data and surveys, it was possible to observe the influence of some parameters.

- **Thermal comfort in open spaces. Comparison of models and their application in cities in arid areas** (Angélica Ruiz & Correa, 2009)**.**

The remarkable fact of this article is that while most of the studies are focused on the quantification of comfort in indoor spaces, this article is based on the obtention of parameters that influence comfort in outdoor spaces.

- **Zona variable de confort** (Variable de Confort Térmico & Propuesto, 2002).

This work explains in a summarized way who are the main actors in human thermal comfort and also shows and explains other parameters that are not so evident. In addition, it explains why its influence helps to understand how human physiology works, and in this way helps to make hypotheses of possible parameters that may have a little or a lot of influence on comfort.

- **El confort térmico adaptativo** (Godoy Muñoz, 2012)**.**

This work has been of great interest because it explains how the two most important theories on thermal comfort have evolved and compares them. It also helps to understand the physiology that affects comfort.

- **Evaluation of thermal comfort in enclosures of 10 public buildings in Chile in winter** (Molina & Veas, 2012)**.**

The aim of this article is to check whether the ASHRAE 55 and ISO 7730 standards, which refer to human comfort and are used as building and public building regulations, are adjusted to the real comfort experienced by the inhabitants. It also compares the values of the conditions with their representation in the psychometric diagram. From these data it also checks whether the traditionally defined parameters are meaningful in terms of other factors and shows their correlation.

- Physical foundations and methods of evaluation of climatic comfort in human bioclimatology studies (Fernández García, 1994).

It provides a deeper insight into the physiological concepts related to thermal comfort and an explanation of the modeling of comfort from energy balances. It also explains the most commonly used methods for modelling comfort and a summary of the variables that influence comfort.

Limitations of the methodology

The main limitation that there is when trying to do a bibliographic review on a scientific subject is that it is not possible to empirically prove the validity of the results offered by the articles. However, the hypotheses of the different articles have been empirically proved.

Another limitation is that it is very difficult to provide what the original paper on the subject says, since it is based on the different articles studied and it is not possible to carry out an experiment to try to prove or realize and prove new hypotheses about factors that may influence human comfort.

There is a limitation to the information because there are a great number of articles dedicated to the study of architectural parameters or other techniques to arrive at the thermal comfort of the inhabitants, but do not study what is the comfort itself, nor the parameters that influence it. Many of these articles are based on the energy balance as a consequence of architectural changes and therefore these parameters are studied, but the energy balance is not studied from the point of view of thermal comfort.

Another limitation is that there is a great number of models and expressions that quantify comfort and this has made it necessary to create a selection of those considered to be the most used and/or relevant. Therefore, the fact that they follow the most used ones does not guarantee that they follow the ones that are closer to reality.

In short, the main limitation has been that we have not been able to carry out experiments on the subject and obtain results from these, the conclusions.

Literature review

Experiments (articles)

- Assessment of man's thermal comfort in practice (Fanger, 1973)**.**

Aim: This article reviews the parameters that are considered to influence the thermal comfort and assesses the features of the main model that were presented in the past. It explains the methodology that is supposed to be used to obtain thermal comfort models. He assesses the different environmental and physiologic parameters: age, adaptation, sex, daily activity rhythm, unilateral heating or cooling of the body (discussed) and the monotonic climate.

Context: International.

What does the report present: This article presents an analysis of the conditions for human thermal comfort, including ideal thermal environments and methods for assessing the quality of thermal comfort. Uncomfortable environments are found in some places where there are people capable of working, and therefore they are the ones studied, as well as the methods to create models more adapted to reality.

Explanation: Before starting to look for parameters that influence thermal comfort, we must ask ourselves: What is comfort? The author quotes the definition made by ASHRAE about this phenomenon as "that condition of mind which expresses satisfaction with the thermal environment" (ASHARE, et al., 1966), this statement can also be affirmed as "the absence of discomfort". Well, due to each organism is different, the distribution of what is comfortable is asymmetric, if you have a group of people in the same space, you can see the biological differences between them and there will be a diversity of opinions on whether the environment is comfortable or not, so it is a matter of creating an environment with the maximum percentage of people who are comfortable.

The thermoregulatory system aims to maintain a constant body temperature, so that the heat dissipated remains equal to that produced by the body itself, maintaining an energy balance. The mechanisms of the body itself are very effective, based on vasocompression and vasodilation.

So it is easy to see that there is a difference in comfort between a person with sedentary activity and a person with high physical activity. From the equations found by Fanger himself in 1967, where he relates the temperature of comfort of the skin according to the metabolism (the metabolism increases in measure that increases the physical activity of the person), it is concluded that "man prefers a skin temperature of about 34 ° C, while the preferred skin temperature is, for example, only about 31 ° C to an activity three times higher than the sedentary level" (P. O. Fanger, Assessment of man's thermal comfort in practice, 1973) and that "he prefers a sweat secretion of zero during sedentary activity (M = 58 W/m2), while for higher activities he prefers a sweat secretion that implies a latent heat loss"(Fanger, 1973).

P.O. Fanger proposed the first static model to quantify the thermal comfort. However, he was aware that this was not sufficient to quantify it perfectly, since he did not take into account the states of transition or the active attitude of the occupants, and he affirms in this article that "The relationship between man's thermal sensation and his physiological reactions during sudden environmental changes is certainly complicated, and further research is necessary before it will be possible to establish quantitative physiological comfort conditions for thermal transients" (Fanger, 1973).

Since it is not possible to quantify the parameters that belong to the active attitude of the occupants and the respective states of transition, he carries out experiments and researches with the main parameters and that is a layer of quantification.

There are four main physical parameters that give great information on whether an environment is comfortable or not, these are:

-Air temperature.

-Mean radiant temperature.

-Relative air velocity.

-Vapor pressure in ambient air.

Apart from these four parameters, human thermal comfort is strongly influenced by two other parameters, which can be further subdivided:

-Activity level.

-Thermal resistance of clothing.

Methodology: The method used by P.O. Fanger is based on the votes of the subjects regarding the thermal comfort or thermal sensation that they perceive in different environmental thermal states, so, with different combinations of the parameters previously mentioned. At the same time, the conditions to which they are exposed should be noted in order to be able to calculate the optimum ambient temperature using statistics. As you can see, it is a matter of laboratory methods.

This same method has been used for a large number of studies in controlled laboratory conditions, so there is a large sample of data.

Therefore, although many data are obtained by setting parameters and varying them, P.O. Fanger is aware that the parameters do not independently affect comfort, but that "it is the combined thermal effect of all the physical factors which is of importance for man's thermal state and comfort. It is therefore impossible to consider the effect of any of the physical factors influencing thermal comfort independently, as the effect of each of them depends on the level of the other factors" (Fanger, 1973).

As well as not being able to consider the influence of parameters independently, Fanger is also aware of the individual differences between people, so he says that there is no temperature that guarantees the comfort of all people who are in a given environment, "Everyone is not alike. How then is it possible, from an equation, to specify one particular temperature which will provide comfort? The answer is that the comfort equation does not necessarily satisfy everyone. It gives, however, combinations of the variables which will provide comfort for the greatest number of people” (Fanger, 1973).

Although he was aware of the limitations of the model, with the data obtained from the laboratory tests, he created a large number of comfort diagrams, using the same parameters as before. It is a matter of maintaining three of the parameters and studying the variable behavior of the other three. Figure 11 shows one of the diagrams. In this case, it shows how the comfort point evolves according to the radiant temperature, the air temperature and the air speed. The comfort point is the relative velocity. In this diagram you can see how the values of physical activity, relative humidity and air quality are fixed.

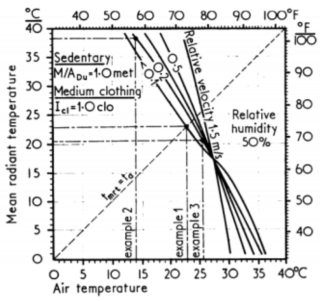

Figure 1. Example of P.O. Fanger diagram.

Comfort zones:

As Fanger commented earlier, there is no single point of comfort for a group of people, so what does exist is a comfort zone, that is, an interval of environmental conditions where a large percentage of the group is shown in a comfortable situation. Therefore, just as the comfort point varies between people, so do the comfort zones, the comfort intervals vary between people, and it could be that the interval of a person who is ill outside the interval of another person in the same group, so it is important to obtain a point with a maximum percentage of 5% of dissatisfaction.

Relevant results:

-Fanger contemplates a new phenomenon linked to the activity of people, that is, with the metabolism. This phenomenon is that the "conditions of comfort are altered during the day since the internal temperature of the body has a daily rhythm, a maximum that occurs at the end of the afternoon and a minimum at the beginning of the morning" (P.O. Fanger, 1973).

As can be seen in Figure 6, the human being prefers a warm environment in the upper reaches and a cooler environment in the lower reaches.

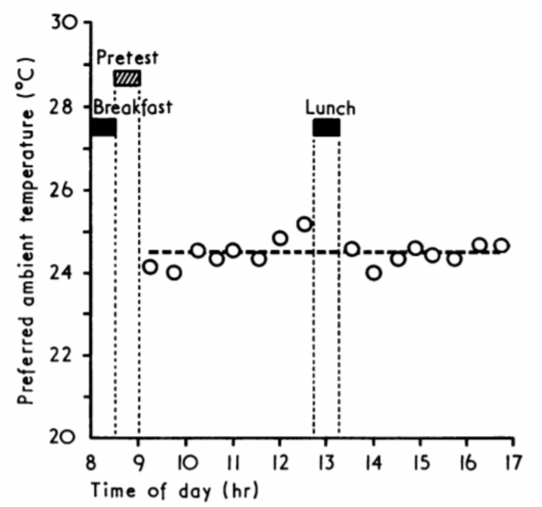

Figure 2. Preferred ambient temperature in front the hours of a day.

-Another study that Fanger shows in this article is the result of studying the climatic monotony as a parameter influencing human comfort. It had been stated, without experimental tests, that a monotonous climate can create fatigue, less excitement and lower performance in people.

After carrying out different experiments, in which people were exposed to variations in temperature and their thermal sensations, mental performance and behavior were studied, it was observed that there were positive effects on performance, but only when the temperature changes were great, so that it created an unpleasant sensation, full of thermal comfort.

-As a last phenomenon related to thermal comfort, Fanger enunciates the phenomenon of unilateral body heating or cooling, so, "Although a person may feel thermally neutral for the body in general, that is, he or she would prefer an environment that is neither warmer nor colder, he or she may not be in thermal comfort if one part of the body is hot and the other cold. This could be caused by an asymmetrical radiant field or local convective cooling of the body (airflow) or by contact with a hot or cold floor. In addition to comfort conditions for the body in general, it is therefore essential to set limits to how asymmetrical the body's heat loss can be without evoking discomfort" (Fanger, 1973).

However, he states that more studies are needed to be able to model this thermal asymmetry and to be able to find out in which conditions a person is in total comfort and asymmetry.

-The static model is incomplete and it is necessary to "establish comfort conditions during transient periods (including temperature and humidity fluctuations and sudden changes, for example, when a person moves from the outside to the inside). In this regard, it would be desirable to conduct more fundamental studies to clarify the correlation between man's thermal sensation and the function of his thermoregulatory system" (Fanger, 1973).

-Another aspect that Fanger considers should be studied is the case of people in a state of rest, namely, sleep. In this way the optimal thermal conditions for the night rest are obtained, which has a great importance in the daily performance of the people.

- **Developing an Adaptive Model of Thermal Comfort and Preference** (de Dear & Brager, 1998)**.**

Aim: This article demonstrates the existence of contextual factors and thermal history that modify the temperature of the building's occupants, so, an adaptive theory of thermal comfort, since previously, the model of P.O. Fanger was based on a static hypothesis, which was not taken into account many factors that have ended up being influential.

Context: International.

What does the report present: By means of a literature review on the 21.000 observations of 160 buildings, the results of the observations have been compared with the static model proposed by P.O. Fanger in 1973, and it has been concluded that there are more factors that are not taken into account. In this way it is possible to understand the occupants as active receptors and they begin to notice thermal stimuli to which they respond. "One of the predictions of the adaptive hypothesis is that people in hot climate areas prefer warmer indoor temperatures than people living in cold climate areas" (de Dear & Brager, 1998). It is important to note that the regulations at that time did not take into account that the occupants were individuals, but considered that they "ignored important cultural, climatic, social, and contextual dimensions of comfort, which led to an exaggeration of the need for air conditioning" (Lutzenhiser, 1993).

Explanation: In order to examine that the hypothesis of the adapted model is true, it will gather a data base of controlled quality from experiments of thermal comfort fields carried out all over the world, consisting of 21,000 observations in 160 buildings. From statistical analysis, it is proven that the anti-model of prediction of vote proposed by P.O. Fanger had a certain adaptive character and that it is adapted in a more accurate way in HVAC spaces than in spaces with natural ventilation. "The occupants of naturally ventilated buildings were tolerant of a significantly wider range of temperatures, explained by a combination of both behavioral adjustment and psychological adaptation. These results formed the basis of a proposed variable indoor temperature standard"(de Dear & Brager, 1998).

Therefore, the objective of the experiment was to propose a standard that links indoor temperatures to the climatic context of the building and that takes into account the thermal history and expectations of the current occupants.

Since the term "adaptation" has a very broad meaning, he decided to "divide it into three subcategories of thermal adaptation: behavioral adjustment, physiological and psychological" (Folk, 1981).

Behavioral adjustment: All the modifications that an occupant can make in a conscious or unconscious way but that affect the heat flow and therefore the thermal comfort. This can also be subdivided into personal, technological and cultural adjustments.

Physiological: Based on the physiological responses of the human body as a result of environmental and thermal factors.

Psychological: Based on the alteration of the perception and sensory reaction of the occupant to present and past experiences and expectations.

One of the main problems that De Dear finds with the static thermal models is that they are based on rigorous experiments carried out in laboratories, so that they do not reflect reality in more complex environments in real buildings where there are real occupants who may not be aware that they are objects of study. However, De Dear considers that "Our opinion is that the adaptive perspective complements, rather than contradicts, the vision of static thermal balance" (de Dear & Brager, 1998), since the static model contemplates part of the proposed adaptive model, such as the environmental thermal parameters, theft and metabolic rate.

Therefore, the methodology to propose a new model that we have adapted is

1- Elaborate and define adaptation processes in the context of indoor climate perception.

2- To examine the scales of preference and acceptability in the model of thermal comfort.

3- To propose statistical models including adjustment, acclimatization and habituation.

4- Compare the adapted models with the static models.

5- To propose a standard of variable temperature.

The role of expectation in thermal comfort research was acknowledged in the earlier work of McIntyre (1980), who stated that "a person's reaction to a temperature, which is less than perfect will depend very much on his expectations, personality, and what else he is doing at the time." Although the least studied of the three adaptive mechanisms, psychological adaptation might actually play the most significant role in explaining the differences between observed and predicted thermal responses. "This can be seen particularly in light of different environmental contexts, such as the laboratory vs. home vs. office, or when comparing responses in air-conditioned vs. naturally-ventilated buildings" (Fishman & Pimbert, 1982).

On 1975, Humphreys found that "building occupants were able to find comfort in indoor temperatures covering a broad band of more than 13 K, and attributed this to the adaptive processes" (Nicol & Humphreys, 2002).Later, Humphreys and Auliciems showed that there was a difference between the internal and external neutral temperatures, which would lead to think that there is also a difference between the HVAC and the naturally ventilated spaces.

Methodology: The method used in this article is based on a literature review, with Brager and De Dear we could see that the one that gives more evidence that the hypothesis of the adapted model was certain is the field work and not past the experiments in laboratories, therefore, will focus exclusively on the data of field work.

Therefore, the first step would be the creation of a data base by sending a research method questionnaire to experts in thermal comfort.

These will include the factors:

• thermal questionnaire responses (sensation, acceptability, and preference)

• clothing and metabolic estimates

• concurrent indoor climate observations (air and globe temperatures, air velocity, dew point, and plane radiant asymmetry temperature)

• thermal indices (mean radiant temperature, operative temperature, turbulence intensity, ET*, SET*, TSENS, DISC, PMV/PPD, and PD draft risk) were "recalculated for each set of observations using the ASHRAE RP-781 software package known as the ASHRAE Thermal Comfort Tool" (Fountain and Huizenga, 1996).

• outdoor meteorological observations including daily temperatures and relative humidities at 600 hours and 1500 hours, and daily effective temperatures (ET*) also calculated with the software package (excluding the effects of solar radiation).

With the data of 160 buildings, we will proceed to make a survey of the buildings that have a small sample size or that have a high hot or cold indoor temperature. This will be done based on a statistical analysis in which if the model does not reach a statistical significance of $p < 0.05$, this building will be automatically discarded.

The statistical analysis is based on finding a thermal neutrality, which will be calculated for each building after the following steps:

1- Variations of the temperature have been made of slight rise and fall in the indoor of the building and the thermal sensations of the occupants have been noted.

2- A linear return model of the type y = ax + b has been made.

3- From this point on, it was possible to observe in which cases the reality followed the model or was far from the linear return.

Relevant results:

- Figure 10 shows the data obtained on the indoor operating temperature depending on the clothes worn by the occupants in the cases of being in an air-conditioned building and a building with natural ventilation.

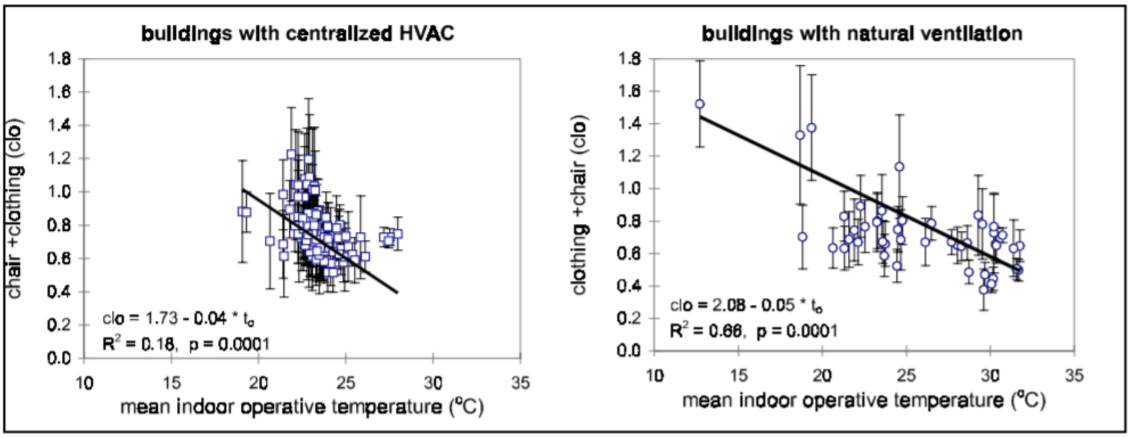

Figure 3. Comparison of clothing level in front the mean indoor operative temperature in HVAC and natural buildings.

As can be seen in Figure 10, the indoor operating temperature decreases faster in the case of air-conditioned buildings than in the case of natural ventilation buildings, i.e., the occupants of natural ventilation buildings are more resistant to wear and tear, i.e., they have a greater comfort level than in the case of occupants of air-conditioned buildings.

- In Figure 11 we can see the relationship between indoor operating temperature and indoor air velocity, both in the case of air-conditioned buildings and naturally ventilated ones.

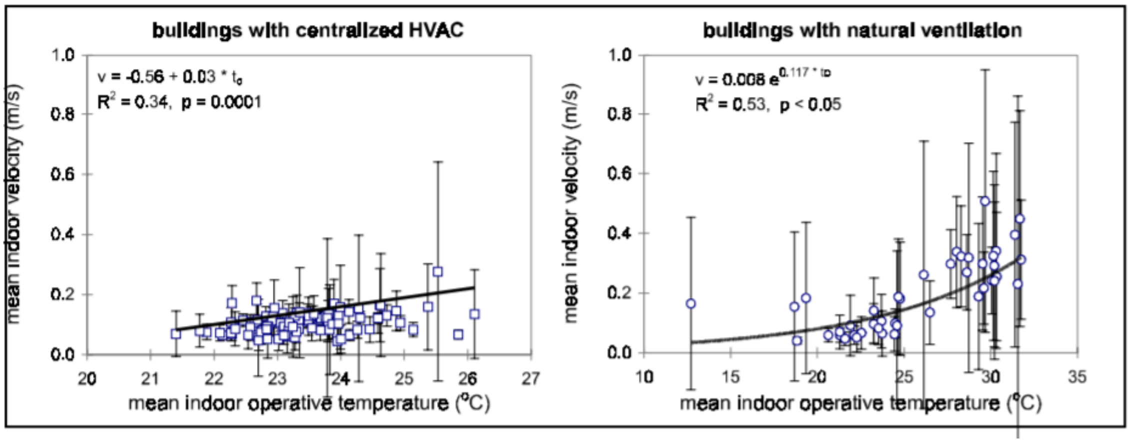

Figure 4. Comparison of mean indoor velocity and mean indoor operative temperature in HVAC and natural ventilated buildings.

As can be seen in Figure 11, in the air-conditioned buildings there is a linear behavior and a range of temperatures much smaller compared to the natural ventilation buildings, where there is a much greater range of operating temperatures with an exponential behavior, the faster they need a higher temperature, as is logical.

- Figure 12 shows the relationship between indoor operating temperature and neutral operating temperature, that is, a relationship between the actual temperature inside and the modified temperature of the occupants in order to find themselves in a comfortable situation.

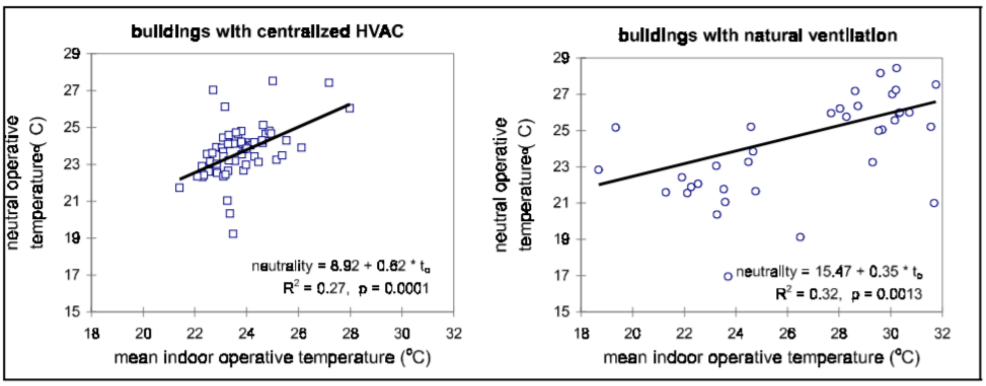

Figure 5. Comparison of neutral operative temperature in front of mean indoor operative temperature in HVAC and natural ventilated buildings.

As can be seen in Figure 12, the indoor neutral temperature and the indoor operating temperature follow a fairly strict linearity in the case of HVAC buildings, whereas in the case of natural ventilation buildings, it is not, because the occupants are less demanding in terms of indoor temperature. That is why it is a psychological action, since the occupant has less expectations of comfort, and therefore, is more resistant to uncomfortable situations.

- Finally, Figure 13 shows the comfort temperature calculated from each model (static and adaptive) according to the outside temperature. This graph has been made both for buildings with HVAC and for buildings with natural ventilation.

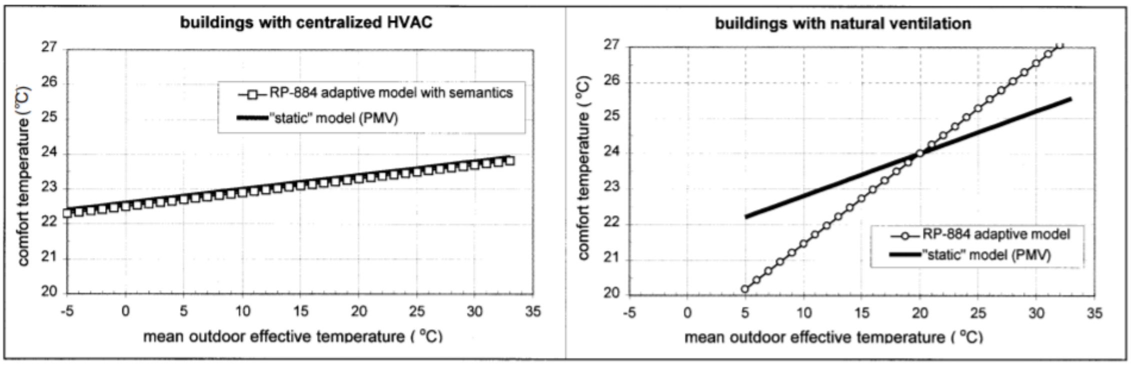

Figure 6. Comparison of confort temperature in front of mean outdoor effective temperature in HVAC and natural ventilated buildings.

As can be seen in Figure 15, in the case of buildings with HVAC, the comfort temperature calculated by the static model and by the adaptive model is the same, but in the case of ventilated buildings the comfort temperature in the adaptive model is lower when the outside temperature is low and higher when the outside temperature is high, This explains that the theory of the static model is partially valid, since it only covers spaces with HVAC, and so De Dear says that it should complement it, since ventilated spaces naturally have a different behavior.

Thermal comfort: Research and practice (Van Hoof et al., 2010)**.**

Aim: This article analyzes the advances that have been produced during the second half of the 20th century. From one band, the models and standards around thermal comfort and from another band, the advances in computer science. On models, it's differentiated in two groups, in one band, the PMV (Predicted Mean Vote) proposed by Fanger the year 1967 and on the other band the models adapted proposed later.

Context: International.

What does the report present: This article offers a general view of the two types of thermal comfort models, commenting on their strong points and weak points and showing how the two models are included in the main thermal comfort standards, especially the PMV model. He also comments on how computer science can influence and bring tools to advance in the research on this field.

Methodology: The methodology of this article is based on office work and its surroundings. Therefore, a number of studies have been carried out in order to analyze the strong and weak points of the models and to analyze how computer science can help in the evolution of comfort.

Not only have studies been carried out in offices/laboratories, but also in residential buildings, third age residences, commercial airlines, places of worship, military fields, health care centers, emergency rooms, schools, transition spaces. Since current standards of thermal comfort do not include outdoor space, the corresponding studies have been ignored.

Explanation:

The advances in computer science have produced an increase in the ability to assess and model complex physical and physiological conditions. This fact has facilitated the resolution of non-linear equipment of the PMV model and the realization of complex simulations of building performance in the design phase in order to provide thermal comfort to the occupants.

Without doubt, the most known and used model is the PMV, also known as a static model, which is based on a hypothesis of constancy of the occupants and environmental conditions.

Therefore, this model is old (P.O. Fanger, 1973) and each time the adaptability hypothesis is used more (de Dear & Brager, 1998) in terms of practical applicability, occupant satisfaction and environmental perspective. The adaptive models are based on the fact that the occupants are able to adapt to the environmental conditions, they are active, and this fact is related to their ability to control the environment and also to the psychology and performance.

On the other hand, the importance of computers in this field is analyzed. The fact that it is available a simulation of building performance and modeling and sophisticated multisegment models of human physiology and thermal dummies, makes it to develop alternative thermal indicators with higher resolution than the previous models. These indicators relate thermal comfort with the use of energy and help designers to create ideal environmental conditions for the occupants.

The PMV model:

The P.O. Fanger model is based on the stationary state, so it assumes three hypotheses. From one band, it is assumed that the body is in thermal equilibrium, from the other band the skin and body temperature are in a marked range and finally, it is assumed that the individual is not disturbed locally.

Therefore, this model cannot provide an exact answer in a transitory state. However, it is possible that the model does not follow the static one, because it is possible to use different input parameters for the model, with different levels of activity or different isolations of the clothing.

The model found by Fanger applies often to the tropics area, but it also admits that this model needs further research.

The PMV model has been validated in many studies and is the one that follows the current ASHRAE regulations, but studies will be carried out that "gave rise to criticism of the model as a whole, its geographical scope of application, its application in various types of buildings and the input parameters of the model" (Van Hoof et al., 2010). Most of the studies confirm that the model is valid for offices with air conditioning systems.

-However, a later study concluded that the PMV model worked reliably when dealing with neutral thermal conditions, i.e. when it was between -0.5 and +0.5, once this interval had passed, the model was very well established, i.e. at least as neutral as the thermal conditions, but beyond the prediction made by the PMV. In a study with 41 samples, up to 5 would exceed the maximum deviation, ±1, so it would be stated that "the PMV is only reliable between the scale units of -0.5 and 0.5 (i.e. the comfort zones indicated in ISO 7730), which has serious consequences for the use of the PMV model in field environments" (Van Hoof et al., 2010).

-Another inconvenient that has been found in a later study is that "in environments different from when PMV=0 and thermal equilibrium is achieved in a neutral physiological condition, PMV is closer to be an experimental index than to be a theoretical index based on thermal equilibrium. It can be said that (a range of conditions with calm air, 0.6 clo) is the only range of PMV application that is supported by experimental evidence" (Mochida & Sakoi, 2003).

-Starting from the PMV model, the validity of the PPD will also be studied and it will be found that "the symmetry of the PPD around the optimum of thermoneutrality was not valid for residential buildings. Particularly on the warmer side, there were fewer dissatisfied people than in the PMV-PPD ratio" (Becker & Paciuk, 2009).

In spite of the criticisms, the PMV model has many strong points, these strong points have made it possible for it to follow the reference model on which it is modified, but also to make the subsequent modifications that have been made useful for a wide application in engineering. So, we must also take into account that the PMV model itself is an adapted model, since it has to take with the adjustments of the people's behavior in some points, such as, for example, in the clothing parameter. In addition, it explains in a very accurate way the behavior of thermal comfort in air-conditioned spaces.

One of the virtues of the model is that within a certain complexity it is a simple model that uses only its parameters and adjusts in a precise manner in many situations, "the more complex the index (PMV, ET*, SET*), the lower the correlation with the subjective heat, which suggests that increasing the exhaustiveness of the index can actually introduce more error than it eliminates" (Nicol & Humphreys, 2002).

Adaptive model:

The adaptive model proposes the hypothesis that there are contextual factors, thermal history and psychological factors that modify the thermal sensation of the occupant, for example, "people living in hot climate areas would prefer higher indoor temperatures than those living in cold climate areas, which contrasts with the hypotheses on which the comfort standards based on the PMV model are based" (de Dear & Brager, 1998). This adaptation can be both for personal behavior and for physiological and psychological factors.

It confirmed a physiological phenomenon, which is that the cardiovascular and thermoregulatory systems are interrelated, "Increases in exercise levels that promote greater cardiovascular activity also increase the production of metabolic heat that must be balanced by the thermoregulatory system" (Stoops, 2006).

The adaptive model contemplates that the occupants have the means to control their thermal environment in a building, also in buildings with natural ventilation, by adopting an active attitude. "The control of the environment is a very effective way to limit the negative effects of stress on health, since external coping strategies can be used" (P. A. Vroon, 1990). "This requires systems designed for user participation, both physical (individual temperature control) and "social, in which physical conditions are considered a natural consequence of the situation, rather than being imposed arbitrarily" (D. A. McIntyre, 1984).

Another process of adaptation is the act of working or storing the windows, a study by Yun concluded that the occupants of a building with a high level of control when it comes to regulating the temperature working or storing windows use this advance more frequently than those who do not have such a high level of control. The fact of having a control on the thermal environment makes the occupants more sensitive and more demanding in the thermal comfort.

Through analysis of factors, he found that "perceived thermal comfort correlated or was associated with (i) employee stress, (ii) over-commitment of employees to work, and (iii) perceived employee privacy. The management characteristics of an organization seem to influence the perceived thermal comfort of its employees" (Vroon, 1990).

Advances in computer science:

The first computer science project that allowed great advances in the field of thermal comfort has been the simulation of building performance where the trajectories of the thermal flow and music can be studied in the same building, which facilitates the design of the buildings.

Another advantage is the possibility of installing thermostats that work at real time, which can be configured according to the user profile that is found in the building from the collection and analysis of environmental conditions preferred by the user. It is expected that “in the future environmental control will be based on intelligent systems that anticipate the needs of the occupants based on the analysis of the external climate, the way of using the space and the preferred temperature profiles” (de Dear & Brager, 1998).

Relevant results:

-The PMV model published by P.O. Fanger (1967) continues to be in force in the standards of thermal comfort and used as the most important method for its evaluation due to its wide range of application.

-Field studies have generated debates about the validity of the PMV model for its use in real world environments and global application in all types of buildings.

-The adapted model, after the previous one, gives the place to the discovery of our parameters that influence the comfort and to deep researches in the direction of the PMV model. In addition, it is also used in some cases in the normative where the PMV model is obsolete. This model has "advantages in terms of practical application and interpretation of results, and deals with human responses and adaptation in environments with natural ventilation" (Van Hoof et al., 2010).

-When an occupant has more control over the environmental conditions to which he is exposed, this becomes more rigid and demanding with the conditions, unlike the occupant who is in a building with natural ventilation.

-Computing has allowed the development of very accurate models of human physiology and fluid dynamics, which has improved the prediction of thermal comfort.

-The increase in calculation capacity allows us to solve high resolution problems in the field of thermal comfort.

-Thermal comfort and visual interaction: a subjective survey (D'Ambrosio Alfano et al., 2019).

Aim: Throughout the late 20th century and the beginning of this one, the hypothesis that light and colors can affect thermal perception has been studied. Concretely, it has been evaluated that the light with short wave length increases the cooler thermal perception and, on the contrary, the light with long wave length increases the warmer thermal perception. This is an influential parameter in thermal comfort, and therefore, worthy of comment and study.

Context: Italia.

What does the report present: This article focuses on the study of how light can influence the thermal comfort. From a study carried out in a laboratory room with bright and warm light, it has been possible to analyze if this possible parameter is significant, so it is interesting to check the existence of a new parameter that influences thermal comfort.

Methodology:

An experimental assembly was carried out in a laboratory consisting of an L-shaped room with two different rectangular parts, the experimental room and the control room.

The experimental room is a neutral environment equipped with different light sources where there is a writer and a chair. The walls of the room are covered by white curtains, one of them divides the laboratory between the two rooms.

The control room, a smaller space, consists of a DALI (Digital Addressable Lighting Interface) unit to control the lighting. This consists of a touch panel that allows you to change light scenes, vary the flux emission and the color temperature of the lights (CCT). For this experiment two different scenes have been used, of 3.000K and 6.000K, the luminous flux has been maintained at 300 lx in both scenes.

From the sensors it has measured the physical parameters that directly affect the thermal sensation; air temperature, radiation temperature, air speed, dew point and ground temperature. These sensors are placed on a tripod in a near place where the occupants are placed, in order to obtain the data more similar to that of the occupants.

The experiment room has been calibrated in a range of 18ºC to 25ºC, measuring the physical parameters every minute for 15 minutes.

81 people (40 households and 41 women) between 18 and 35 years old participated. They have gone to the experimental room one by one, and before entering they has had to answer

a personal information questionnaire (age, weight, height...) and after entering the experimental room, they have waited there for 10 minutes so that the organization could adapt to the environmental conditions of the room.

The body has to be adapted to the conditions of the room, and next respond to a questionnaire centered on thermal perception. After responding, they leave the room for 10 minutes in order to change the light scene and they made the change, repeating the same experiment with an identical questionnaire.

The questionnaire consists of the following options: The Heat Sensation Vote TSV in the typical 7-point scale [29] from -3 (cold) to +3 (warm), the evaluation vote EV expressed in the scale from 0 (comfortable) to +3 (very uncomfortable), the preference vote PV expressed in the scale from -3 (much colder) to +3 (much warmer) and the humidity vote HV expressed in the scale from -1 (wet) to +1 (dry).

Explanation:

Although it is widely accepted that thermal comfort can be influenced by non-tactile stimulation, few researches have managed to consider visual stimulation as such. There is a belief that lights and surfaces proper to red color are denoted as warm and those proper to blue color are denoted as cold, so it implies a set of environmental parameters and chromatic characteristics to be studied.

These beliefs are supported by several studies that has found that "thermal comfort was significantly affected by the color of the walls, and that participants felt colder in the blue/blue-green room" (J. Itten, The Elements of Color, 1970), in part, Fanger obtained similar results in an article in 1975 stating that "a slightly lower room temperature (about 0.4 °C) was preferable to extreme red light compared to extreme blue light (E=150÷190 lx)" (P.O. Fanger, Proceedings of Symposium on Physiological requirements on the microclimate in industry and problems of their technical realizations, 1975). Another fact is that "people wear significantly more clothes under cold light than under warm light" (Huebner GM, Shipworth DT, Gauthier S, Witzel C, Raynham P and Chan W, Energy Research and Social Science, 2016).

Relevant results:

Table 11 shows the results obtained during the experiment, where the means of the scales of the respective sensations related to the comfort that answered in the questionnaire. These means are differentiated by gender and total. On (W) is the light scene at 3.000K and (C) is the light scene at 6.000K:

Parameter	Females		Males		Overall	
	(W)	(C)	(W)	(C)	(W)	(C)
Mean TSV	0.60	0.23	0.87	0.41	0.74	0.32
p (F)	**0.082 (3.12)**		**0.016 (6.10)**		**0.0033 (8.92)**	
Mean EV	0.58	0.46	0.90	0.59	0.70	0.51
p (F)	0.278 (1.19)		0.155 (2.07)		0.076 (3.20)	
Mean PV	-0.71	-0.42	-0.69	-0.45	-0.70	-0.43
p (F)	0.190 (1.75)		0.464 (0.54)		0.138 (2.22)	
Mean HV	0.20	0.20	0.10	-0.05	0.15	0.07
p (F)	0.295 (1.11)		1 (0.00)		0.450 (0.57)	
Number of words	25.4	26.5	20.5	22.4	22.9	24.3
p (F)	0.356 (0.86)		0.202 (1.65)		0.145 (2.15)	

Table 1. Confort sensations of males and females with 3.000K and 6.000K light scenes.

As you can see in Table 11, the thermal sensation both for men and for women with the 3,000K light scene is slightly warm (TSV), but with the 6,000K light scene, the thermal sensation is slightly shifted to the cold-blooded side and still a slightly warm sensation.

It is also possible to observe that the light represents a value of the EV, therefore, people are more comfortable, but not following statistics mean this fact.

-This study has verified that the characteristics of the light can contribute to an improvement of the thermal comfort of the occupants, increasing the sensation of heat in the winter and the sensation of cold in the summer, maintaining the temperature of the heating, ventilation and air conditioning, allowing a healthy energy balance.

-The study allows us to affirm that a frying light causes a displacement of the thermal sensation from cold to hot and a heating light causes a displacement of the thermal sensation from heat to cold.

-Thermal Comfort and the Heat Stress Indices (Epstein & Moran, 2006)**.**

Aim: Thermal stress is an important factor in many situations in industry, such as sports events, which can affect the productivity and health of people with less tolerance to uncomfortable thermal situations. The indices for quantifying thermal stress are divided into three groups: rational, empirical and direct. The first two are complex, because they are a mix of environmental and psychological variables, and therefore difficult to calculate.

Context: International.

What does the report present: This article reviews the history of the indices of thermal stress. It also explains how the expressions in the indices are obtained and why they are used. It explains what parameters are related to this phenomenon.

Explanation: The human body needs to maintain a balance of ±1ºC at a temperature of 37ºC in order to remain in good condition. To achieve this, the human body is constantly performing a heat exchange with the environment that guarantees this temperature.

According to Fanger, there are several parameters that influence this phenomenon, which are: Metabolism rate, Clothing insulation, Radiant temperature, Wind speed and Humidity.

Fanger defined comfort as "the state in which these conditions are complicated: the body is in thermal equilibrium, the sweat rate is within limits and the average skin temperature is within comfort limits" (P.O. Fanger, et al., 1970). Therefore, the body is in a comfortable situation: the temperature of the center of the body is 36.5-37.5ºC, the temperature of the skin is 30ºC and the steam of the body and the cap is 34-35ºC. Any deviation from this situation causes an uncomfortable state, and therefore a situation of thermal stress, leading to a poor thermal balance between the body and the environment.

Thermal stress assessment indices:

A thermal stress index is a value that considers the effects of basic environmental parameters with the thermal stress experienced by the individual.

The first index of thermal stress is limited to the combined effect of purely environmental parameters. Later, the parameters of metabolic rate and clothing, as published by Fanger in the PMV model, will be taken into account. At the end of the 1970s, it was stated that "there cannot be a universal valid system for rating heat stress, mainly because of the number and complexity of interaction of determining factors" (Belding, Gagge, Nishi, et al., 1978). It was stated that in order for an applicable index, there has to be the following conditions: feasible and accurate in a wide range of environmental and metabolic conditions, considering all important factors (environmental, metabolic and clothing), the relevant measurements must reflect the worker's exposure without interfering with his performance, the limits must be reflected by physiological and/or psychological responses that reflect an increased risk of safety.

As previously mentioned, the rational and empirical indices are the ones that are most appropriate to reality, but at the same time they are too complexes because they take a large number of variables, so that the most used indices are the direct ones, which only use environmental variables.

In 1923 the first direct index of the effective temperature (ET) was proposed, which was established "to provide a method for determining the relative effects of air temperature and humidity on comfort" (F.C. Houghton, C.P. Yaglou, 1923). Later, in 1932, the dry-bulb temperature was replaced by the black-globe temperature in order to capture the radiation and obtain a more accurate effective temperature (CET). After this change, many modifications were made on the basis of this index. Of all the indices, two stand out that have been used today and for many years.

The wet-bulb globe temperature (WBGT) index:

This is the most widely used index of thermal stress, and it is based on a weighting of the dry-bulb temperature (Ta), the wet-bulb temperature (Tw) and the black-globe temperature (Tg), thus obtaining the following expression:

$$WBGT = 0{,}7T_w + 0{,}1T_a + 0{,}2T_g$$

This expression is used in the case of open sites. In the case of indoor sites, the expression is modified as follows:

$$WBGT = 0{,}7T_w + 0{,}3T_g$$

As you can see, this index does not use physiological parameters.

The biggest limitation of the WBGT index is its applicability, since it cannot measure the black-globe temperature in a precise way in all situations, there are circumstances where it is impractical.

The discomfort index (DI):

Due to the complication of the measurement of the black-globe temperature, it was proposed "a simple direct index (WD) based on a weighted summation of aspirated wet-bulb temperature (Tw) and dry-bulb temperature (Ta) in the following form" (A.R. Lind, R.F. Hallon, Assessment of physiologic severity of hot climate, 1957):

$$WD = 0{,}85T_w + 0{,}15T_a$$

This index was criticized for not taking into account the radiant temperature. However, it has been widely used in industrial conditions.

Afterwards, following the model of just weighing the wet-bulb temperature and the dry-bulb temperature, the DI index was proposed, which was exceed the following expression:

$$DI = 0{,}5T_w + 0{,}5T_a$$

The most important aspect of this index is that it reflects a correlation with physiological parameters, since it considers whether the person is in a state of rest or is physically active. In addition, the results of this index are very similar to those of the WBGT.

From various experiments, we can see that

-If the DI value is below 22, there is no thermal stress.

If the DI-value is between 22 and 24, some people may suffer from thermal stress.

-If the DI value is between 24 and 28, most people can suffer from thermal stress.

-If the value is above 28, it is a risk situation.

Relevant results:

Throughout the last century, many efforts have been made to propose an index that defines the conditions of thermal stress and zones of discomfort in order to establish safety criteria for workers exposed to this stress. These indices are separated into three groups: rational indices, empirical indices and direct indices. The latter have been used throughout the years to simplify the process.

-The most widely used index is the WBGT, which is simple and applied in many cases, giving accurate results.

-Another index that is often used is the DI, which includes physiological parameters in its expression.

-It can be concluded that nowadays, in order to define thermal stress, the Fanger parameters are used, which simplifies its definition.

-Practical evaluation of the thermal comfort parameters (Markov, 2002).

Aim: This article goes into detail in Fanger's study in which the main parameters influencing thermal comfort are considered: clothing, activity level, air temperature, average radiation temperature, air speed and air humidity. Therefore, it studies in depth the thermal asymmetry of poaching or local cooling, as suggested by P.O. Fanger in his work.

Context: International.

What does the report present: This article studies another parameter that influences thermal comfort, the thermal asymmetry. P.O. Fanger suggests in his work that this phenomenon may influence thermal comfort. This article, based on studies, confirms that this is an influential parameter and explains what are the ways in which it influences.

Explanation: Although the three hypotheses proposed by Fanger for accepting that a person is in thermal comfort are fulfilled, these are not the only requirements that must be met to arrive at a feeling of thermal comfort. The thermal dissatisfaction can be due to a scaling or cooling in a specific part of the body. This phenomenon is known as local thermal discomfort.

Local discomfort can be divided into four groups: local cooling of uncovered body parts by the air flow, cooling or heating of body parts by the radiation, but also cold and heatings by a strong vertical temperature gradient and cold or heatings by the extreme temperature of the ground.

Air currents:

The most common phenomenon is airflow, which is caused by the speed of the air, the turbulence of the flow, the air temperature and the fluctuation of the skin temperature. In order to predict the percentage of dissatisfied people who are exposed to this airflow, ISO 7730 has introduced an index to calculate the optimum speed:

$$DR = (34 - t_a) \cdot (v_{ar} - 0{,}05)^{0{,}62} \cdot (0{,}37 \cdot TU \cdot v_{ar} + 3{,}14)$$

Radiant temperature asymmetry:

These phenomena are normally caused by floors, walls, ceilings and panels that are heated or cooled. From various experiments in which subjects were exposed to a radiant asymmetry in a thermal laboratory room, it can be seen that this phenomenon had a certain expression of type:

$$y = a + b \cdot e^{cx}$$

Where y is the percentage of dissatisfied people and x is the radiant temperature asymmetry to which the subject is exposed. From this model and from the respective experiments, Figure 14 is obtained, which presents the percentage of dissatisfied people in relation to the radiant temperature asymmetry.

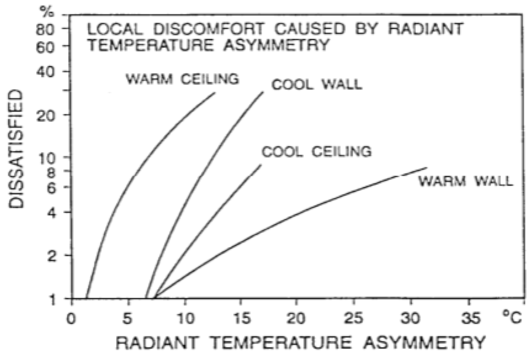

Figure 7. Dissatisfied percentage in front of radiant temperature asymmetry.

As can be seen in Figure 14, the sub-connect is "more sensitive to the asymmetrical radiation caused by a hot roof than by a cold vertical surface. The influence of cold ceilings and hot walls was also studied, but it was found that people are less sensitive to them" (Van Hoof et al., 2010).

Vertical temperature difference:

If there is a great difference in temperature between the head and the feet, it can also give rise to a situation of thermal discomfort. From a similar study to the previous ones, it is possible to obtain an expression that gives the percentage of dissatisfied people. Figure 15 relates the percentage of dissatisfaction with the difference in temperature between the feet and the head.

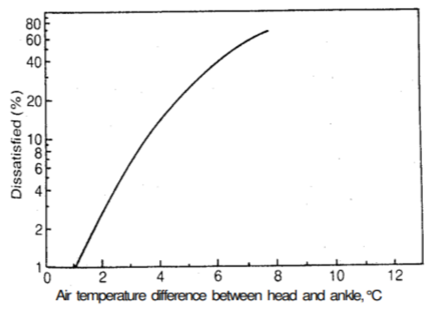

Figure 8. Dissatisfied percentage in front of air temperature difference between head and ankle.

As can be seen in Figure 15, "the above considerations refer to the increase in temperature from head to toe. The opposite case will not be as critical for the occupants and, as with people doing higher activities, they will be less sensitive and can tolerate greater differences" (Van Hoof et al., 2010).

Thermal discomfort of the workers:

This phenomenon can be caused by an extreme temperature of the floor, the fact that it causes a very high heat flux (position or refusal) through the skin, so there is a feeling of discomfort. This is why the conductivity, the heat capacity of the material and the type of ground cover of a building can influence the thermal comfort. This phenomenon disappears quickly if the person wears shoes.

Relevant results:

Local discomfort is another factor that has a real influence on thermal comfort, and this can be separated into four groups: local cooling of uncovered body parts in the draught, cooling or heating of body parts in the radiation, but also cold and heat in a strong vertical temperature gradient, and cold or heat in the extreme temperature of the ground.

-**Thermal comfort models: A review and numerical investigation** (Cheng et al., 2012).

Aim: Thermal comfort is easier to achieve in non-uniform conditions than in uniform conditions, and these are normally transient. This is why we make a great effort to find models with these two characteristics, so that it is possible to find models that are very accurate in terms of thermal comfort.

Context: International.

What does the report present: This article explains how, starting from Fanger's model, we have been trying to arrive at models that try to simulate a series of assimilated and transient conditions, the real ones. There are also two models that can be simulated, and this article focuses on explaining one of them, the University of Berkeley.

Explanation: Over the last few years there have been advances in the search for a model of thermal comfort that can analyses comfort in a localized part (in the different parts of the body) and in transitory states.

Givoni and Goldman will develop a model based on a node that represents the human body. More importantly, Pierce will separate the human body in two: the central layer and the superficial layer of the skin.

Further down the line, Stolwijk presents a multi-nodal model, with the body divided into six segments, each of which is divided into four layers in a radial direction. Therefore, this model was more accurate than the previous ones, although it was limited to constant environmental conditions.

There were many models, but this one was able to represent the two important conditions: the division by parts of the body and the transitory state.

Most of the models are based on the Stolwijk model.

There were many models, but only one was able to represent the two important conditions: the division by parts of the body and the transitory state. Normally only one of the two conditions was achieved, or more complex models with the impossibility of soldering were achieved.

Of all the models, there are only two that make a significant number of layers to show the two conditions, from one band the model of the ISO 14505 standard and from another band, the Comfort Model of the University of Berkeley.

One of the best of the Stolwijk model is the University of Berkeley Comfort Model, which is considered one of the best current models. This model theoretically simulates an arbitrary number of segments, which are usually 16 in practice, which are the ones that the University of Berkeley Thermal Manikin has. Figure 16 presents these 16 segments in which the body is divided.

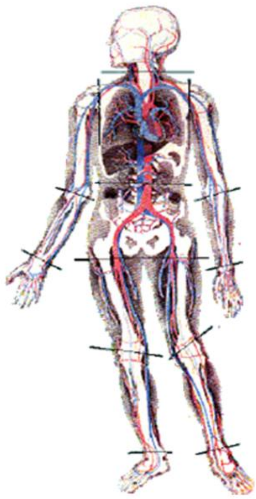

Figure 9. Segmentation of University of Berkeley Thermal Manikin.

It was developed a model of blood flux that includes the respective heat exchanges to measure that flows to the length of the body. Each segment is represented by a series of nodes and a blood object, and the heat exchange is produced between the adjacent nodes and between the nodes and the blood. The model also takes into account the heating capacity and humidity of the clothing and the loss of heat due to contact with the body.

The only thing that kept this model was the need for a manual coupling with CFD simulation. Gao and Niu were able to combine the model with a Computational Fluid Dynamic Simulation in order to assess the thermal comfort of a ventilation displacement system (DV) and a mixed system (MV) with personalized ventilation (PV), which completed the model at the University of Berkeley.

"First the environmental parameters around the human body, including speed and temperature, are calculated by means of a CFD simulation based on the initial boundary conditions; then these parameters are entered into the thermoregulation module of the UCB model to obtain the new skin surface temperatures. If the iteration is not convergent, the new skin surface temperatures will be imported into the CFD as the new boundary conditions for the next cycle (Cheng et al., 2012). The effect of the clothing is similar adding a resistance to the surface of the skin. In this way, the two ventilation systems, a mixed ventilation system (MV) and a displacement ventilation system (DV), are created, thus creating a personalized ventilation system (PV). When the air flow rate of the system was set to 0 l/s, this meant that there was a pure MV or DV system. "The boundary conditions in our simulations were set as in the previous cases, except that the surface temperature of the human body skin was fixed, with a resistance of the summer clothing. In this study, the Naviere Stokes equations were solved using a commercial Fluent code based on the related volume method. The standard k- model was adopted to simulate air velocity and temperature distributions, and radiant heat transfer was also considered using the discrete ordinate model" (Cheng et al., 2012).

A couple of the simulations were followed with the comparison of results between the ISO 14505 model and the University of Berkeley model. Figure 17 shows the thermal sensation of each body segment depending on the air flow and the model used.

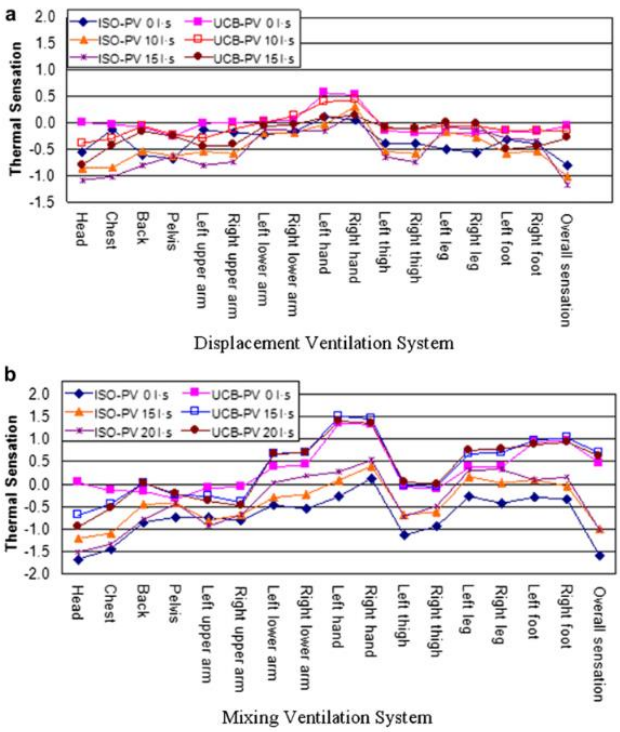

Figure 10. Comparison of UCB and ISO 14505 models thermal sensation.

As can be seen in Figure 17, in a displacement ventilation system (DV), for the same environment, the thermal sensations shown in ISO 14505 are lower than in the UCB model. In the case of parts exposed directly to the air, they move faster than in the case of the UCB model. It was therefore concluded that for local thermal sensations, ISO 14505 is less sensitive than the UCB model in a cold environment, but for a general thermal sensation, the ISO 14505 model is more sensitive than the UCB model. The same phenomena can be observed in the case of mixed ventilation (MV).

Relevant results:

-Although the complexity of the modelling of thermal comfort in transient and localized conditions, computer technology has been of great help in obtaining more accurate models.

-As many as there are a great number of researchers looking for ways to model thermal comfort in transient and localized conditions, there are only two methods that have been achieved in an accurate way. One is the ISO 14505 model, which is recognized by ASHRAE, and the other is the University of Berkeley UCB model, which required a CFD simulation and which has now become possible.

-According to this study, the ISO 14505 model seems to be more sensitive to warm environments and less sensitive to cold environments. This suggests that the ISO 14505 standard is only suitable for heat-neutral situations.

-The model of the University of Berkeley UCB is more sensitive to the variation of thermal sensation in localized spaces, and less sensitive to the global evaluation of thermal sensation.

-It is possible that in the long term it will be possible to obtain accurate models from CFD simulations.

-A method to weight three categories of adaptive thermal comfort (Cheng et al., 2012)**.**
Aim: The adaptive model has many aspects of adaptation that are not yet determined. We know that the parameters that influence the model are the behavioral, the physiological and the psychological, but we do not know what weight each of them has on the thermal comfort of the person. In addition, these parameters can be divided into others, of which the weight is not known. It is a matter of developing a method of quantity to determine the significance of the respective parameters.

Context: UK and China.

What does the report present: This article shows the methodology and results of a study to determine the significance of the parameters of the adaptive model, so, from a quantitative method to obtain an adaptive model with the parameters proposed in previous studies of the model. This is a hierarchical analytical process carried out in the UK and China, where several experts have evaluated the weight of the parameters and, from a mathematical process, have arrived at statistical results.

Explanation: As previously mentioned, the adapted model is divided into three categories and these can be divided into sub-categories:

-Physiological adaptation:

Within this category there are two sub-categories:

Genetic adaptation: This involves the mechanisms of the body itself to regulate temperature and combat adverse environmental conditions. These mechanisms include vascular mechanisms for non-adverse situations, and for more extreme situations they include the sweat and tremor.

Acclimatization: It uses artificial mechanisms to control the thermal environment.

-Behavioral adaptation:

In this category there are three subcategories:

Personal: An exemplary case is the fact of put or leave steals in order to maintain the body temperature.

Technological: Approve the technology to achieve environmental conditions of comfort.

Cultural responses: Mechanisms instilled by different cultures, for example, taking a nap in the heat of the day.

-Psychological adaptation:

This category is not directly observable, but all parameters related to perceptions and expectations that can affect thermal comfort.

Methodology: The AHP method developed by Saaty (The Analytic Hierarchy Process, McGraw-Hill, 1972) is "a powerful and flexible, multi-criteria, decision-making tool designed to address complex problems where both quantitative and qualitative dimensions need to be taken into account" (Saaty, 1982). The great characteristic of this method is that it is able to decompose a multi-criteria complex problem into a hierarchical structure. From comparisons by partners, it is possible to observe how all these are related to each other.

The steps to follow to complete this method are as follows:

1- Qualify the goal, criteria and alternatives in a hierarchical way. The goal is at the highest level of the pyramid, followed by the criteria and sub-criteria, and the alternatives are at the last level. Figure 18 shows this hierarchical structure.

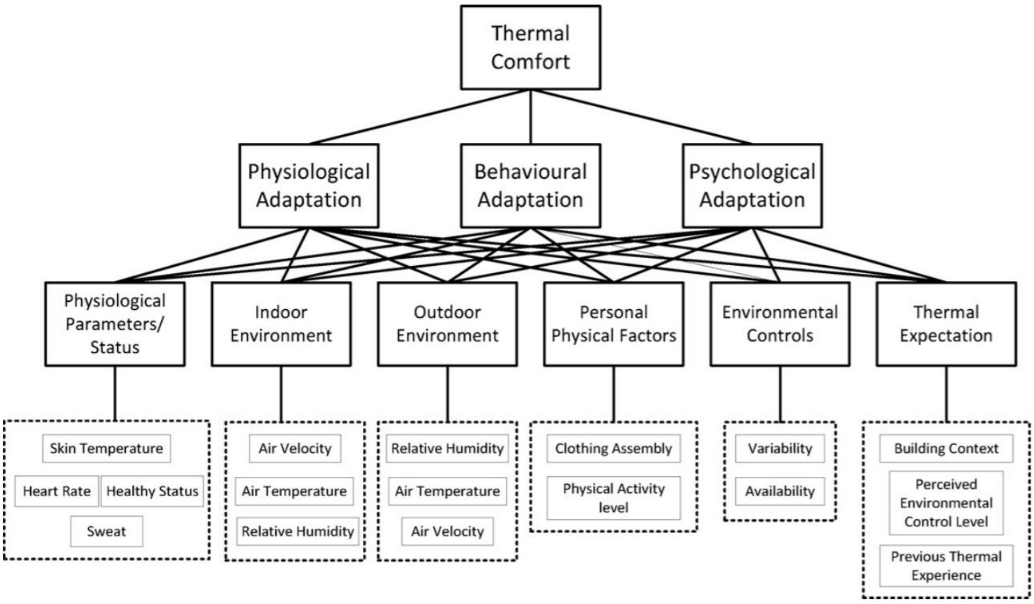

Figure 11. Pyramid of hierarchy on thermal comfort.

2- Quantify the weights of the criteria, sub-criteria and alternatives by comparing them with all possible parameters that can be formed. This quantification is done in the following way:

2.1- Create a matrix of comparisons. Figure 19 shows the type of dimensional N-matrix.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1m} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2m} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nm} \end{bmatrix}$$

Figure 12. Matrix of comparisons.

This matrix is square, with each element representing an index of the importance of activities on a scale of 1 to 9 as shown in Table 12. These values have been determined by 41 experts in this UK field and 33 experts in China.

Values of a_{ij}	Definition	Explanation
1	Objective *i* and *j* are equal importance	Two activities contribute equally
3	Objective *i* is just more important than objective *j*	There is evidence suggesting one activity is probably more important than another
5	Objective *i* is much important than objective *j*	Good evidence and logical criteria exist to demonstrate that one is more important
7	Objective *i* is demonstrably more important than objective *j*	Conclusive evidence show the importance of one activity over another
9	Objective *i* is absolutely more important than objective *j*	The evidence in favour of one activity over another is absolute
2, 4, 6, 8	Intermediate values between the two adjacent judgments	E.g. a value of 8 is midway between demonstrably and absolutely evident

Table 2. Values of importance in thermal comfort.

As can be seen in Table 12, it is useful to compare parameters one by one. In the case of comparing the same parameter the value would be 1, because one parameter is as important as the other. If parameter "i" is more important than parameter "j", the value would be 9, and this creates a scale from 1 to 9 with intermediate values.

2.2- Resolve the matrix system.

This system has the following aspect:

$$A \cdot W^T = B \cdot W^T$$

Where B is a constant value and W = [w1 w2 ... wn] on each w_i represents the weight of each parameter "i".

2.3- Consistency test.

First of all, the maximum value of matrix A must be found, which are expressed with the following expression:

$$\lambda_{max} = \frac{1}{n} \cdot \sum_{i=1}^{m} \frac{(A \cdot W^T)_i}{(W^T)_i}$$

Once found the maximum eigenvalue, the consistency index (CI) is calculated from the following expression:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

From the consistency index, the consistency ratio (CR) is calculated with the following expression

$$CR = \frac{CI}{RI}$$

If CR<0.1, the consistency of the matrix is satisfactory. The value of RI depends on the dimension of the comparison matrix. Table 13 shows the values of the parameter according to the dimension.

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Table 3. RI value depending on the matrix dimension.

Therefore, the first thing to do is to implement this method with the first level of the pyramid, the criteria, which are: Physiological adaptation, Behavioral adaptation and Psychological adaptation. In the case of the UK and China separately, where a consistency ratio was obtained which showed that the matrix was satisfactory, the respective comparison matrixes obtained are shown in Table 14.

	Physiological adaptation		Behavioural adaptation		Psychological adaptation	
	UK	China	UK	China	UK	China
Physiological adaptation	1.0000	1.0000	1.6475	1.3644	2.6672	1.4810
Behavioural adaptation	0.6070	0.7329	1.0000	1.0000	0.6845	0.9838
Psychological adaptation	0.3749	0.6756	1.4609	1.0165	1.0000	1.0000

Table 4. Matrix of weights of the criteria parameters on UK and China.

Table 15 shows the origin of the comparison matrix, i.e. the weight of each parameter in thermal comfort.

Eigenvalue	
UK	China
0.5062	0.4154
0.2356	0.2947
0.2582	0.2900

Table 5. Eigenvalues of the matrix of weights on UK and China.

As we can see, the weights obtained vary between the UK and China, but they are very similar, in both cases the most important parameter is the physiological one, which is even more important in the UK. The other two parameters are of lesser importance than the physiological one and the same between them.

The same method will be repeated for the next level of the pyramid, the sub-criteria. Table 16 shows the matrix of comparisons obtained from the UK and Chinese experts with the respective weight of each parameter.

Factors	Physiological adaptation		Behavioural adaptation		Psychological adaptation		Eigenvalue	
	UK 0.5062	China 0.4154	UK 0.2356	China 0.2947	UK 0.2582	China 0.2900	UK –	China
P.P/S	0.1577	0.2999	0.2559	0.3127	0.1572	0.2831	0.1807	0.2988
I.E.	0.3262	0.2394	0.2360	0.2109	0.1943	0.2097	0.2709	0.2224
O.E.	0.0665	0.1080	0.0575	0.1139	0.1179	0.1476	0.0777	0.1212
P.P.E.	0.1578	0.1167	0.2040	0.1168	0.2146	0.1202	0.1833	0.1177
E.C.	0.1633	0.1275	0.1425	0.1415	0.1389	0.1309	0.1521	0.1326
T.E.	0.1285	0.1085	0.1040	0.1042	0.1772	0.1084	0.1353	0.1072

P.P/S, physiological parameters/state; I.E., indoor environment; O.E., outdoor environment; P.P.F., personal physical factors; E.C., environmental controls; T.E., thermal expectation.

Table 6. Matrix of weights of the sub-criteria parameters on UK and China.

As can be seen in Figure 29, there is a difference between the UK and China in this sub-level. In the case of the UK, the most influential parameter is the indoor environment, followed by the personal physical factors and the physiological parameters/state (as can be observed, related to physiological parameters). On the other hand, in the case of China, the most influential parameter is the physiological parameters/state, followed by the indoor environment and subtracting it from a long distance.

Relevant results:

Thermal comfort is the result of multifactorial effects related to physical and non-physical dimensions. Although there are many factors, it is important to know which are the ones that have more weight in comfort and which are the ones that have less.

The AHP method is effective in structuring the problems of objects and subjects in a hierarchical way from different levels. The disadvantage of this method is that it requires experienced people in the field of study.

-The results of this study concluded that physiological adaptation is the most important parameter in thermal comfort. The other two adaptations have similar weights between them. Therefore, providing a propiate physical thermal environment is the most important point for the thermal comfort of the occupants.

-The results of the second sub-level of the pyramid indicate that the most important parameters are: indoor environment, personal physical factors and physiological parameters/state.

- Impact of Social Network Type and structure on modeling normative energy use behavior interventions (Anderson et al., 2014)**.**

Aim: The behavior of the occupants has a significant effect on the demand and consumption of energy in the habitat. Due to the tendency to design more efficient buildings oriented towards human comfort, the impact of the occupants' behavior would influence the energy consumption more and more.

This article is based on how individuals make decisions or give opinions about comfort based on social relations with different people who are in the same habitat, so social norms such as interpersonal influence and pressure are the cause of changes in the opinion of the others.

Context: International.

What does the report present: This article explains how to carry out an experiment to study the thermal comfort of a group of people in a building that depends on the type of interpersonal relationships between them. In this case, it is a matter of differentiating four types of different neuronal axes that simulate human interpersonal behavior. The article explains theoretically and practically how the respective experiments has been developed. It tries to find if there is an other factor that influences human comfort: the influence that people have on others in the type of interpersonal relationship that exists in a given place.

If we have to use these models to make predictions, it is very important to identify the type and structure of the social network (SNTS), since these change in each group of people and consecuently in each building.

Methodology and explanation: The fact of giving importance to "listening" the decisions or the way the occupants feel about comfort in the home has given rise to various effects in terms of energy consumption. For example, he has studied (Bittle and others 2005, 1979a; Hutton et al. 1986; McClelland and Cook 1979; Van Houwelingen and Van Raaij 1989; Wilhite and Ling 1995) “on it has been concluded that there is a difference between 5 and 15% of energy, others in that there is no change in consumption” (Katzev et al. 1981; Sexton et al. 1987), and others in that there are negative effects in terms of energy balance.

The agent based modeling (ABM) is an analytical method that allows the modeling of heterogeneous agents in different environments and decision rules. This method is effective in the study of social relationships within a building, because the occupants (agents) are not homogeneous, they are adaptable and their behavior varies according to the social influence.

Therefore, we will proceed to investigate four different types of social networks: Randomized Graphics (RND), Regular Ring Networks (REG), Small Size Networks (SWN) and Non-Scale Networks (SFN). In addition, the effect of the structural variables of the networks is investigated, such as the number of people (the size of the network) and the number of interpersonal relationships per occupant.

In order to model the networks, the occupants of the habitat are considered agents with the following attributes: energy standard (EUS) that can vary with time and interactions, interpersonal relationship between the occupants and the susceptibility to be influenced by someone else.

In this way, it is simulated that after each unit of time, the occupants compare their opinion about comfort (EUS) with the others one, where there is a relationship (direct or indirect) and depending on the susceptibility coefficient that presents the opinion (EUS), varies more or less, EUS values are modified according to the following time unit for each agent and in a synchronized way. Unless the EUS of each agent has been calculated in a given unit of time, it is not updated to this value and the following unit of time.

The basis of the model is that people change their opinion and behavior to adjust to social norms on many occasions, and energy use is no exception. In the model, it has been assumed that there is an installation that gives the occupants information about the energy used by themselves and data about the consumption of their mates in the same building where there was not yet this information. It has also been assumed that the occupants have a relationship with each other and that not all the occupants are as influential as the others (depending on parameters such as self-esteem, self-confidence, etc.).

Therefore, each network begins with 35 agents (occupants), with a half of their relations per occupant. The EUS of each occupant is generated from a normal logarithmic distribution based on building observations in which the occupants are not responsible for the energy used, i.e. one public building per example. The susceptibility of the occupants has a standard deviation (obtained in previous studies), the values of each individual are truncated to 0 and 1, with 0 representing someone who is not influenced and 1 a person totally influenced by others.

For the creation of random nets (RND), regular nets (REG) and small measures nets (SWN), it is created a ring in which each occupant is connected to K=2 occupants, where the first connection is the node (occupant) of the right and the second is the next one of the right, in order to achieve the last node of the ring. To create the different models there is a p value, ranging from 0 to 1, which indicates the probability of connecting or not to the foreseen node, but it is connected to a random node. Therefore, we have to set p values of 1, 0 and 0.1 for the random networks, the regular network and the small measurement network respectively.

The network without scale is generated differently. The maximum number of connections for each occupant is established as K. Initially, K+1 occupants are created and each one is connected to the other. Then a new occupant is assigned, this one is connected to the node already created with a probability of Cn=ΣC, where Cn is the number of nodes and ΣC is the sum of the number of connections of all the nodes. The new node searches on the list of all the nodes in order to reach the maximum number of connections. Once this process is done, it proceeds to create a new occupant, and so on.

The occupants influence each other in a weighted way, starting with a weight (w_{ij}), which represents the influence that the occupant has on the i:

$$w_{ij} = \frac{s_i c_{ij}}{\sum_k c_{ik}}$$

Where s_i is the susceptibility of the occupant i, and c_{ik} is the personal distance between the occupant and the k.

Therefore, the increase or decrease of EUS of each occupant for each unit of time is given by the expression:

$$y_{i,t} + 1 = (1 - s_i) y_{i,t} + s_i (w_{i1} y_{1,t} + w_{i2} y_{1,t} + \cdots + w_{iN} y_{N,t})$$

Where $y_{i,t}$ is the EUS of the occupant i in the instant t.

In order to investigate the influence of the fact that in a building the group of occupants share more or less interpersonal relations between them, the four models of the network has been adopted and each has had a number of relations with other nodes (K), increasing K=2, 4, 6... but maintaining the total number of occupants that are in the building (N).

In order to investigate the influence of the measure of the sample, so, the total name of occupants that are in the building, just repeat the experiments with different N but maintain a fixed value of name of relations of each member (K), in this case it would take a standard measure (N=35), a group of small people (N=7) and a large group of people (N=441).

Finally, in order to see the influence of the type of social network, an EC (environmental field) is affected, i.e., the occupant is hidden with the lower EUS and if he is totally susceptible, i.e., his "s_i" value becomes zero.

The first experiment to be carried out would be to analyze the connectivity of the buildings, i.e. changing the value of the relations of each occupant (K=2,4,6,8,10 and 12). The results would vary between the four types of social network and the different levels of connectivity. Each social network would give us a result different distributions of changes in energy use, but surprisingly, gived a half of variation of the total EUS of zero, that it does not modify the total energy consumption. With low K values, it was more difficult for the experiment to converge, as the measure that increases it decreased the time it took to converge.

The second experiment that has been carried out was to analyze the influence of the measurement of the social network. The variation of the EUS continued to remain at zero. The method for reaching equilibrium only vary in the case of the REG network for the large-measure network, where it has been regularly grouped, in the other cases it would be the convergence of behavior. The time to reach equilibrium was also significant.

The third experiment analyze the influence of the type of social network, by means of an environmental field (CE) on the habitat as explained above in each type of social network. It is observed that the change in the EUS in each type of network is similar to that of the others. All the simulations converged and it is not observed that the type of social network influences them.

When doing a statistical experiment based on simulating a model, it is important to validate that this model or experiment is adapted to reality, since if we were not, we would not have felt that the simulations were being carried out, since the results would not reflect reality.

Therefore, first of all, there are extremely valuable tests and unitary tests of the model and sub-models, which shows that these values have been trailed in experiments based on other articles where it has been demonstrated how the different social areas are modelled.

Relevant results:

- Although the experiment has been validated, it must be taken into account that it is a matter of modelling human behavior, which cannot be really exact, since humans are not linear.
- The change in the EUS has been analyzed, as well as the time needed for this to happen and the behavior of the network when the change was made. It is believed that this is why people with low acceptance of centralized services have a strong influence on the rest of the occupants, which also explains the low variation in the regular network. It would be interesting, therefore, to influence the behavior of the most centralized and influential people in the building, in case the network continues without scale, obviously.

- An interesting fact has been the time in converging or arriving to the balance. When the occupants have few relations (K), they modulate their opinion or behavior in a slower way than if they have a high number of relations.
- This study concluded that a lower energy consumption is not achieved by "listening" the design of human behavior, but rather that it is kept the same. We cannot say that there are no changes in the behavior of the occupants, but on the contrary. The occupants who normally spend more energy are asked to consume less energy, and the occupants who spend less are asked to give feedback.
- A possible solution to obtain a reduction of energy consumption is to introduce an environmental field in cases where the responsibility for energy bodyts is still centralized. Since it is the occupant with the lowest EUS, this can provide incentives to other occupants so that they take over the consumption of the farm and reduce it.
- Finally, this study concluded that there is an influence on the individual's thermal comfort due to the type of interpersonal relationship that the person has with the rest of the group.

- **Heritage buildings and energy performance: Mapping with GIS tools** (Fabbri et al., 2012)**.**

Aim: This article deals with energy and historical heritage buildings, with the points:

-Number and energetic impact of the buildings of historical patrimony.

- Influence of building typology on the energy status of heritage buildings.

- Use of GIS technology to refer to EPC (Energy Performance Certificate), type of energy to assign an energy zone indicator (ZEI) to delimit the city and the surrounding area.

Context: Ferrara, Italia.

What does the report present: The aim is to present a study of the historical center of a city (Ferrara) that analyses the distribution of the energy yield and represents it graphically, as it can help in the analysis.

The energy performance of buildings is an issue of the day in the construction sector. It is obviously that it is always preferable to have a building with an energy certificate class A, but there are buildings that cannot get it, because they are traditional buildings of historical heritage, they cannot be modified.

In order to improve the performance and/or the energy supply of traditional buildings, it is not possible to use new technological solutions or renewable energy sources:

- Urban planning, in order to evaluate the influence of energy on buildings and use of the ground.

- Restoration in order to improve the energy performance of buildings while preserving their historical and architectural coherence, therefore it is necessary to calculate the possible improvements and their performance in order to take them into account when planning the works to improve energy performance.

Therefore, this study is located in the city of Ferrara, in the north-east of Italy, and it tries to study the quality aspects of the historical heritage buildings, such as making a survey on the plan that preserves the architectural value.

Methodology and explanation: In order to define the objective of the study, two factors must be taken into account:

- Pre-industrial building: The building that precedes the industrialization of components and the organization of the contemporary construction process, is, in other words, industrialized.

- Improvement of energy efficiency: Functional, architectural and technical solutions in a building or structure in order to achieve this energy balance while preserving the historical and cultural value of the property.

In the city of Ferrara there are 36% of pre-industrial buildings of the total number of buildings in the city. In Italy, the proportion is 30% and can be extrapolated to the rest of the continent, as there is a certain similarity in architecture and urban planning. Therefore, it represents a significant part of the total number of buildings, and therefore, an important consumption of the total on which it is trying to influence.

This study has been centered on the buildings of the historical center which date from the 7th century BC to the 20th century just after the Second World War.

This study is applicable to many European cities, which perfectly differentiate the historical nucleus from the rest of the city, so you can compare these two parts.

Therefore, this study also tries to determine the degree of tolerance of the possibility of destruction, change or alteration of the characteristics of the buildings.

The approach consists of:

- Defining the constructive characteristics of pre-industrial buildings, except for non-monumental buildings or those with specific purposes such as churches and similar.
- Identify in GIS platforms the register and information it provides and energy performance indicators from the SACE (data base). Thus, it is possible to locate the different energy classes and the evolution over time. In this way, it is also possible to see the influence of the Energy Performance Certificates (EPC).
- Being able to separate the city by Energy Zones (EZ), since with the classification of the EPC that goes from A to G (from best to worst) is able to make a simple map and see which zones have buildings with more performance and which have less.

The GIS tools provide information for each:

- Analyze aspects that influence energy performance (building age, work, surface area...).
- To represent in a compact and concise way, geographically and graphically, the aspects studied in the previous point.

Energy behavior factors:

We have started to introduce the concept of energy feedback in the restoration of historical heritage buildings, but these are now causing the destruction of this heritage. The energy behavior factors are the technical characteristics of the building that affect its energy performance.

These factors can be divided into three different groups:

- Geometric and construction factors:

Aggregation system: Solar orientation, relationship between building surface and volume, entrance hall, staircase block, balcony and patio.

Construction system: Wall, exterior wall, ground floor, floor, pillar, support and theatres.

- Technical and plant factors:

Finished works: All the construction elements are included, except HVAC plants; doors, windows, blinds, curtains and sunshades.

Proto-plants: Including fireplaces, ovens and stoves.

Industrialized plants: Include HVAC systems, wiring and lighting.

- Use factors:

Categories of occupation: one building and its own buildings.

Energy management: The consumption habits that are reproduced in the building.

The data base of the SACE (Energy Accreditation and Certification System) collects all the data and information related to the EPC (Energy Performance Certificates): The energy class (from A to G), heating needs, primary energy performance, geometry, register data and energy parameters.

In September 2010, a total of 3.046 EPC certificates had been registered for buildings in Ferrara, representing 4.86% of the buildings in the city as a whole, a percentage that has grown significantly. Of these, 1.081 are located in the historical center of the city.

Therefore, from the different certificates, a geostatistical analysis of the distribution of the indexes of the certificates is carried out, where the energy behavior has to be considered as a black box.

Firstly, the total energy consumption of buildings is calculated; for non-inhabitable buildings it is calculated from the total volume of units with certificate. In the case of housing, the same result has been divided by the average height: 2,70 m.

As you can see, the habitats (89.36%) are the most significant of the EPC, then we have the offices (5.37%) and other buildings.

It can also be observed that the primary energy consumption follows the same distribution as the number of rooms of each type.

As you can see in Table 1, in all the city of Ferrara, including all areas of the city, there are 20.07% of buildings with a good energy class or good performance (type A to C), 30.44% of buildings of an acceptable class (type D and E), 44.34% of buildings of a poor class (type F and G), and 5.16% undetermined, as they have no heating installation.

Continuing to observe Table 1, it can be seen that as far as the historic center of Ferrara is concerned, which is where the pre-industrial buildings are concentrated, there are 9.44% of buildings with good performance, 29.23% of acceptable class, 56.15% of poor class and 5.18% of undefined buildings.

Table 6
Energy class rating distribution for Ferrara city and historical centre divide by building use.

Energy class	A	B	C	D	E	F	G	Not determinate	Total
Ferrara city	22 0.72%	175 5.75%	414 13.60%	505 16.58%	422 13.86%	361 11.86%	989 32.48%	157 5.16%	3.045 100.00%
Historical centre	0 0.00%	38 3.52%	64 5.92%	135 12.49%	181 16.74%	171 15.82%	436 40.33%	56 5.18%	1.081 100.00%
Historical centre – dwelling buildings (E.1)	0 0.00%	36 3.73%	47 4.87%	112 11.59%	165 17.08%	146 15.11%	428 44.31%	32 3.31%	966 100.00%
Historical centre – office buildings (E.2)	0 0.00%	1 1.72%	13 22.41%	16 27.59%	12 20.69%	11 18.97%	5 8.62%	0 0.00%	58 100.00%

Table 7.Energy class rating Distribution for Ferrara city and historical center divide by building use

The idea is to create a map to easily locate each building unit with its energy class. Based on the data and the energy classification of each building unit, it will be possible to easily make this map, where each building unit is painted with the color of the energy class it belongs to (from A to G). As it is not possible to separate an apartment from the whole building, this building unit can refer to the whole building as well as to a single apartment. You can see the distribution in Figure 1.

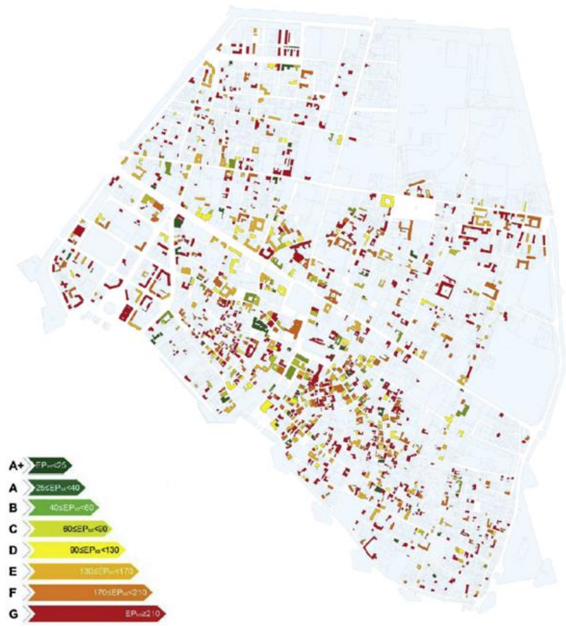

Figure 13. Energy class of the buildings of the center of Ferrara.

Relevant results:

- Figure 1 shows how class G is more present in some areas that has been built in the 20th century, such as the District of Aria Nuova (North) or the District of Rione Giardino (South-West).
- On the other hand, it can be observed that in the districts that has been built in the 20th century, such as Via Carlo Mayr (more or less in the middle of the map), there is a strong incidence of the D class.
- It can be concluded that GIS technology can play a crucial role in identifying aspects of energy efficiency that simply cannot be seen. Having the data mapped makes it possible to observe relationships or patterns that, in its absence, are much more visible. It also helps to identify the energy classes with the years in which the buildings have been constructed, which, as in the case of Ferrara, there is a relationship between class G and the buildings constructed in the 20th century, and the type D constructed previously.

- **Characterizing the household energy consumption in heritage Nanjing Tulou buildings, China, A comparative field survey study** (Li et al., 2012).

Aim: There is one type of traditional building in China called Tulou that has severe architectural differences with the typical rural building of the area and it's important to see how do this differences influences in the thermal comfort.

Context: China.

What does the report present: China accounts for 56% of the population living in rural areas, which is a very important part of the country. It is estimated that the energy consumption of this part of the population would be between 4.01 x 10^{12} and 8.58 x 10^{12} MJ, but a later study showed that the real consumption was 9.37 x 10^{12} MJ, much higher than the first estimation. Therefore, it was found that in one case there was either an excessive energy consumption, or there were buildings with energy shortage, or other hypothesis, the case was that it was necessary to study why.

There are several studies in many rural regions of China to better understand this high energy consumption.

There is a type of old residential building, typical of rural areas of China, which is the Tulou, built with earth and whip. Houses with two or more double floors that are well preserved today, at the point of having been declared a World Heritage Site by UNESCO.

The fact that they exist and are preserved, makes it possible to study the energy behavior between these buildings and the current rural buildings.

In this article the energy consumption and the indoor environmental quality of the Tulou buildings and the normal rural buildings is studied.

It studies a total of six buildings Tulou and normal rural buildings, all in the same area.

Methodology and explanation: The Tulou buildings have an average height of 1.2 meters, while the normal rural buildings have 0.4 meters. The average area covered by Tulou is 1,250 m^2, while that of the normal rural buildings is 90 m^2.

Therefore, a total of 139 plots of land in Tulou buildings (88% of the total) and 97 plots of normal rural buildings (24% of the total) has been done, the latter being completely set aside. Table 2 shows the characteristics of the buildings studied.

Table 1
Basic information of studied Tulou and normal rural buildings.

Investigated location	Number of buildings	Name of buildings	Thickness of envelope (m)[a]	Cover area (m^2)[a]	Height (m)[a]	Number of floors[a]	Number of rooms per storey[a]	Number of investigated households[d]	Population per household[d]
Tianluokeng Tulou cluster	5	Ruiyun	1.2	1063	11.2	3	26	51	3.9
		Zhenchang	1.2	976	11.5	3	26		
		Buyun	1.2	1050	11.9	3	26		
		Hechang	1.2	1268	12.3	3	22		
		Wenchang	1.2	1288	11.8	3	32		
Hekeng Tulou cluster	14	Chaoshui	1.7	729	11.3	3	20	62	3.4
		Yongsheng	1.4	676	14.4	4	30		
		Shengqing	1.0	2310	12.0	3	24		
		Yongrong	0.8	525	11.5	3	18		
		Nanxun	N/A	729	12.6	3	21		
		Yangzhao	1.8	1156	12.0	3	26		
		Yonggui	0.7	1680	10.3	3	32		
		Yuchang	1.2	1838	11.1	3	36		
		Dongsheng	1.0	870	11.0	3	22		
		Chungui	1.0	1808	11.5	3	32		
		Xiaochun	1.0	1808	11.0	3	32		
		Yongqing	1.1	1661	11.0	3	32		
		Yuxing	0.9	907	11.0	3	20		
Huaiyuan Tulou	1	Huaiyuan	1.2	1385	13.5	4	29	14	4.4
Hegui Tulou	1	Hegu	1.4	1547	18.0	5	28	6	3.3
Other Tulou buildings	2	Fuyuan Degui	N/A	N/A	N/A	N/A	N/A	6	3.5
All Tulou buildings[b]	23		N/A	N/A	N/A	N/A	N/A	139	3.7
Normal rural buildings[c]	97		0.4	90	N/A	1–2	4	97	4.1

[a] These data were obtained from UNSECO (2008).
[b] The data of all Tulou buildings were average values.
[c] The data of normal rural buildings were average values, which were obtained from the questionnaire survey.
[d] These data were obtained from questionnaire survey.

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Table 8. Characteristics of the normal rural and Tulou buildings.

The band deals with questions related to cooking, heating, refrigeration, lighting, water consumption and household appliances. Also included is the total energy consumption, the breakdown of this for each energy source.

The energy sources of the rooms, as a result of the surveys, are electricity, LPG, coal and wood. The energy consumption of the electricity, converted to primary energy in the power station can be calculated as follows:

$$E_{ele} = \beta_{ele}(E_{ele-cook} + E_{ele-heat} + E_{ele-cool} + E_{ele-light} + E_{ele-hotwater} + E_{ele-appliance})$$

Where β_{ele} is the conversion coefficient of the thermal energy generation between electricity (kWh) and the heat equivalent (MJ) is 9,66 MJ/kWh. This coeficient is based on the current promotion of energy generation efficiency that China has.

$E_{ele-cook}$ is the consumption of electricity destinated to the kitchen. It can be calculated as,

$$E_{ele-cook} = \sum_i (n_i P_i t_i d_i)$$

Where i is the kitchen index (it can be electric, induction, microwaves), P is the kitchen power, determined from the average power of the kitchen equipment most used in Xina. For each type of kitchen (index), there is a determined value of power. N is the name of the team and it is the time in hours that the kitchen is used. The "d" is the total number of days the cooker is used.

$E_{ele-heat}$ is the consumption of electricity destinated to the heat, it can be calculated as,

$$E_{ele-heat} = \sum_i (n_i P_i t_i d_i)$$

Where i is the type of heat (electric blanket, electric poacher or unit), P is the power of the type of equipment.

$E_{ele-cool}$ is the consumption of electricity destinated to the cool, it can be calculated as,

$$E_{ele-cool} = \sum_i (n_i P_i t_i d_i)$$

Where i represents the type of device (electric fan or split type air conditioning), P is the nominal power of the equipment, it must be taken into account that this may not be constant, so this consumption both in the Tulou as in the normal buildings is very small, does not influence the results.

$E_{ele-light}$ is the consumption of electricity destinated to the illumination, it can be calculated as,

$$E_{ele-light} = \sum_i (n_i P_i t_i d_i)$$

Where i represents the type of illumination (daylight lamp, energy lamp and filament lamp) with its respective P, power of the equipment.

represents the electrical consumption for water heating, ACS, can be calculated as

$$E_{ele-hotwater} = \frac{n_p m_{ht} c_p \sum_i n_{f,i} (t_{hw} - t_{0,i})}{\eta_{ele} \beta'_{ele}}$$

Where i represents the different stations of the year, "n_p" is the quantity of people that lives in the home, "$n_{f,i}$" is the frequency with one the habitants have a shower, "c_p" is the heat capacity of the water (4,2 kJ/Kg·ºC), "m_{ht}" is the mid value of wàter with one is the shower used (25 kg), "t_{hw}" is the temperature of the water that goes out of the shower (40ºC), and "$t_{0,i}$" is the temperature of the water before it is poached, after each season of the year, it is considered that this water is at the same temperature as the ambient, "η_{ele}" is considered a 90% efficiency, "β'_{ele}" represents the direct heat equivalence between electricity and standard heat, so, 3,51 MJ/kWh.

$E_{ele-appliance}$ is the electrical consumption of the appliances, which can be calculated as

$$E_{ele-appliance} = \sum_i (n_i P_i t_i d_i)$$

Where i represents the type of household appliance (refrigerator, renting machine, television, computer...).

Analogous to the cases of LPG, coal and whip.

Relevant results:

- The main source of energy in both the Tulou house and the normal rural buildings is the electricity, the other three sources are secondary.

  Specifically, in the case of Tulou, 77.1% of the energy is in the form of electricity, 14.5% LPG, 0.1% coal and 8.3% whip. On the other hand, in the case of normal buildings, 80.9% of energy is obtained from electricity, 13.8% from LPG, 3.2% from coal and 5.4% from wood.

- In terms of the total annual consumption of primary energy for the building, it is obtained that the annual consumption of a Tulou building is 2.43 x 10^4 MJ, with a maximum of 2.84 x 10^4 MJ and a minimum of 1.93 x 10^4 MJ. On the other hand, the annual consumption of the normal rural buildings was 3.37 x 10^4 MJ, which represents 28% more than the Tulou building, as shown in Figure 2.

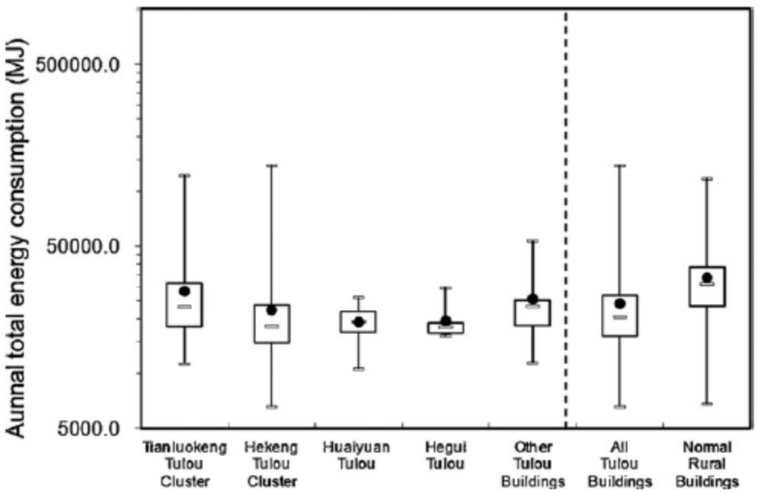

Figure 14. Annual total energy consumption of normal rural and Tulou buildings.

- Most of the energy consumption, both in Tulou buildings and in normal rural buildings, is related to the kitchen, 65.7% and 55.5% respectively. According to the location, the appliances consume 20.7% and 19.2%, respectively. Finally, the energy consumption for water heating was 12.3% in the Tulou buildings and 21.1% in the normal rural buildings. Therefore, it can be observed that the second most energyconsuming use in rural buildings was water heating, while in Tulou buildings it was household appliances.

In a much smaller percentage, we find the energy used for cooling, 0.8% in the Tulou buildings and 3.5% in the normal rural buildings, and heating and lighting, which were totally insignificant percentages.

- Influence of the station changes: As you can see, the total and weighted energy consumption in the case of Tulou buildings is constant in all seasons except winter, when there is an increase in total consumption and an increase in water consumption. We can also observe how the total energy consumption is kept lower than the consumption of the normal rural buildings throughout the year.

  As far as the normal rural buildings are concerned, it can be seen that the energy consumption varies in each season of the year. The consumption in the kitchen is kept constant, as expected, but the consumption of water for heating varies a lot between each season of the year, having a minimum in the summer and a maximum in the winter. An interesting fact is that in this case there is a significant consumption in refrigeration, while this consumption in the Tulou buildings is non-existent, because they are architecturally well refrigerated. The Figure 4 shows the consumption per season.

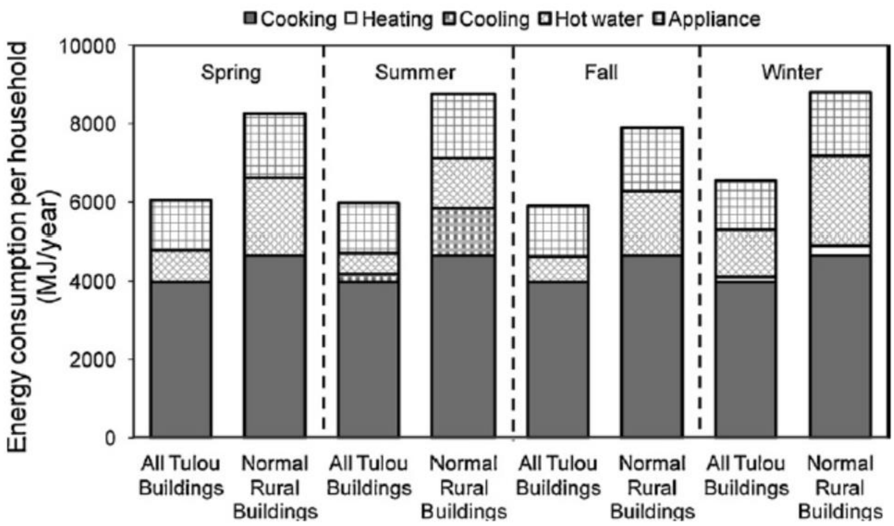

Figure 15. Consumption of normal rural and Tulou buildings per season.

- As you can see, the energy consumption in the Tulou buildings is significantly lower than that of the normal rural buildings, so we can explain this with a few examples.

On the one hand, the percentage of Tulou buildings that use electricity with fans and air conditioning is 74.8% and 0%, while in normal rural buildings it is 96.95 and 11.3%. However, this may not be related to energy consumption if the amount of time that they are used in the respective types of buildings is not known. Therefore, it is possible to certify the relationship with consumption by knowing that in normal rural buildings, electric fans are used 5 hours a day and 3.6 months a year, much longer than in Tulou buildings, which is 1.8 hours a day for 2.2 months a year. Therefore, in order to reach comfort, the normal rural buildings need to consume more energy in refrigeration than the Tulou buildings.

- A study also carried out to measure thermal comfort during the summer and winter, and the results, as expected, is favourable to the Tulou buildings in front of the normal rural buildings. The results of the enchestra are those indicated in Table 3:

	Tulou buildings	Normal rural buildings
Satisfaction summer	0,64	0,5
Satisfaction winter	0,48	0,3
Thermic sensation summer	0,29	0,71
Thermic sensation winter	-0,5	-0,78
Thermical confort summer	0,12	0,54
Thermical confort winter	0,34	0,65

Table 9. Results of the enchestra on rural normal and Tulou buildings.

Note on the values of the Table 3:

In terms of satisfaction: -1 is dissatisfied and 1 is satisfied.

In terms of thermal sensation: -3 very cold, +3 very hot, 0 neutral.

In terms of thermal comfort: 0 comfortable, 4 molt uncomfortable.

- Therefore, it is possible to observe how, in all cases, the results are favourable to Tulou-type buildings. Thus we can think of an interesting hypothesis. It may be that the sensation of comfort can be related to the fact that the user is still aware that there is a waste of energy oriented to the assimilation of human comfort, and thus to be more aware that the climate is not totally comfortable and therefore increases the sensation of discomfort.

- **Thermal comfort in open spaces. Comparison of models and their application in cities in arid areas** (Angélica Ruiz & Correa, 2009)**.**

Aim: There is a great amount of studies about thermal comfort in an indoor space, but the factors that influence thermal comfort in an outdoor space in a city are not widely studied. This is very important, because, with a satisfactory thermal comfort outside, the habitats are more likely to carry out activities in the open air. In addition, there are many activities, cultural events, sports... that are carried out in the outdoor environment of a city, so it is important to carry out a study on the parameters that influence the thermal comfort of people in the open air. From a psychological perspective, it is possible to define thermal comfort as the perception that a person has of not letting his or her climatic environment continue to be warmer or cooler. This definition implies that there is a certain subjectivity in the way that comfort is used. However, from a physiological point of view, comfort is based on the activation of the skin's thermal recievers and the hypothalamus, in that the less the recievers' nerves are affected, the greater the thermal comfort.

Context: Mendoza, Argentina.

What does the report present: A study is carried out in the city of Mendoza. In this city they can differentiate 16 meters (5%), 20 meters (70%) and 30 meters (5%) of extension. Regarding the forest species found in the city, so, open, 83.78% of all the forest area is formed by Platanus acerifolia (21.52%), Morus alba (38.27%) and Fraxinus excelsior (19.36%). As far as the energy aspect is concerned, it is important to analyse the thermoluminescent characteristics offered by these species. In this way, it is also possible to differentiate between the different types of thermoluminescent configurations: continuous tunnel on roadway and road, tunnel on roadway and homogeneous screen on roadway.

In the city of Mendoza, the first configuration is formed by Platanus acerifolia, the second by Morus alba and the third by Fraxinus excelsior. Thus, it already had the different configurations with the different forest species that dominate the city. It was also decided to analyse the 20-metre wide avenues, since they were the most common in the city.

Methodology and explanation: From an energy point of view, thermal comfort is usually achieved when the balance between the human body and the environment is in balance, and therefore there is no heat flow from one side to the other.

Thermal comfort has many parameters of thermal environment, which are:

- Air temperature: responsible for heat exchange with or without mass transfer and its heat transfer coefficient.

- Wind speed: Responsible for losses due to convection and evaporation.

- Relative humidity: When there is no sweat, the exchange of latent heat from breathing and skin perspiration are the transfers associated with humidity. Therefore, the humidity of the air affects the evaporation of sweat, and so does the humidity of the skin.

- The average radiant temperature: This is the uniform surface temperature of a black area where the same heat for radiation is exchanged as with the real environment. For external spaces, the mean radiant temperature represents the uniform surface temperature of a room with all the surfaces of the room at the same temperature.

On the other hand, there are other external parameters for calculating the thermal comfort conditions outside, as they could be:

- Level of activity: The amount of energy produced per unit of time is the metabolic rate, and this varies according to the type of activity that facilitates the individual.

- Clothing: It is a barrier between the body and the environment, it can be more or less thermally efficient, it can be more or less graceful.

Once the study has been carried out, a temperature, relative humidity and absolute humidity sensor were installed in the roads and covered with perforated boxes to prevent the radiation of the same sensors. Speed sensors were also installed to measure the wind speed and the cell visualization factor was calculated from aerial images.

The sensors were checked every 15 minutes, in the heating stage (from 8:00 AM to 8:00 PM) and in the cooling stage (9:00 PM to 7:00 AM).

Comfort indexes:

The comfort indexes were calculated using four different methods: decomfort index (DI), vintage index (PE), heat sensation index (TS) and the COMFA method.

Each of them uses different formulas and parameters, but by knowing the different indices it is possible to reach conclusions in a more accurate way.

THI Categories	
Very cold	DI < -1,7
Cold	-1,7 < DI < 12,9
A Little cold	13 < DI < 14,9
Comfortable	15 < DI < 19,9
Hot	20 < DI < 26,4
Very hort	26,5 < DI < 29,9
Torrid	DI > 30

VINJE Ranges (PE)
Cold > 11
Comfortable 5 – 11
Hot < 5

Sensation level	
TS = 1	Too cold
TS = 2	Very cold
TS = 3	Cold
TS = 4	Comfortable
TS = 5	Hot
TS = 6	Very hot
TS = 7	Torrid

Balance (W/m^2)	Sensation
S < -150	People prefer to be much hotter
-150 < S < -50	People prefer to be hotter
-50 < S < 50	People doesn’t want changes
50 < S < 150	People prefer to be colder
150 > S	People prefer to be much colder

Here you can see the different levels of each index or method.

They got results both for the heating period and for the cooling period, but they only analyzde the heating data because this was the time range where the most people are outside.

Therefore, they could compare the comfort level of each model used and see how much it depends on the model.

In the case of the temperature-humidity model (THI), they could see how the views with plants are the ones that present a higher degree of comfort, followed by the Morus alba and finally the Fraxinus, in which there are no moments of comfort. It was also possible to observe how the vies with Morus alba are those that present more indices of "Very Hot", which is surprising, since in principle it would have to be the Fraxinus. This is why they could explain the thermoluminescent characteristics of each species.

The model of Vinje, in contrast, showed a uniform variation between the different types of vineyards, and equally it is kept in order from more comfort to less comfort, thus the vineyards are the most comfortable. Above all, it is more uniform in the hours of greatest solar radiation.

As far as the index of thermal sensation is concerned, it is possible to observe how the streets of Morus alba and the beaches have the same index, that is, the same degree of comfort.

As for the results of the COMFA method, it is clear that there is a similar distribution of comfort ranges, but they are shifted towards the lower range, and the rooms with Morus alba are the most comfortable ones, since the rooms with plants have a lower mass.

The result is that you can observe the Figure 4.

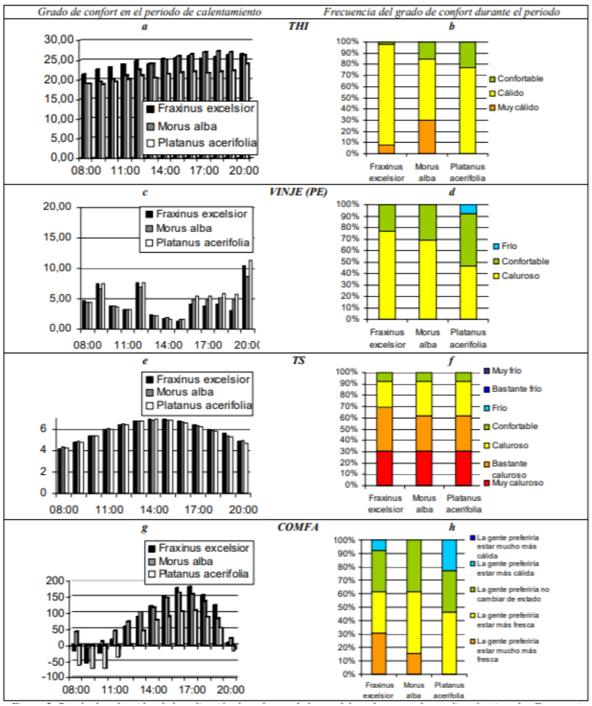

Figure 16. Results of THI, VINJE, TS and COMFA methods.

Relevant results:

- It is very important to identify what is the best method to measure the comfort depending on the location or configuration of the space. When trying to obtain a diagnosis of the degree and frequency with which a space is in conditions of comfort or discomfort, the inductive methods with little complexity and few variables are the most appropriate. For arid areas, the THI index is the most appropriate. When there is a continuous tunnel over the road, the PE index is the most appropriate. For broken channels, the TS index is the most appropriate. Finally, in order to design urban strategies, the COMFA method is the most appropriate, since it allows a more precise evaluation of the impact of the interrelations between climatic, morphological and forestry variables.

- Another conclusion that could be reached is that solar radiation has a great influence on the feeling of thermal comfort, since the sensors will be covered in order to avoid this factor and more or less all the methods present similar results.
- The variables that are collected in this article, is to say, in the total of the four methods and that influence the thermal comfort are: Air temperature, relative humidity, wind speed, solar radiation, surface temperature of the earth, metabolic energy produced by the organism, sensitive heat by convection and loss of heat evaporation.

- **Zona variable de confort** (Variable de Confort Térmico & Propuesto, 2002).

Aim: This article explains the mechanisms that human being has to combat thermal discomfort, so, it gives a more physiological explanation about thermal comfort, in this way they can explain many of the factors or parameters that influence on it. In addition, he explains the empirical definition, in the form of expression, that P.O. Fanger published, who is considered the first scientist to give a mathematical expression to human comfort. It also explains various later theories, such as De Dear's theory, which have been an important tool in the study of thermal comfort and have demonstrated many influencing factors.

Context: International.

What does the report present: The human body maintains a temperature of approximately 37ºC from a homeostatic process. This process is based on different reactions that the human body has when there are changes in temperature.

When the temperature of the body pushes in exces, first it carries to finish the vasodilatation, where the flux of blood across the skin and the body begins to sweat. The act of sweating is a very effective cooling process, because the energy required by the water (sweat) to evaporate is taken directly from the skin is not used.

In contrast, when the temperature of the body is low in exces, vasoconstriction is produced, with which, on the contrary, the blood flow through the skin is reduced, thus increasing the production of internal heat by stimulating the muscles, which is known as "trembling".

Explanation: The two sensors that have the human are found in the skin and the hypothalamus and they are not heat flux sensors, they are the recievers of cold and hot. Obviously, the cold sensors are excited at lower temperatures and the hot sensors are excited at higher temperatures.

A big part of the thermal balance is the metabolism rate. The mechanisms that have the effect of producing heat are linked to biochemistry and make it possible to serve molecules such as glubodye. The molecules that provide energy to the body are macronutrients that are found in food, such as carbohydrates, lipids and proteins. The majority of cells use carbohydrates and fats to survive, but they do not use glubodye, like the beer. In the case of a decrease in glubodye levels, the neurons stop working, the consciousness is lost and the body is dead.

Evolution of the concept of comfort:

Today, there are two widely used theories on comfort, one is the thermal balance theory (linked to PMV/PPD indicators) and the other is the adaptive theory.

Thermal balance theory:

In 1973 Povl Ole Fanger published the first works on the influence of the thermal conditions of the indoors of buildings on people. In these works, two methods will be defined for the first time that serve to give value and thus be able to quantify human thermal comfort, these are the PMV (Predictive mean vote) and the PPD (Predictive percentage dissatisfied). These two methods are used today to define the parameters of comfort.

- Predictive mean vote: This is an indicator that foresees the mean value of the votes that a group of occupants in a scale of -3 to +3 in reference to the thermal sensation that they have in a determined state. The Table 10 reflects the different votes in reference to the thermal comfort. This method takes into account the level of activity, the characteristics of the clothing, the dry temperature, the relative humidity, the medium radiant temperature and the air speed.

Very cold	Cold	A little cold	Neutral	A little hot	Hot	Very hot
-3	-2	-1	0	+1	+2	+3

Table 10. Ranges of PMV.

- Predicted percentage dissatisfied: This indicator shows the presence of people who feel a sense of discomfort from the PMV value they have obtained. As can be seen in Figure 5, when there is a PMV of 0, it is, in fact, neutral, when there are fewer percentages of dissatisfied users and when the PMV is both 0 and negative, this percentage increases and does so symmetrically. It is possible to see how a PMV value of -3 or +3 is the percentage of dissatisfied users up to the maximum point, 100%.

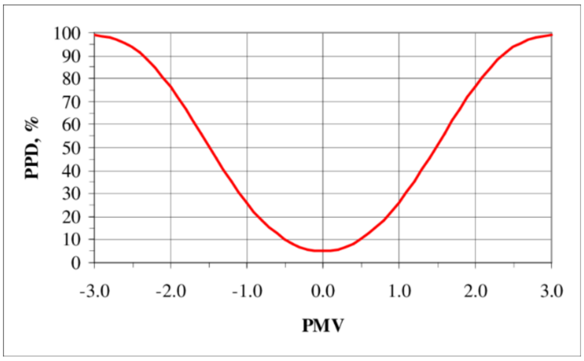

Figure 17. PPD values.

The models of thermal balance are also static or constant, and with the experiments in static conditions it was demonstrated that the sensations of cold are related to the temperature of the skin, while the sensations of heat are related to the humidity of the skin.

Experimenting with the static model:

Fanger took 1296 young people in a thermal chamber, and each of them indicates their thermal sensation in the scale described above, which ranges from -3 to +3, and repeat this experiment with different climates. Afterwards, the youngsters would also be able to regulate the same thermal conditions in order to reach their comfort zone.

In order to develop his theory, he based himself both on this experiment and on physiology and thermoregulation, reaching the conclusion that the human body is a very efficient thermoregulatory, capable of resisting a wide range of climatic conditions.

Afterwards, in order to obtain a more reliable model, the same experiments were carried out, but the youngsters were dressed with different fishes and performed different levels of physical activity. In this way, Fanger arrived at the equation to obtain the PMV:

$$PMV = \left[0{,}303 \cdot e^{-0{,}036 \cdot M)} + 0{,}028\right] \cdot [(M - W) - 3{,}05 \cdot 10^{-3} \cdot [5733 - 6{,}99 \cdot (M - W) - p_a] - 0{,}42 \cdot [(M - W) - 58{,}15] - 1{,}7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0{,}0014 \cdot M \cdot (34 - t_a) - 3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a)]$$

From the PMV is going to obtain the equation of the PPD:

$$PPD = 100 - 95 \cdot e^{-(0{,}03353 PMV^4 + 0{,}2179 PMV^2)}$$

These indexes are currently used, but they do not take into account all the factors that influence comfort, and so they represent a good approach and are used for building regulations and a wide range of applications.

The Theory of Adapted Thermal Comfort:

The Theory of Adapted Thermal Comfort was proposed by De Dear in 1998. Adaptive thermal comfort takes into account other factors that are not taken into account in the Theory of Thermal Balance, such as the behavior of people and their expectations, so, that people adapt their thermal preferences, and in which three categories can be distinguished:

- Adjusting behavior: Adjusting people's activity, posing or treading, regulating air conditioning...

- Physiological: The changes in the psychological response to exposure to environmental thermal factors.

- Psychological: The altered perception of and reaction to sensory information leads to expectations, social relations...

Variation of the pleasant or unpleasant sensation produced by an external stimulus depending on the internal state of the subject. Alesthesia leads people to look for stimuli that make them feel unpleasant, for example, to look for water when they have just had sport.

To understand this concept properly, one must know how to differentiate between thermal sensation and thermal comfort. Sensation is a detection of environmental stimuli, while thermal comfort is part of perception, which includes a series of post-processes congruent with sensory impulses.

In 1972, Cabanac carried out an experiment in which individuals with a wetsuit could regulate the temperature in a bathtub. From the temperature of the water, the temperature of the skin and of the indoor one were modified. First of all, they should not be able to change the temperature of the wetsuit, but then they were ordered to change it without changing the temperature in order to reach comfort. The result was that the comfort temperature of the wetsuit rised against the deviation of the internal temperature and respected the internal transition temperature. In other words, when the indoor temperature is higher, the inhabitants select lower temperatures.

The thermal sensations are triggered by the recievers of the skin, while the perception is more complex, because it depends on thermorecievers, but also on the neuronal impulses and the actions of the body itself to the regulatory effect.

Functioning of the cutaneous thermorecievers:

It is a tract of nerve endings to the surface of the skin, which are the most influential in thermal aesthetics, as they provide external sensory data that is compared with those of the indoor.

As explained above, these thermorecievers are divided into two groups, heat and cold. Figure 6 shows their behavior.

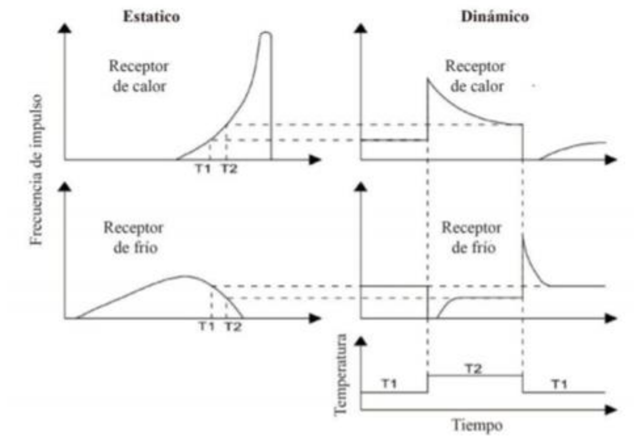

Figure 18. Thermorecievers behavior on external stimulus.

As can be seen in the graphs, initially, so, at temperature T1, the frequency of impulses from the receivers of cold is greater than that of heat, see clearly the two graphs of the earth. Therefore, if the temperature rises to T2, the impulse frequency is statically higher in the heat recievers than in the cold recievers. In terms of the dynamic response, as can be seen in the graphs of the right, when the temperature starts to increase, the heat recievers presents a peak in terms of impulse frequency and decreases in order to reach the static state corresponding to the T2 temperature. As it does to the impulse frequency of the dynamic network receiver, it is seen as the moment in which the temperature starts to increase, this frequency is reduced to 0 and increases in order to reach a static state corresponding to the temperature T2, which is slightly lower than the frequency it had when the temperature was T1.

An important fact to note is that, as can be seen in the graphs, the frequency of impulses in the cold recievers arrive more quickly to the balance that the heat recievers. De Dear will carry out an experiment to prove this fact by a group of students and introduce them in chambers at high temperature and then at low temperatures and vice versa. It was verified that when it is passed from a frying chamber to a heating one, the students have a similar sensation to the final static state, so, that the intensity of change that they perceive was moderate. In contrast, when they passed from the heating chamber to the freezing chamber, the impressions they had at first were much more intense, but were less so, as can be seen from the graphics. One possible reason for this is that the fed thermorecievers are more sensitive to the surface of the skin (0.2 mm) than the heat (0.5 mm).

- **Evaluation of thermal comfort in enclosures of 10 public buildings in Chile in winter** (Molina & Veas, 2012)**.**

Aim: One of the objectives of this article is to check whether the ASHRAE 55 and ISO 7730 standards are applicable as a reference for comfort in medium-sized buildings. This would be based on a comparison between the comfort values defined by Fanger in the PMV, the values defined by Givoni in the psychometric diagram and a study carried out in 10 public buildings in Chile. This analysis presupposes that people are actors who are active about the stimuli of the environment, and is based on the theory of thermal balance by De Dear.

The other objective is to check whether the environmental parameters defined by Fanger as neutral are also considered as neutral by the users of the different buildings. In other words, to study the real acceptability of the environment based on satisfaction surveys and to observe how it relates to different factors such as the context, behavior, personality and expectations of the users.

Context: Chile.

What does the report present: This article tries to show how people respect the thermal comfort in different buildings of public use and in different regions of Chile by means of surveys. The results obtained are later compared with the PMV of Fanger and the ISO 7730 and ASHRAE 55 standards, which define the standard comfort conditions.

Methodology and explanation: The methodology of this study is based on carrying out comfort surveys with a group of people in different areas of the country during a week: 5 offices, 4 educational centres and 1 service centre. One in the summer and one in the winter. These areas were monitored to obtain data on the climatic conditions that people encounter. A total of 64 people will participate during the summer and 81 people during the winter.

Therefore, the first thing to do is to calculate the PMV and PPD of each building monitored from the conditions of each person and, after carrying out the experiment, the users were asked about their thermal satisfaction.

The results obtained with the surveys and the monitoring of the buildings are shown in Table 5.

EDIFICIOS	REGIÓN	USO	PMV	MV	PPI	PI	ISO 7730	ASHRAE 55	T° OPERATIVA	T° EFECTIVA
MOP	II	OFICINA	-0,3	-0,4	6,5	30	ACEPTABLE	CLASE B	20,5	20,33
LABOCAR	II	OFICINA	-0,5	-1,7	10,3	66,67	N/A	CLASE C	20,5	19,1
AEROPUERTO	III	SERVICIO	-0,6	-1,3	12,9	50	N/A	CLASE C	19,8	17,9
MOP	III	OFICINA	0,0	0,7	5,0	33,3	ACEPTABLE	CLASE A	20	21,25
RUCAMANKE	IX	ESCUELA	-2,0	-2,0	76,2	71,4	N/A	N/A	19,8	9,75
FCO VALDÉS	IX	ESCUELA	-1,0	-0,7	25,7	12,5	N/A	N/A	19,8	14,95
PDI	X	OFICINA	0,2	0,5	5,8	0	ACEPTABLE	CLASE A	20	22,15
MOP	X	OFICINA	-0,1	0,9	5,2	0	ACEPTABLE	CLASE A	20,5	21,15
GABRIELA MISTRAL	XI	ESCUELA	-2,0	1,0	78,4	0	N/A	N/A	20,5	11,7
TENIENTE MERINO	XI	ESCUELA	-1,1	0,4	30,2	60	N/A	N/A	21,7	15,25

Table 11. Results of acceptability on the different methods.

In general, it is possible to observe how there is a difference between the PMV calculated from Fanger's equation and the actual acceptability presented by the user (MV).

Relevant results:

As can be seen in the results, there is a lower real acceptability in offices and services than on Fanger’s one, both for hot and cold climates. In other words, users feel cooler than on Fanger’s one in lightly cold or windy neutral climates, and feel warmer than on Fanger’s one in lightly hot or windy neutral climates.

It can be observed that in schools happens the opposite, most of them have a higher real acceptability than the one calculated by Fanger.

These results show that the parameters of temperature, humidity, activity and clothing not only influence the calculation of thermal comfort, but also other parameters, both physiological and psychological.

One reason why schools are more acceptable than Fanger's calculation, and why offices and services are less acceptable, is that students are not able to change most of the conditions that influence comfort and, in the case of offices and services, they are freer to change factors in order to be more comfortable. Thus, psychologically, schools are more tolerant of uncomfortable climates that do not occur in the office, even if the opposite is true.

In the Figure 7 it is possible to observe where the different buildings are located during the winter as far as the comfort zone drawn on the psychometric diagram of Givoni. As can be seen in the school areas (5, 6, 9 and 10), all the buildings are located in the comfort zone, and all the people who are there have a strong feeling of comfort.

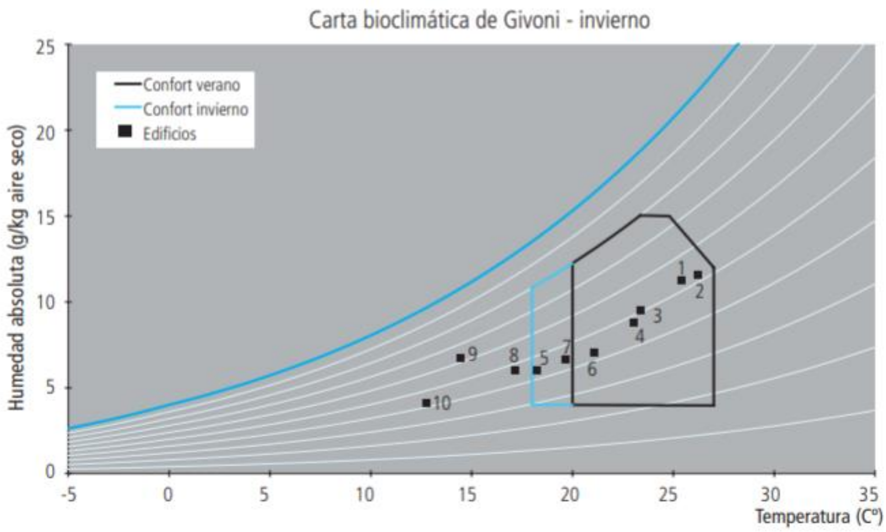

Figure 19. Psychometric diagram of Givoni

- Physical foundations and methods of evaluation of climatic comfort in human bioclimatology studies (Fernández García, 1994).

Aim: The temperature sensors of the body are in charge of identifying the thermal variations of the environment and transmit signals to the brain so that the mechanisms that correct this deviation are activated. In order to explain the process easily, the cold thermorecievers send negative signals and the heat thermorecievers send positive signals to the brain. This is responsible for interpreting the sum of negative and positive impulses that are cancelled out between them and thus activating the correction mechanisms, which as mentioned above is based on the dilation and contraction of the blood vessels.

Context: International.

What does the report present: By means of a physiological explanation of human comfort, this article relates the fact of comfort and thermal decomfort with the exchange of heat between the human body and the environment that the wrap is, so, it bases the phenomenon of human comfort on a constant energy balance between body and environment.

Explanation: As has already been mentioned, the human body has a regulation system that is responsible for correcting the thermal deviations that are produced as a consequence of both internal and external conditions.

Therefore, according to the degree and intensity of the adaptation process, it is possible to delimit the thermal lists that are essential when evaluating comfort:

- Vasomotor regulation zone against cold: Set of environmental conditions on the heat losses of the skin activates the mechanisms to reduce the blood flow to the skin and surface tissue. Underneath this area, the body generates heat from muscle movement.

- Functional regulation zone against cold: When the previous mechanisms are not enough and it is necessary to rest more stealing or realize physical activity to increase the production of heat.

- Cooling zone: When the previous actions are capable of regulating the temperature, they can produce lesions in the organism, so, decreases of the internal temperature of the human body where they generate heat losses and arrive at 31ºC can be a cause of death.

- Neutral point: When the weather should not make an effort to maintain the indoor temperature.

- Vasomotor regulation zone against heat: When the temperature is slightly higher than the neutral point, there is an increase in blood flow to the skin and superficial tissues so that the temperature of this zone is equal to that of the previous tissues.

- Evaporative regulation zone: When the skin temperature exceeds 35ºC, it begins to produce sweat in order to cool by evaporation. Not only depending on the temperature, but all the zones depend on a large number of factors.

- Poaching zone: When the heat can cause injuries, when the internal temperature exceeds 37ºC. An internal temperature of more than 43ºC can cause death.

Modeling of the heat balance:

The human body has several mechanisms to produce heat or to disperse it. Table 6 shows the ways in which the heat transfer can be regulated.

Gains	Losses
Heat produced by the body: Metabolism, physical activity, muscle stress.	Outdoor radiation: in the cell, in the air if the temperature is lower.
Absorption of radiant energy: Directly from the sun or reflected. From the environment.	Heat conduction to the outside: By convection when the air temperature is lower than the skin one. By contact with colder objects.
Heat conduction to the body: In the air if it has more temperature than the skin, to contact with hoter objects.	By evaporation: From breathing. From evaporation generated by the skin.
Hoting by condensation of the weat on the skin.	

Table 12. Heat gains and losses on the human body.

One way of comparing or observing the heat management that is the proper way to do this is to perform an energy balance, i.e., the net emmated heat is the result of subtracting the losses for radiation, convection and evaporation from the heat provided by the intake of food or beverages. The following expresion therefore presents this balance.

$$M + \Delta R + \Delta C - E = S\ (\frac{W}{m^2})$$

Where M is the heat provided by the food that is cremated according to the physical activity performed by the person, R, C and E belong to the losses by radiation, conduction, convection and evaporation respectively, and S is the net heat emmagnetized.

As can be deduced, the neutral point is, in other words, the point of theoretically maximum comfort is when the net heat emmated is, in other words, that the heat provided by the food (metabolism) is equal to the sum of the losses.

In order to observe how this value fluctuates and to make first estimates, Table 7 shows the approximate values of this value, which are different for each organization.

Actividad	W/m^2	Met	W/pers
Dormir	40	0.7	72
Estar acostado (despierto)	45	0.8	81
Estar sentado en reposo	60	1.0	108
Estar sentado con actividad ligera	64	1.1	115
Estar de pie sin movimiento	70	1.2	126
Estar de pie con actividad ligera	78	1.3	140
Estar de pie con actividad moderada (industria ligera)	93	1.6	167
Trabajo manual ligero, cocinar	100	1.7	180
Caminar en horizontal (2 km/h)	110	1.9	198
Bailar (actividad social)	111	1.9	200
Construcción ligera	125	2.2	225
Trabajo manual moderado, ejercicio ligero	139	2.4	250
Lavar platos	145	2.5	261
Limpieza doméstica	150	2.6	270
Ejercicio moderado	167	2.9	300
Lavar a mano, planchar	170	2.9	306
Construcción moderada	180	3.1	324
Caminando en horizontal (5 km/h)	200	3.4	360
Trabajo manual pesado	235	4.1	423
Ejercicio intenso	250	4.3	450
Construcción pesada	275	4.7	495
Ejercicio y trabajo muy intensos	450	7.8	810
Correr (15 km/h)	550	9.5	990

Table 13. Work values of the different activities.

The units are in [W/m^2], so, Watts per square of skin of the person.

Of the energy obtained by the ingestion of food, it is known that approximately 20% is used for physiological functions, but 80% is dissipated in the form of heat to the environment, that is, this 80% is to be taken into account in the equation as the term M.

These units of W/m^2 are difficult to work with, so it is calculated that an adult has a half of 2 square meters of skin.

In order to understand and quantify this value, it is interesting to observe how many calories each person takes in a day. Table 8 shows an approximation of how much food we eat.

Alimento	Densidad (cal/g)	Alimento	Densidad (cal/g)
Lechuga	0.15	Quinoa	1.43
Espinaca	0.23	Salmon	1.45
Sandia	0.30	Huevo	1.48
Frutillas	0.32	Aguacate	1.60
Zanahoria	0.40	Pan integral	2.48
Naranja	0.48	Carne	2.50
Leche semidescremada	0.50	Pan Blanco	2.64
Manzana	0.52	Hamburgesa	2.82
Uvas	0.69	Queso Mozzarella	3.00
Papa hervida	0.87	Pasas	3.00
Banana	0.89	Papa frita	3.07
Salsa de tomate	1.00	Frejol Negro	3.41
Pechuga de pollo	1.10	Cereal Zucaritas	3.67
Arroz integral	1.10	Mayonesa	3.86
Pescado (tilapia)	1.13	Nutella	5.41
Atun	1.16	Mani	6.00
Arroz blanco	1.30	Mantequilla	7.21
Spaghetti	1.31	Aceite de oliva	8.85
Cerdo	1.36		fitcultur.com

Table 14. Calories of the different food.

From the conversion factor you can obtain these values in Joules, so it is easier to quantify how much it takes for a physical activity to release all the heat that has been ingested, that is, the heat input is still the same as the output. For example, in the case of a 100g burger, this value is:

$$100\ g \cdot \frac{2{,}82\ kcal}{1\ g} \cdot \frac{4{,}18\ kJ}{1\ kcal} = 1.178\ kJ$$

With this value, it is possible to observe how much of each physical activity must be done in order to dispel and maintain the energy balance. As it has been commented before, 80% of this value must be taken, since the rest is for physiological functions, that is, 942 KJ.

For example, it is calculated that there is a need to be in a poor state of movement in order to dissipate this heat.

To be in a poor state of mind: 70 W/m^2

$$70\frac{W}{m^2} \cdot \frac{2\ m^2}{person} \cdot \frac{1\ J}{1\ W \cdot s} \cdot \frac{1\ burger}{942\ 000J} \cdot \frac{3600s}{1h} = \ 0{,}53\ h^{-1} = 1{,}87\ h$$

So, if a person eats a quantity of 100 grams of hamburger, he would have to be quiet for 2 hours without any movement to eliminate this heat and turn into a balance of energy of the body.

The WHO establishes that a person with half a body would consume between 1.600 and 2.000 Kcal in the case of the female sex and between 2.000 and 2.500 in the case of the male sex.

In order to carry out an illustrated calculation, it is assumed that a person takes in 2.000 Kcal, 80% of which is heat that can be dissipated, that is, 1.600 Kcal.

This would mean a total of 13.2 hours of maintenance without movement, so that the most adapted to the reality and the daily life of the people is able to make a model like the following:

It's supposed to be 8 hours of sleep, 1 hour of walk per day, 1 hour of exercise, 4 hours of activity and 8 hours of rest.

With this total of hours, it is possible to calculate approximately how many calories a person uses during the day. In this case, it shows the activity of an active person and a sportsman, the result is much less if it is about people who do not exercise or have a more sedentary lifestyle.

$$40\ \frac{W}{m^2} \cdot \frac{2\ m^2}{1\ person} \cdot \frac{1\ J}{1\ W \cdot 1\ s} \cdot \frac{3600s}{1h} \cdot 8h = 2.300\ KJ$$

$$200\ \frac{W}{m^2} \cdot \frac{2\ m^2}{1\ person} \cdot \frac{1\ J}{1\ W \cdot 1\ s} \cdot \frac{3600s}{1h} \cdot 1h = 1.440\ KJ$$

$$250\ \frac{W}{m^2} \cdot \frac{2\ m^2}{1\ person} \cdot \frac{1\ J}{1\ W \cdot 1\ s} \cdot \frac{3600s}{1h} \cdot 1h = 1.800\ KJ$$

$$64\ \frac{W}{m^2} \cdot \frac{2\ m^2}{1\ person} \cdot \frac{1\ J}{1\ W \cdot 1\ s} \cdot \frac{3600s}{1h} \cdot 4h = 1.840\ KJ$$

$$60\ \frac{W}{m^2} \cdot \frac{2\ m^2}{1\ person} \cdot \frac{1\ J}{1\ W \cdot 1\ s} \cdot \frac{3600s}{1h} \cdot 8h = 3.450\ KJ$$

$$Total\ of\ calories\ = 2.300 + 1.440 + 1.800 + 1.840 + 3.450 = 10.830\ KJ = 2.590\ Kcal$$

So, this person uses a total of 2.590 Kcal. If it is a tea in account that has eaten less than the amount of calories from the meal, this person has a caloric deficit, and therefore the body would take heat reservations that previously possessed of fats or other nutrients and therefore to realize the phenomenon known as "getting ready", will have a feeling of comfort more displaced cap to the fred in relation to the neutral point. This is not to say that the person must have a feeling of discomfort, but that he or she is more likely to feel it because of the deficit of calorie intake, but it must be taken into account that this is one of the many factors on which human comfort depends.

Thus, a situation of caloric deficit has been explained, but the opposite happens if the person does not use the calories that he or she takes in daily.

Heat transfer by conduction:

This is the heat exchange that takes place between the skin and the surface of the clothing that is in contact with the outside. This value depends on the temperature difference between the skin and the clothing and the insulation capacity of the clothing. Therefore, in order to quantify this coeficient C of the energy balance equation, the following expression has been arrived at, where it can be observed that the mentioned temperature difference and the insulation coeficient of the clothing are used.

$$C = 0{,}155\ Icl\ (tsk - tcl)$$

Where I_{cl} is the coeficient of isolation of all the clothes that the person carries, and is measured in [W/m2-ºC]. It has a linear behavior and depends on the sum of the surface covered and the amount of clothing worn:

$$Icl = 0{,}524 \sum Icli + 0{,}056$$

In Table 9 it is possible to observe the value of each I_{cli}:

Prenda de vestir	Clo	m^2·K/W	Prenda de vestir	Clo	m^2·K/W
Desnudez			Pantalones		
Ninguna prenda	0.00	0.000	Pantalones cortos	0.06	0.009
Ropa interior inferior			Pantalones ligeros	0.20	0.031
Medias	0.02	0.003	Pantalones normales	0.25	0.039
Bragas y calzoncillos	0.04	0.006	Pantalones de franela	0.28	0.043
Calzoncillo 1/2 pierna de lana	0.06	0.009	De alto aislamiento		
Calzoncillo pierna entera	0.10	0.016	Suéter chaleco	0.12	0.019
Ropa interior superior			Suéter fino	0.20	0.031
Sujetador	0.01	0.002	Suéter fino cuello de cisne	0.26	0.040
Camiseta sin mangas	0.06	0.009	Suéter normal	0.28	0.043
Camiseta manga corta	0.09	0.014	Suéter grueso	0.35	0.054
Camiseta manga larga	0.12	0.019	Chaqueta ligera de verano	0.25	0.039
Camiseta térmica nylon	0.14	0.022	Chaqueta normal	0.35	0.054
Camisas			Multicomponente relleno	1.03	0.160
Camisa manga corta	0.09	0.014	Abrigos		
Blusa ligera, manga larga	0.15	0.023	Abrigo	0.60	0.093
Camisa ligera, manga larga	0.20	0.031	Sobreabrigo	0.52	0.081
Camisa normal, manga larga	0.25	0.039	Gabardina	0.55	0.085
Camisa franela, manga larga	0.30	0.047	Calzado		
Blusa larga de cuello de cisne	0.34	0.053	Calcetines normales	0.02	0.003
Falda, vestido			Calcetines gruesos tobillos	0.05	0.008
Falda ligera, 15 cm sobre rodilla	0.10	0.016	Calcetines gruesos largos	0.10	0.016
Falda ligera, 15 cm bajo rodilla	0.18	0.028	Zapato suela fina	0.02	0.003
Falda gruesa hasta la rodilla	0.25	0.039	Zapato suela gruesa	0.04	0.006
Vestido ligero sin mangas	0.25	0.039	Botas	0.10	0.016
Vestido de invierno manga larga	0.40	0.062	Guantes	0.05	0.008

Table 15. Clo of the different pieces of clothing.

NOTE: 1 Clo is 0,155 m2·ºC/W.

The tsk term corresponds to the temperature of the skin, and this depends on the metabolism (M), of the clothes that are carried (I_{cl}) and the temperature of the ambient air (t_a). The expression is the following, where it is expressed with ºC and M in met:

$$tsk = 29{,}55 + 0{,}196 * ta - 1{,}064 \cdot M \cdot (1 - 0{,}295Icl)$$

The temperature of the tcl is related to the temperature of the garment, and this depends on the temperature of the skin (tsk), the temperature of the air in the room (ta) and the surface area of the skin covered by the garment (f_{cl}). The expression is as follows:

$$tcl = tsk - 0{,}155I_{cl}[0{,}71f_{cl}(tsk + ta)$$

In Table 10 it is possible to observe the values that are f_{cl}:

	Factor ropa	
	Icl (clo)	fcl
Desnudo	0	1
Pantalón corto	0,1	1
Pantalón y camiseta	0.3/0.4	1,05
Pantalón largo ligero y camiseta	0,5	1,1
Chandal y ropa deportiva	0,6	1,1
Traje con ropa interior ligera	1	1,15
Traje y ropa interior pesada	1,5	1,2

Table 16. Values of factor on pieces of clothing.

Heat transfer by convection:

It's the heat exchange that occurs when the surface of the skin or clothing is different from the air in the room. Therefore, the feeling of the heat exchanger goes from the warm focus to the cold focus. The expression for the calculation of the latter is the following:

$$C = hc \cdot fcl \cdot (tcl - ta)$$

On hc is the coeficient of heat transfer by convection, depending on the temperature of the clothes, the air and the wind speed:

$$if\ V < 0{,}1\frac{m}{s} \qquad hc = 2{,}38 \cdot (tcl - ta)$$

$$if\ V > 0{,}1\frac{m}{s} \qquad hc = 12{,}1 * \sqrt{V}$$

Heat transfer by radiation:

Every body, regardless of the temperature at which energy is emitted from the surface to the outside, this is the radiant energy and it is transferred through electromagnetic means, i.e. it can also be transferred from the buit, as is the case with solar radiation. Therefore, two things that are found at different temperatures give rise to a heat exchange with the aim of reaching thermal equilibrium. As it has been commented, it is a product of one, and therefore, there can be two types of radiation:

- Shortwave radiation: This is the incident solar energy absorbed directly by the skin. It can be modelled from the following expression:

$$Rc = (ask \cdot trancl \cdot Rinc)/fcl$$

Where ask is the absorbency of the skin, trancl is the transmissivity of the theft.

- Long wave radiation: This is the radiant flux that is produced or lost by the external surface of the person, and can be expressed in the following way:

$$Rl = hr \cdot fcl \cdot (tcl - trm)$$

Where hr is the heat transfer coefficient for radiation, which varies with the emissivity of the theft.

This is particularly important in urban areas where there is solar radiation on the road and on the ground, which gives off this energy.

Heat transfer by evaporation:

It deals with the latent heat of the air that passes to the environment, both by the evaporation of the sound of the skin and by breathing. Therefore, it can be divided into three types:

- For the respiratory tract:

From one band there is the heat exchange sensitive to the difference in temperature between the air expelled from the body and the outside air, and from another band the latent heat exchange sensitive to the difference in water vapour concentration between the environment and the lungs.

The expression of sensible heat is:

$$C_{res} = 0{,}0014 \cdot M \cdot (34 - ta)$$

As you can see, it depends on the metabolism and the temperature of the air.

The expression of latent heat is:

$$E_{res} = 0{,}0173 \cdot M \cdot (5{,}8 - Hr - Pva)$$

This dependence on metabolism, steam pressure and relative humidity.

- Heat exchange by skin evaporation:

It's about the evaporation of water that's found in the skin. This transfer will have a maximum level when all the surface of the skin is covered with sweat and a minimum level when the skin is covered with moisture (not sweat) depending on the temperature of the skin and the humidity of the atmosphere.

The maximum level can be quantified with the following expression:

$$Emax = 16{,}7 \cdot hc \cdot fpcl \cdot (Pv_{tsk} - (Hr \cdot Pv_{ta})$$

On hc is the heat transfer coefficient, Pv is the saturation steam pressure at skin temperature, Hr is the relative humidity of the air and fpcl is the permeation factor of the clothing.

NOTE: The value of fpcl can be calculated as:

$$fpcl = 1/(1 + 0{,}143 \cdot hc \cdot Icl)$$

In this way, a person with a completely waterproof jacket has a coefficient of 0, while a person with a completely waterproof jacket has a coefficient of 1.

Relevant results:

Once it has been verified that thermal comfort can also be shown as a simple energy balance, is automatically demonstrated a number of factors or parameters that really influence comfort, these are:

The air temperature of the environment, the temperature of the human body, the relative humidity, the metabolic rate, the type of clothing, the weight, the intake of food or drink, the thermal history, the time of stay and the air speed.

List of factors and parameters

Parameter	Summary	Supporters
Outdoor air temperature	The temperature of the outside air is important and influences the comfort of the person in an indoor environment, since it will obviously influence the indoor environment by the transfer of heat between the exterior and indoor environment.	- Q. Li, X. Sun, C. Chen, X. Yang, Characterizing the household energy consumption in heritage Nanjing Tulou buildings, 2012. - M. Angélica Ruiz, E. N. Correa, Confort térmico en espacios abiertos. Comparación de modelos y su aplicabilidad en ciudades de zonas áridas, 2009. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. -Yoram Epstein, Daniel S. Moran, Thermal Comfort and the Heat Stress Indices, 2006. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - A. Auliciems, V. Szokolay, Thermal Comfort, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002. - Yuanda Cheng, Jianlei Niu, Naiping Gao, Building and environment, Thermal comfort models: A review and numerical investigation, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Sex	According to different studies, women have less cardiovascular capacity, metabolism, evaporative capacity and skin temperature than men, so comfort depends on sex. It is calculated that this variation in the sensation of comfort is between 0.5ºC and 1ºC.	- Francisco Javier Chávez Del Bosque, Zona variable de confort térmico, 2002. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002.

		- Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973.
Age	The age is linked to the metabolism, it has been demonstrated that when people gets older, their metabolism rate is reduced, so, there has been a reduction of heat produced by the body itself, which is compensated by the reduction of the disposition that the body has to delete. Olgyay developed an expression to quantify the age factor in thermal comfort: $f_{age} = age \cdot 0{,}025$	- Francisco Javier Chávez Del Bosque, Zona variable de confort térmico, 2002. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997 - J. Hensen, Thermal comfort: Research and Practice, 2010. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Metabolic rate	Metabolism refers to the change that makes the body's own food into simpler composites that end up being the body's energy source. This can be divided into basal and muscular metabolism. The basal metabolism is the energy that a cell needs to survive, which depends on age and sex. The muscular metabolism depends on the activity of the person's muscles, so, what they are made of. It is not the same muscular work when a person is resting as when he is doing sport, the muscular metabolism is much higher in the second person. If a person produces more heat than he needs, for example, because she is doing sport, she	- M. Angélica Ruiz, E. N. Correa, Confort térmico en espacios abiertos. Comparación de modelos y su aplicabilidad en ciudades de zonas áridas, 2009. - Francisco Javier Chávez Del Bosque, Zona variable de confort térmico, 2002. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. -Yoram Epstein, Daniel S. Moran, Thermal Comfort and the Heat Stress Indices, 2006.

	will tend to have a much greater sensation of heat than if she is on the move, and therefore have a feeling of cold.	- Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Auliciems, V. Szokolay, Thermal Comfort, 1997. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002. - Yuanda Cheng, Jianlei Niu, Naiping Gao, Building and environment, Thermal comfort models: A review and numerical investigation, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Clothing	The clothes act as a barrier between the person and the environment, that is, it's an isolator. It prevents the transfer of heat between the organisation and the outside. Therefore, in a cold environment, people is protected by the insulating effect of the clothing, by this way the heat produced by the clothing is not transferred so easily to the outside, and therefore the feeling of cold is reduced. On the other hand, in warm environments, people is interested in deleting this thermal barrier represented by the clothing in order to easily transfer the heat generated by the skin, thus reducing the feeling of warmth. In a humid environment it is also interesting to make the minimum barrier between our skin and the environment in order to facilitate the loss of convection of our skin from the contact between the skin and the air and the loss of moisture present on the surface of the skin.	- M. Angélica Ruiz, E. N. Correa, Confort térmico en espacios abiertos. Comparación de modelos y su aplicabilidad en ciudades de zonas áridas, 2009. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Felipe Fernández García, Fundamentos físibody y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002. -Yoram Epstein, Daniel S. Moran, Thermal Comfort and the Heat Stress Indices, 2006. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Auliciems, V. Szokolay, Thermal Comfort, 1997. - Yuanda Cheng, Jianlei Niu, Naiping Gao, Building and environment, Thermal comfort models: A review and numerical investigation, 2010.

		- Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Weight	The weight of each person is linked to the surface of the skin and the volume of the body. The surface of skin exposed to the outside is proportional to the amount of heat that is transferred between the skin and the outside, and the volume of the skin is directly proportional to the amount of heat produced by the skin itself. Therefore, as the weight increases, the relationship between the surface area and the volume of the weight decreases, as more heat is produced and less is transferred. Therefore, a person with a high weight in a warm environment will have a greater sense of discomfort than a person with a lower weight, and conversely, in a cold environment, a person with a high weight will have a greater sense of comfort than a person with a lower weight, who may have a feeling of cold and not of comfort.	- Francisco Javier Chávez Del Bosque, Zona variable de confort térmico, 2002. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Auliciems, V. Szokolay, Thermal Comfort, 1997. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Contribute	It's about the heat exchange that is made by the intake of food and drinks. To give an example that this phenomenon exists, it is only necessary to check that people who do physical exercise tend to consume cold drinks again. Therefore, when we eat or drink, it enters into our body, which is at a different temperature to that of the food, where a transfer of heat is made so that the temperatures of both arrive at the thermal balance, and therefore the temperature of the human body is modified. Apart from this phenomenon, there is also a not so evident alternative, and that is that there is also an effect on the composition of the elements that are ingested in the metabolism, for example, in the case of fats or alcohol. When we eat	- Francisco Javier Chávez Del Bosque, Zona variable de confort térmico, 2002. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Auliciems, V. Szokolay, Thermal Comfort, 1997. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.

	or drink something, we are getting calories, so we are making a heat transfer between our organism and the food.	
Thermal history	This refers to the different actions performed by the body to adapt to the environment where it is. For example, in warm environments, the blood vessels in the skin are dilated and the blood vessels are able to transfer heat to the environment. So if a person is in a warm environment, and he or she changes to a cooler environment, it takes time to adapt, it is not instantaneous, and therefore, the blood vessels transfer more heat than they have warned because they are still dilated, in this way the person will notice more cold than he or she would if they were there. Outside, the temperatures are very high and therefore the blood vessels are very dilated, so when you enter a shop or commercial centre that has air conditioning, it is very common to experience a feeling of cold during the first five minutes. In the previous case, it is a matter of immediate effects, but there is also the influence of the thermal history in mediated effects. For example, when the season changes, if the temperature is different from the one it should be at the time of the year, a feeling of discomfort is experienced.	- Francisco Javier Chávez Del Bosque, Zona variable de confort térmico, 2002. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - A. Auliciems, V. Szokolay, Thermal Comfort, 1997. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Time of stay	This fact is linked to the thermal history of the body. As there is a change in the thermal conditions, it is necessary to carry out tasks to maintain the thermal balance and to avoid heat loss. This fact implies a physical wear of our body that cannot be maintained indefinitely. If the amount of heat lost is less than the body can produce, the temperature of this will decrease and vice versa. The more extreme the conditions are, the	- Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - A. Auliciems, V. Szokolay, Thermal Comfort, 1997.

	faster they rise to this limit, which is a sign of thermal stress. This thermal stress can be caused by a very long time of permanence in conditions that are not normal, but it also follows extreme conditions because that is what the phenomenon is.	- Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Expectations	This parameter depends on various circumstances, there are not the same expectations if it is outside than inside, where the expectations of comfort are much higher. Another circumstance that influences comfort is whether people know that they can decide on which thermal environment they can be or whether they can't. There are several examples of this. When a person is exposed to the sun on the desert, this instinct lowers his expectations of comfort and he automatically tolerates more the ambient heat to which he is exposed. Other cases: Priorities, season of the year, geographical location, economic range.	- Q. Li, X. Sun, C. Chen, X. Yang, Characterizing the household energy consumption in heritage Nanjing Tulou buildings, 2012. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Visual contact	If a person is in an indoor environment without visual contact with the outside, the thermal environment he or she will perceive will be different from if there is visual contact with the outside. This phenomenon is easily explained by a few examples. For example, if the person is in an indoor thermal environment and it is slightly cooler than the comfort standards and does not have visual contact with the outside, this person will experience a feeling of discomfort. Therefore, if in the same thermal environment, the person has visual contact with the exterior and sees that outside it is all snowy, this person will have a feeling of comfort or will be more tolerant of discomfort.	- Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - F. R. d'Ambrosio Alfano, L. Bellia, F. Fragliasso, B. I. Palella and G Riccio, Thermal Comfort and visual interaction: a subjective survey, 2019.

	On the contrary, it would happen in warm situations, but the most evident example is the snow.	
Indoor air temperature	The human body has been for years with a temporal variability of temperature, both indoors and outdoors. In this way, you do not feel like talking about a fixed temperature indoors, but it can fluctuate and is still a feeling of comfort. Therefore, in indoors, the temperature is lower in winter than in summer, and you will find that with less thermal contrast between indoor and outdoor, less comfort will be provided, as long as the indoor temperatures remain within a comfortable range.	- Q. Li, X. Sun, C. Chen, X. Yang, Characterizing the household energy consumption in heritage Nanjing Tulou buildings, 2012. - M. Angélica Ruiz, E. N. Correa, Confort térmico en espacios abiertos. Comparación de modelos y su aplicabilidad en ciudades de zonas áridas, 2009. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. -Yoram Epstein, Daniel S. Moran, Thermal Comfort and the Heat Stress Indices, 2006. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002. - Yuanda Cheng, Jianlei Niu, Naiping Gao, Building and environment, Thermal comfort models: A review and numerical investigation, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Relative humidity	The higher the humidity of the environment, the lower the rate of evaporation of sweat, and therefore the less heat is lost through evaporation. This is because humidity is the amount of water vapour in the air, and relative humidity is the percentage of humidity compared to the maximum humidity that could be present in the environment without the water vapour starting to	- M. Angélica Ruiz, E. N. Correa, Confort térmico en espacios abiertos. Comparación de modelos y su aplicabilidad en ciudades de zonas áridas, 2009. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973.

	evaporate. This is an anomalous humidity of saturation, and is determined by the temperature at which the environment is found, which can be easily observed in a psychometric diagram. Another phenomenon in which humidity participates is in the capacity of thermal insulation of the clothes, since humidity is present among the tissues displacing a volume of air, and since water has a specific heat coefficient greater than air, the thermal conductivity of the clothes increases. Not only does it influence the transfer of heat from the clothes, it also does so through the convection with the skin, because the specific heat of the mixture is greater and thus makes the heat flow from the body to the air even greater if the temperature in the room is lower than that of the skin.	- Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997 - A. Auliciems, V. Szokolay, Thermal Comfort, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. -Yoram Epstein, Daniel S. Moran, Thermal Comfort and the Heat Stress Indices, 2006. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002. - Yuanda Cheng, Jianlei Niu, Naiping Gao, Building and environment, Thermal comfort models: A review and numerical investigation, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Radiant temperature	There is a great quantity of radiant sources, the clearest and most important example is the sun, so, it is possible to define the radiant temperature as the temperature that is obtained when there is a source or thing that is at a temperature and it gives off to the environment. For this same reason, the human body is also a radiant source, because it is normally at a different temperature from the ambient temperature, and therefore sends heat to the room. The walls and the ground of a building are also radiant sources, although they are indirect, as they make use of solar radiation. There is a heat exchange between the person and the surfaces affected by radiation, the amount of which depends on the difference in temperature between the two surfaces. It is obvious that this heat exchange influences the	- M. Angélica Ruiz, E. N. Correa, Confort térmico en espacios abiertos. Comparación de modelos y su aplicabilidad en ciudades de zonas áridas, 2009. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Felipe Fernández García, Fundamentos físicos y métodos de evaluación del confort climático en los estudios de Bioclimatología humana, 2002. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. - Yuanda Cheng, Jianlei Niu, Naiping Gao, Building and environment, Thermal comfort models: A review and numerical investigation, 2010. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002. -Yoram Epstein, Daniel S. Moran, Thermal Comfort and the Heat Stress Indices, 2006. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997

	temperature perceived by the person and therefore directly influences the thermal comfort.	- A. Auliciems, V. Szokolay, Thermal Comfort, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Air velocity	This parameter is important in the heat exchange that occurs between the skin and the environment. The contact between the skin and the air implies the existence of a heat exchange by conduction, therefore, if this air is static, there is a layer up to the temperature of balance with the skin and this heat transfer is at less. If we are in a warm situation, then we will have more sensation of discomfort, so, normally the speed of the air makes to refresh the skin and therefore, to lower the thermal sensation, always and when, the air of the environment is in a lower temperature to the one of the human skin. Therefore, if there is movement of air, the volume that has to be poached to reach the thermal balance is much greater than if it is static, and therefore there will be a greater transfer of heat.	- M. Angélica Ruiz, E. N. Correa, Confort térmico en espacios abiertos. Comparación de modelos y su aplicabilidad en ciudades de zonas áridas, 2009. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002. -Yoram Epstein, Daniel S. Moran, Thermal Comfort and the Heat Stress Indices, 2006. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - A. Auliciems, V. Szokolay, Thermal Comfort, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010. - Yuanda Cheng, Jianlei Niu, Naiping Gao, Building and environment, Thermal comfort models: A review and numerical investigation, 2010. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Architectural parameters	The characteristics of the building also influence the perception of the people who are in it, such as curtains, windows, blinds, fans...	-Kristian Fabbri, Marco Zuppiroli and Keoma Ambrogio, Heritage buildings and energy performance: Mapping with GIS tools, 2012. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Richard de Dear, Gail Brager, Donna Cooper, Developing an Adaptive Model of Thermal Comfort and Preference, 1997. - J. Hensen, Thermal comfort: Research and Practice, 2010.

Adaptability of the space	It refers to whether the people inside have the ability to modify the indoor climate from architectural and mechanical elements. This is a psychological factor, since when people know how to interact with the building to achieve greater thermal comfort, they are more demanding and intolerant of feelings of discomfort.	- Q. Li, X. Sun, C. Chen, X. Yang, Characterizing the household energy consumption in heritage Nanjing Tulou buildings, 2012. - Alfonso Godoy Muñoz, El confort térmico adaptativo, 2012. - Jing Liu, Runming Yao, Rachel McCloy,A method to weight three categories of adaptive thermal comfort 2011.
Interpersonal relationship	Depending on the type of relationship between the inhabitants, these would be more or less ambitious with the comfort.	-Kyle Anderson, SangHyun Lee and Carol Menassa, Impact of Social Network type and Structure on modeling normative energy use behavior interventions, 2014.
Light	The characteristics of the light can contribute to an improvement of the thermal comfort of the occupants, increasing the sensation of heat in winter and the sensation of cold in the summer, maintaining the temperature of the heating, ventilation and air conditioning, allowing an energy break. A frying light causes a displacement of the thermal sensation from hot to cold and a heating light causes a displacement of the thermal sensation from cold to hot.	- F. R. d'Ambrosio Alfano, L. Bellia, F. Fragliasso, B. I. Palella and G Riccio, Thermal Comfort and visual interaction: a subjective survey, 2019.
Thermal asymmetry	The thermal dissatisfaction can be due to a scaling or cooling in a specific part of the body. This phenomenon is known as local thermal discomfort. Local discomfort can be divided into four groups: local cooling of uncovered body parts by the air flow, cooling or heating of body parts by the radiation, but also cold and heatings by a strong vertical temperature gradient and cold or heatings by the extreme temperature of the ground.	- Povl O. Fanger, Assessment of man's thermal comfort in practice, 1973. -Detelin Markov, Practical evaluation of the thermal comfort parameters, 2002.

Table 17. List of factors and parameters

The HOME Project and the new techniques for studying comfort

The HOME Project (Human Observations Meta Environment) is an interdisciplinary project based on the study of how new technologies act on the interactions between humans, buildings and the environment. Through this relationship, an attempt is made to reach higher levels of comfort by reducing the energy used. The different technologies proposed by the HOME Project are explained below and how they can influence the study of thermal comfort. These technologies are: Living Lab, Adaptive Thermal Comfort (this one is not included in this section as it has been commented before), Crowdsensing, Artificial Intelligence and Natural Interactions.

Living Lab:

The Living Lab concept can be identified as a real test bed and an experimental environment where users and producers can co-create innovations. They are spaces where technological prototypes are developed and tested for the improvement of citizen welfare, and which will have a real and proven effectiveness.

This concept has an important role in the HOME project, because the fact of being able to create a real work or home environment and at the same time to obtain data on factors that influence human thermal comfort, without this influencing the perception of the users or disturbing them, makes the data obtained closer to reality than in the case of a traditional test laboratory.

In conclusion, a Living Lab is a laboratory camouflaged in a real home, where users carry out their daily activities over a long period of time, which can be weeks or months, and therefore obtain more real data than a normal thermal laboratory.

Over the last two decades, the Living Lab has been defined as a methodology, an environment and a system. "From the point of view of methodology, the Living Lab focuses on user participation, from the point of view of the environment, it is based on the approach of user communities and the information technology infrastructure, and from the point of view of the system, it focuses on analysing the interaction between the environment and the users, and the objects" (Cottafava et al., 2019).

A Living Lab is considered to be well designed and executed when it complies with the following key principles, set out in the Corelabs Reports, Living Labs Roadmap (2007-2010):

- Continuity to plan a long-term Living Lab.

- Openness to focus on the process of open engagement

- Realism to replicate the real world environment.

- Empowerment of users to actively engage users.

- Spontaneity to reproduce everyday situations that do not affect users' perception.

By complying with the above principles, more real results are achieved, which are impossible to achieve with a traditional laboratory.

The Living Lab is also defined as a "user-driven open innovation ecosystem based on a government partnership between businesses and citizens that enables users to actively participate in research and the innovation process" (E. Commission, Living labs for user-driven open innovation, an overview of the living labs methodology, activities, achievements, 2009).

A fundamental aspect of the Living Lab is that users are no longer considered as final clients but as co-creators in the research and innovation process, and so they participate in the decision-making process of defining the factors that are studied and modified to obtain a common welfare. In the case of a Living Lab for the HOME project, users would have the power to decide on the environmental thermal conditions to which they are exposed, i.e. energy conditions.

One of the objectives of the Living Lab is also to obtain a sustainable energy expenditure while achieving the well-being of the users, so it is very important that the users have control over the expenditure.

"Buildings designed to follow energy-focused standards have not been consistently associated with improved occupant satisfaction" (Abbaszadeh et al., 2006), "this is due to the heterogeneity of reactions to environmental conditions among individuals over time" (Jamrozik et al., 2018).

As much as the effect that environmental conditions have in isolation is known, this cannot predict the effect on the combination of these, which is why the Living Lab methodology is also important, as it analyses the effect of the combination of many environmental conditions.

The Living Lab methodology takes a transdisciplinary and interdisciplinary approach to all those involved in the research, since it includes the users as mentioned above. "In the industry, including the research user, the one who has asked the questions that had concerned him all along is the standard and usually ensures a sufficiently comprehensive research design" (Spreng, 2014), in this case, both researchers and users are asking the questions, and this is where we see that it is also a methodology of transdisciplinarity, defined as "The central idea of transdisciplinarity is that different academic disciplines work together with professionals to solve a real-world problem. It can be applied in a wide variety of fields" (Thompson et al., 2001).

The Living Lab methodology can be carried out in the HOME project, since it has a perfect space for its implementation: the university. A university can create a Living Lab that complies with the principles set out in the Corelabs Report. Obviously, this is a very large space that is divided into several areas, so a very powerful infrastructure is needed to cover it all. The point is that only by choosing a site can the Living Lab be created with its respective facilities, obtaining real data on the daily lives of the students, who in this case are the users.

Living Labs have already been set up in several universities and other centres, and the following are some examples:

In Cahors, a Living Lab was built to understand thermal renovation in old buildings in complex urban territory. Three temperature and relative humidity data-loggers, 18 thermocouples and an external weather station were installed in an old building in the historical centre of Cahors to measure air temperature, wall surface temperature, solar radiation and indoor/outdoor pressure differential. The most interesting aspect of this study is that as it is a historical building, there were no users, so the conditions of user occupation were simulated by means of heating and humidification. Several agents participated in this project, from architects to laboratories, and from various disciplines, which confirms the need for the transdisciplinarity of this methodology.

The main objective of this study was to observe how to monitor the buildings in an optimal way, what types of materials could be used that would help the energy sustainability of this type of building without damaging the historical heritage and the parameters that could greatly influence the air conditioning solution of these buildings. Thanks to the cooperation and co-creation, a solution accepted by all was achieved. "The climate emergency is highlighting the importance of transdisciplinarity in bringing a variety of viewpoints to energy research and in questioning the solutions offered by conventional economics. It is imperative that social scientists, natural scientists and others with important contributions to make, such as artisans or politicians, work hand in hand. This co-creation will allow the most acceptable solution to be found and implemented more quickly"(Claude et al., 2017).

Another example is the ZEB Lab (Zero Emission Building), which is a Living Lab consisting of a 100 m2 single-family house with the aim of achieving zero emissions by selecting materials and systems to reduce emissions. A monitoring system was installed to record the most relevant environmental quantities, measure the energy demand for heating, ventilation, lighting and domestic appliances and collect renewable energy from the photovoltaic panels on the roof. The main objective is to evaluate the environmental and energy balance of the building and the interaction of users with the building.

Thus, this Living Lab tries to analyse the optimal environmental conditions of a home with the daily life of its inhabitants. To this end, the following key points have been considered:

- To obtain data with a similar accuracy to that of a traditional laboratory.

- The sensors must be integrated into the building as in a real house.

- The number and location of the sensors should be as close as possible to what happens in a real world application.

- The measurement system must be flexible and allow for later updating in case new, more accurate technologies are developed.

In order to obtain data for later analysis and to reach conclusions, different sensors were installed throughout the interior and exterior of the Living Lab, which measured: exterior temperature and humidity, CO_2 concentration of the exterior air, horizontal and vertical solar irradiance, exterior air speed, interior temperatures (sensor 1.6 m from the floor), interior relative humidity, CO_2 concentration of the interior air, interior diffuse lighting, movement and position sensor, position of the windows, generation of renewable energy generated, heating consumption and electricity consumption. Thanks to this extensive number of factors, it is possible to continuously analyse the model of comfort conditions presented by the inhabitants of this single-family house, and this model can be similar to many other homes. This study provides information on the environmental conditions of comfort and consumption in a single-family home, with the added intention of achieving zero emissions housing.

Another example is the case of the study of work environments converted into Living Labs. In a study in Rochester (USA), a Living Lab was built in an office, where data was taken over 18 weeks, workers were interviewed and comments on thermal comfort were gathered on a daily basis. The Living Lab allows us to study the reactions of the occupants to the environmental conditions over time with a group of individuals. However, one drawback is that the sample size is limited, as there are also variables such as age that cannot be studied since in an office the ages tend to be in the 30-year range. Six different environmental scenes were created, one of which dealt with the supposedly common environmental conditions in offices and the rest were distanced from it. The workers spent the days of the study working as usual and the environmental conditions varied. Daily surveys were conducted with workers focusing on their experience in and out of the office on a scale and interviews were also conducted at three points in the study so that workers could share experiences and other observations not previously captured. The interviews showed that workers were enthusiastic about being part of the study and finding a new working environment and were not bothered by the number of sensors in the office. Thanks to the interviews and surveys, new building designs and new environmental conditions were proposed that would satisfy the workers.

These three examples show that it is possible to implement Living Labs in order to find new designs and comfort models that take into account the heterogeneity of the building's occupants and their active attitude towards environmental conditions. In addition, the factors are analysed in a combined way, not as in traditional laboratories, where the isolated effects of environmental factors were normally observed.

Crowdsensing:

The constant evolution of computing is giving the opportunity to create methods of obtaining data from smartphones, tablets, or other electronic devices in a very simple way, since these devices are equipped with different types of sensors. Crowdsensing is a new technique for obtaining data, where devices from different users constantly send data about different variables captured by them, and once the data has been collected, it can be analysed and conclusions can be drawn.

In the case of the HOME project, this technique is of great importance, since by combining the Living Lab concept with the Crowdsensing concept, more and more robust data can be obtained. Users who are present in the Living Lab send position data or other factors through their smartphones to the centralised data system. In this way, it is possible to obtain information about who and where a user is, which makes it possible to locate the individual and have information about how many people are in the premises in question.

Crowdsensing uses simple applications such as "the alarm signal when any person passes the sensor, the ventilation system for indoor air quality based on human occupation, infant monitoring, and monitoring systems based on human behaviour" (Othman et al., 2018). Others focus on detection, counting of human presence or differentiation between human and non-human subjects.

Data extraction can be collected by computer, either by individuals or groups of people who rely on the limitations of a particular sensor and the user's application to make a higher-level decision.

There are 6 types of sensors mostly used in Crowdsensing, they are Visual sensor, acoustic sensor, capacitive, infrared, radio frequency and carbon dioxide gas.

The image sensor has simple processing and a lightweight algorithm that allows it to work in real time, which is very effective in estimating the number of people in crowds.

The ultrasonic acoustic sensor generates from the footstep acoustic and the Doppler effect as human detection and that is different from other inert objects in movement. It is sensitive to sound from sliding contacts.

The radio frequency sensor is used to transmit the identity of an object via radio waves. RFID tags are used which are placed on the devices and in this way the presence of the device can be detected and identified.

The infrared sensor uses differential temperature changes depending on whether a human body is found or not.

The capacitive sensor reacts to metals and non-metals that exceed a certain capacity when approaching the sensor surface.

The carbon dioxide sensor uses the concentration of CO_2 present in a given enclosure to estimate the occupancy of the enclosure and to assess the level of physical activity of the occupants. In general, this type of sensor is less accurate, has a low response time and tends to have more compensation components compared to other types.

As previously mentioned, thermal comfort does not only depend on physiological factors, there are many more factors, so we cannot know if a person is in a comfortable situation just by knowing the environmental factors. It may be that the person is not comfortable even though the environmental conditions are theoretically optimal, so it is very important to know their opinion about the comfort they experience at any given moment. For this reason, crowdsensing also uses methods to find out the user's opinion. Normally, from an app, with which the user gives information about how they are, at what time and where. In this way, it is possible to "create a fruitful dialogue and interaction between people, buildings and energy management in order to increase users' comfort levels and reduce energy consumption" (Cottafava et al., 2019). This introduces the concept of MCS (Mobile Crowdsensing), which is being implemented in most studies, due to the advantages and facilities presented by Smartphone technology.

"MCS is an emerging sensing and geo-crowd sourcing paradigm, based on the mobile device's sensor, that enables acquiring local geospatial information and knowledge and giving the possibility to share this information/knowledge with other users and wider community" (Boulos et al., 2011).

Another definition of MCS is "the data sharing and information extraction process, based on the collaboration of individuals with sensing and computing devices, to measure and enumerate mutual interest phenomena" (Ganti et al., 2011).

Crowdsensing aims at obtaining information from the crowd, as it is based on the principle that "the crowd is smarter than any individual member of a group, we improve and generalise existing adaptive comfort approaches" (Surowiecki, 2005). "Improving users' ability to interact with the building should be the key to their behaving more sustainably, both during the project and after its completion. People and places interact in daily life, influencing the amount of energy required and consumed" (Cottafava et al., 2019).

So, it is important to differentiate the two components in a system dedicated to thermal comfort, on the one hand there is the technical component (heating system, ventilation, sensors...) and on the other hand there is the social component (people's behaviour, perception of comfort, habits, relationships...). The MCS makes it possible not to exclude either of these two components and to study the correlation between them, thus obtaining more reliable data and models that are closer to reality.

MCS has several advantages over its predecessor, the Wireless Sensor Network: resource capacity, network deployment and coverage, hybrid sensing approach, heterogeneous network connectivity, network disruption tolerance, wireless networking technologies, sensing platforms.

The CSM can be categorised as follows:

Separate sensing: When there is no collaboration in the process and the data is obtained individually and only for personal use.

Cluster sensing: When a group of users collaborate and share the data they have collected.

Community sensing: When communities of users collaborate with each other.

The MCS is used for several applications, the most important and developed so far are: space weather, air pollution, noise pollution, infrastructure applications, social applications, behavioural applications.

A known and used structure of crowdsensing is composed of: an application for smartphones, a network of wireless sensors, an online dashboard and some prediction algorithms (Direct Virtual Sensors).

Crowdsensing is a relatively new technique, so although it is useful and allows numerous successful studies to be carried out, it is still under development and therefore has some challenges or drawbacks that are being worked on.

On the one hand we have the human sensing involvement, as it is necessary to encourage volunteers and keep them committed. Mechanisms have to be found for volunteers to agree to cooperate, and these can be monetary, social...

On the other hand, there are the data quality issues: It must be ensured that the data is of high quality and is not redundant. It should be noted that this quality is affected by latency, integrity, scarcity, mobility of participants, type of sensor data, variation due to communication channels and preferences of device owners.

And finally, another very important challenge or inconvenience is security and privacy. The collection of volunteer data implies that there are several threats to the security, privacy and integrity of volunteers.

Artificial intelligence:

Traditional methods of controlling environments, such as on/off, PI or PID controllers, show instabilities and sometimes exceed the thermostats, so more energy is used than necessary. A control system is needed that optimizes energy consumption while maintaining the comfort level of the occupants and that is not unstable and is faster. This is where artificial intelligence (AI) comes into play. "Cutting edge technologies based on large data, cloud computing, machine learning and artificial intelligence algorithms are combined with traditional architectural design theories. Energy consumption in buildings is an interdisciplinary research direction consisting of multiple influencing factors" (Zhao et al., 2020), and there is a complex correlation between each factor. Thanks to the development of computer science, statistics, applied mathematics and hardware, iterative progress is being made in IA.

AI-based methods "offer advanced analytical techniques capable of modelling the complex and non-linear nature of the interaction between occupants and their thermal environments (Ngarambe et al., 2020). Thus, artificial intelligence can be defined as "the ability of computers to develop intelligent, human-like qualities and thus perform tasks that could previously only be performed by humans" (Ngarambe et al., 2020).

Another advantage of AI is that it can better manage slight dynamic changes in occupant preferences, which could not be achieved with PMV or adaptive theory. It allows occupant thermal comfort to be achieved more efficiently through communication and coordination of a set of devices that control and analyse the thermal environment.

The combination of AI methods with Crowdsensing and Living Lab techniques, with which more and better data are obtained, makes AI the complement to the processes of the previous techniques, since AI needs the two previous processes to obtain data and create efficient models and control systems. That is why all the techniques are needed for the development of Project HOME.

Artificial intelligence uses data from previous experiments to design machines that reason in a similar way to humans and arrive at predictive models that humans alone cannot reach. Most AI methods are based on Machine Learning, a technique in which the machine is trained from historical data in order to create forecasts, future events and predictive models that go far beyond the human mind. The combination of physical sensors or devices and computer algorithms plays a similar role to that of IoT.

Another thing that artificial intelligence and the IoT allows is the ability to create personalised comfort models, i.e. based on each person, as the IoT makes it possible to generate highly granular and personal data. In this way, there is no need to make forecasts for a group of people. "It leverages the Internet of Things and Machine Learning to learn individuals' comfort requirements directly from the data collected in their everyday environment" (Schiavon et al., 2018).

The aim of the ML is to detect hidden patterns in the data sets.

Figure 20 presents an intelligent thermal comfort control system based on the IoT and algorithms such as the HFL.

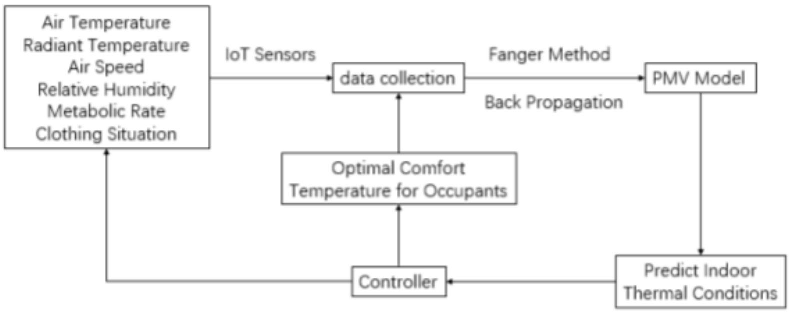

Figure 20. Intelligent thermal comfort control system.

As can be seen in Figure 20, first the environmental and behavioural parameters (clothing and metabolic rate) of the occupants are detected. With these data, the value of PMV is obtained and a neuronal network is used to establish a multivariate relationship. Then statistics and other methods are used to relate the optimum comfort temperature of the occupants to the given PMV value. After predicting the trend of environmental conditions for the next period and adjusting the parameters of each controller. The optimal occupant comfort temperature is then predicted for the next period and compared with the actual measurement. And finally, collect information from users about the new optimal comfort temperature. And so repeatedly, this is how an intelligent thermal comfort system for the building is achieved.

It is clear that the optimal comfort temperature of the users requires the willingness of the users to participate in this process, so a communication mechanism between user-computer is necessary, such as an app or an interface.

In order to be able to rigorously analyse a thermal comfort system, there are four fundamental descriptive aspects: performance measurement, the environment, the actuators and the sensors. These need a second component to make decisions that can be categorised into the following concepts:

Search algorithms: Artificial systems must know which routes give the best performance and which are the most efficient. The algorithm must have completeness, optimisation, time complexity and space complexity.

Logical Inference: It tries to achieve a rational thought to make decisions and achieve a goal. Binary logic is not used, but often decisions are based on partial information within a range.

Machine learning: Programming computers so that they can interpret complex data and be able to perform an evolution with experience.

There are other methods of AI apart from ML, especially used in the energy study of buildings, the most prominent of which are

Non-causal and inverse model: It follows engineering principles for the prediction of energy consumption. It uses historical data to predict energy consumption in the design phase of the building. Some common methods are the black box method and the grey box method.

Artificial Neural Net (ANN): This method simulates the structure and functioning of the human brain, a non-linear and parallel distribution. It is a simple and precise algorithm, so it is used in a wide range of fields.

Support Vector Machine (SVM): It uses statistical theory and mathematical foundations, distinguishing itself from ANN theory, which uses biology instead of mathematics.

Thanks to AI methods it is possible to create models of different factors that influence human comfort:

Temperature and relative humidity models: With a set of data, a model is developed to achieve a desired result or reward. In this case, another AI technique, fuzzy logic, is used. This technique is like an improvement of the Boolean system of 0's and 1's, since it considers intermediate values that represent a partial truth. These models do not take into account human behaviour, but even so, they are very useful to predict indoor temperatures and humidities according to outdoor conditions.

Wind chill models: These are predictive models for estimating PMV. For these models the LS technique is used, where historical data of the factors described by Fanger are used to obtain the PMV index. In this way it is possible to obtain the index with fewer sensors and a capacity to control the HVAC systems instantly. "In general, one of the main advantages of deep learning algorithms and the ML is their ability to provide accurate estimates of desired elements using limited explanatory variables (i.e. input variables)" (Lecun et al., 2015).

Dress and activity patterns: Here again, the LFA method is used because of the difficulty of obtaining accurate data on occupants' clothing and activity. On several occasions, a neural network model has been used to predict the occupants' daily clothing isolation levels, as well as their physical activity and metabolic rate.

Personal comfort models: The ML technique is also used. In this case, data on environmental conditions are used together with responses (categorised on a scale) on the wind chill of each occupant.

In recent years it has been shown that traditional data processing is inefficient due to its complexity and new data management techniques are solving traditional problems. It is data technology that is leading the way and therefore great care has to be taken in obtaining, processing and using data to achieve great advances.

It is clear that AI methods provide great advances in energy saving and the achievement of thermal comfort. Even so, it still has limitations, as at present it is very useful for individual thermal comfort, but not for a group of people, so it still has to be improved in order to be used for everyday buildings.

“More research is needed to turn the insights generated from personal comfort models into actionable control strategies in order to yield atangible impact on people's comfort satisfaction in buildings” (Schiavon et al., 2018).

Apart from the above, there are a few issues that should be investigated in the future to achieve the scope of AI in the whole area of thermal comfort, some of them are:

There is a lack of AI models that can predict conditions for sleeping occupants.

There is a lack of quality and quantity of data.

There is a lack of generalisation, transparency and deterministic conclusions.

Optimization of techniques and parameters.

Quantification of the benefits of AI-based comfort control systems.

Natural interaction:

Over the past decades, the interaction between humans and computers has been the subject of much research, due to the potential for progress in science and technology. This interaction is in line with the cognition of users' habits regarding thermal comfort, and a good interaction can efficiently process information and thus improve the occupants' experience while reducing the cognitive burden.

The aim of studying human-computer interaction is to enable machines to help human complete tasks, increasing comfort, efficiency and safety.

"In recent years, with the in-depth research of facial recognition, speech recognition, gesture recognition, posture recognition and other technologies in the field of artificial intelligence, traditional human-computer interaction can no longer be adapted to the efficient transmission of information between humans and computers in an intelligent multimodal environment, so scholars are beginning to look for new interaction methods to adapt to the development of new technologies in an unstructured environment" (Fu & Lv, 2020).

A very important aspect of human-computer interaction is the interfaces, in the case of the HOME Project, would be the building interfaces. "There are many differences in types of interface, the level of control, understanding and expectations of participation" (Julia K. Day et al., 2020). The design of interfaces is often underestimated, although a trend of change is being observed. This requires a series of investigations to observe how users interact with interfaces, how these provide feedback and user satisfaction along with the control they perceive.

The factors that motivate occupants to interact with the environment are both internal and external. The internal ones are biological, sociological and psychological. The external ones refer to the environmental conditions.

The interface plays a fundamental role in control and feedback.

Although control can be conceptualised with the level of automation, it also takes on a wide meaning with respect to the behaviour, beliefs and perceptions of the users. The increase in automated control is offering significant benefits, yet the increased presence of automated control raises concerns about the effects on the occupants' experience.

In terms of feedback, providing information to the occupants significantly influences their perception of the environment and environmental conditions. A clear example is when the user feels the air conditioning being turned on or off, this generates a change in their perception of the environment. Feedback can enable occupants to learn, understand, interpret, motivate and/or interact in and with buildings, and information can be disseminated visually, auditory and/or hepatically, depending on the contextual need and available technology (Julia K. Day et al., 2020).

The main interfaces in human-computer interaction are

Operable Windows: Windows with which the user controls their opening or closing, that is, the direct exchange of heat between the building and the outside.

Windows shade/blind interfaces: Blinds protect the interior environment from solar radiation, avoid glare, admit natural light, mitigate overheating...

Thermostats: Devices that ensure that the temperature of the building is maintained at a fixed value.

Lighting interfaces: The electrical lighting is controlled on/off by switches, i.e. safety, visual comfort and aesthetics.

In a process of information transmission between occupant-computer, three phases are distinguished: input, processing and output. As shown in Figure 21, in the input phase, the natural magnitudes (smell, voice, click...) are captured by sensors. In the processing phase, the signal emitted by the sensor is identified and computed. Finally, in the output phase there is an information feedback and action is taken on the devices that have to vary their behaviour or magnitudes.

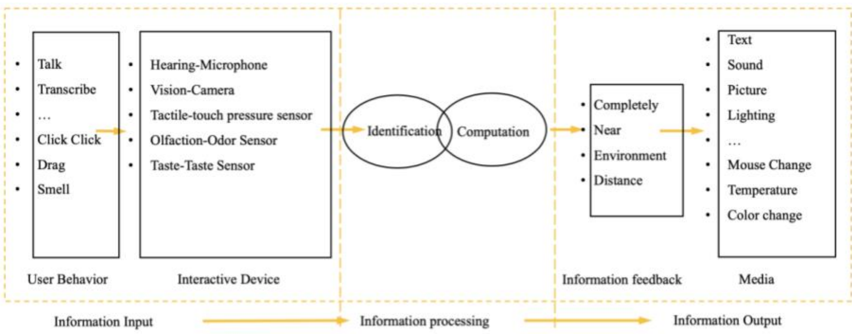

Figure 21. Process of information transmission.

The most important thing for a good natural interaction is the understanding and modelling of the human-machine-environment interaction.

In information transfer there are three concepts relating to occupants or users: cognitive load (the human memory capacity to learn or solve a task), the cognitive-emotional impulse (the interactive form acts on the user's perception and cognitive level of multiple levels of information), and the task scenario impulse (an imposition of knowledge of the situation allows occupants to evaluate it).

In order to obtain a human-computer interaction system centred on the occupant, it is necessary to take into account the following principles:

Capability level: The user's ability to operate, perceive and understand must be taken into account.

Feedback: The occupant must be able to know the current conditions and have instant feedback, thus eliminating waiting time.

User control interaction process: The occupant can modify environmental conditions from the computer.

Efficiency and safety: Reduce the cognitive resources of the users, information on the state of security and privacy. Error-proof and useful design.

There are different types of interaction between humans and computers, the main or most used ones are

Voice interaction: It is based on speech recognition and its magnitudes.

Posture interaction: Along with speech, this is a common form of communication.

Gesture interaction: Through gesture recognition, the user can give orders and information.

Tactile perception interaction: Information on the response to force and the force of confrontation with the interaction of the entity.

Monitoring and data input in the line of sight: Interaction between eyes and machine through bioelectric signals.

Brain-computer interaction: From nerve signals, and algorithms.

The development of computer technology and advances in human-computer interaction has facilitated the creation of virtual reality. The current technology of human-computer interaction has changed from being computer-centred to being human-centred. So, humans are no longer satisfied with the traditional movement of the mouse, and that is why virtual reality emerges. Virtual reality itself is not a technique that can help the study of comfort nowadays, but it allows progress in many fields (such as sensors, human-computer interaction...) that do. It requires concepts in the design of natural interaction, and progress in these concepts will facilitate techniques for researching thermal comfort.

Technological advances are making the interaction between humans and machines increasingly natural. The demand for this is growing in many fields, such as intelligent manufacturing, safety and medicine, and further progress is expected in this study, especially in design that integrates humans with computers.

The fact that progress is being made in sensor technology and precision facilitates the creation of personal thermal models, which are made using IoT and Machine Learning. This is another example of the synergies that exist between the different new technologies. So, it is considered that the data provided by the sensors "could be potentially incorporated into HVAC system control for occupants' satisfaction and energy saving. The low-cost wearable sensors and cloud computing allow real-time thermal comfort/preference prediction using physiological and environmental data" (S. Liu et al., 2019).

This interaction can advance information research in multi-modal environment perception, adaptation and cooperation between humans and computers. It is therefore a multidisciplinary task.

Another advantage offered by the natural interaction is that it allows a personalised interaction between each user and the system, and this in itself entails "significant opportunities for enriched comfort, energy performance and enhanced satisfaction with the indoor environment" (Altomonte et al., 2019).

Although natural interaction already has tangible benefits in buildings, much research is still lacking in this field. For example, "doors or other mechanical ventilation controls have not been extensively addressed" (Julia K. Day et al., 2020). Furthermore, there is a lack of studies on how users interact with interfaces, this field can give a lot of information about human behaviour and thermal comfort.

Other factors that need to be investigated are cultural diversity and variety, how these influence natural interaction and thermal comfort.

To conclude, the more advanced the technology, the more opportunities for design and participation in human-machine interaction will exist.

Conclusions

As it has been possible to observe throughout the research of articles related to thermal comfort, most of the experiments are based on the method of surveying people who find themselves in the same space and in different environmental conditions or other factors. These people answer the question of whether they are in a comfortable situation or whether they have a feeling of warmth or cold. Frequently, not only answers this question with a simple answer, but on a certain scale people evaluate in an adverse situation, how adverse it is, for example, if they have a sensation of heat, it is evaluated if this situation is hot but bearable or if the sensation is so hot that it is unbearable. In this way they can create models that represent reality in a more accurate way, since there is more information than if the answer was simple, whether there is comfort or not.

The method of surveying people provides a great deal of information, since the parameters of space with which to create a model vary, and they can also enter into the list of parameters that may hypothetically influence human comfort and observe how the sensation of people at ease varies as they enter and/or are introduced to various parameters. “Surveys rely on subjective measures and are best used if supported by physical data collection and in-person interviews to appraise building performance holistically” (Altomonte et al., 2019).

The fact that many studies are based on surveys of large samples of individuals shows that not only are there typically physical and physiological factors, but that psychological factors are also present, and are the most complicated to demonstrate and to find. However, it must be taken into account that each person's physiology is different, and this is a factor that also makes comfort vary between different people.

The factors can be classified in many ways, the most common way of doing this is by differentiating the different groups: physical factors, physiological factors and psychological factors. As you can see, the first group does not depend on the human being, that is, it is the same result for all the surveys. The physiological and psychological factors are what make each individual feel comfortable.

Most of the studies are very recent, so there are different reasons for this. On the one hand, although throughout history humanity has always tried to create the most comfortable environments possible, it was not until 1973 that the first human comfort model was published (Fanger), which, although it has few variables, is still used today as a method of quantifying comfort. Since the first model made by Fanger, we have been researching and presenting our models with different and more variables in order to know more about them, where there is a great amount of methods and models of thermal comfort quantification.

One of the problems that has dragged the study of comfort over the years is that the effect of the "group" of people has not been considered. The study has “concentrated on individual factors, without considering multi-layered interactions between parameters. Lastly, most research has not considered (or distinguished between) inter-individual variability (differences between building users) and intra-individual variability (different responses were given by the same user, e.g. at different times or circumstances)” (Altomonte et al., 2019).

On the other hand, in the last decades the technology of automation has seen a revolution with great advances, so it has favored the creation of autonomous and very precise air conditioning systems. This fact, however, can not work if it is not a precise quantification of the human thermal comfort, and is one of the reasons why there have been many studies in recent years to find the model that takes into account all the factors that really influence the thermal comfort.

A favorable factor for the study of the quantification of thermal comfort is that the last century has seen the creation of very precise measurement devices, which have improved the precision of the proposed models.

With the great advances in the field of computers, it is increasingly possible to carry out simulations that represent the thermal comfort of humans or an indoor environment with more precision. The fact that we can use finite elements and the segmentation of the body gives us more precise and localized information, as it studies the thermal conditions of each part of the body separately.

And even further away from the powerful use of finite elements, there is Project HOME. This is an interdisciplinary project that bases its study on how new technologies can help the interactions between humans, buildings and the environment, that is, to achieve greater thermal comfort together with sustainable energy consumption. The project focuses on five technologies that are being developed in recent years:

Living Lab: The idea of creating a laboratory in the everyday environment. For example, making an office one laboratory at a time.

Adaptive thermal comfort: The user shows an active attitude towards comfort.

Crowdsensing: Being able to collect a lot of data from a large number of users, usually from smartphones.

Artificial Intelligence: To make machines "think".

Natural interaction: Create an interaction between humans and computers that is as natural as possible.

All this and the fact that these technologies are in the development phase already play an important role in the field of thermal comfort. Due to their great potential, it is expected that much progress will be made in this field in the coming years thanks to the development of these technologies.

Due to the different studies we have been able to find out which are the factors that influence human comfort, but we cannot guarantee that the results of this project are the only ones that really influence it, because over the years and with different studies, there are more and more factors or parameters found. Therefore, it is possible that the factors that are found to have a lesser influence than the ones already determined, since if they are really very influential, they have been found much before.

Figure 22 shows the number of articles that have mentioned and affirmed the different parameters that influence thermal comfort. As can be seen, there are a number of parameters that are mentioned by most of the authors, and because of this, they can be considered to be the main parameters, although this has an explanation, they were the first parameters mentioned in the work of P.O. Fanger, which has served as inspiration for the rest of the studies. The rest of the parameters, although they are mentioned less in fewer studies, do not mean that they are not valid or not very influential, it means that they have been observed later and that they were not as evident as the previous ones. This classification has been made on the basis of the number of articles that cite the articles chosen in this literature review and by observing which factors are named in each article. The number of times the different articles have been cited is shown in table 18.

Article	Citations	Factors
Thermal comfort. Analysis and applications in environmental engineering. (Fanger, 1972)	9545	Outdoor air temperature, sex, age, metabolic rate, clothing, weight, indoor air temperature, relative humidity, radiant temperature, air velocity, thermal assimetry, sex
Developing an Adaptive Model of Thermal Comfort and Preference. (de Dear & Brager, 1998)	2163	Outdoor air temperature, sex, age, metabolic rate, clothing, weight, contribute, thermal history, time of stay, expectations, indoor air

		temperature, relative humidity, radiant temperature, air velocity, architectural parameters
Thermal comfort: Research and practice. (Van Hoof et al., 2010)	127	Outdoor air temperature, sex, age, metabolic rate, clothing, weight, contribute, thermal history, time of stay, expectations, indoor air temperature, relative humidity, radiant temperature, air velocity, architectural parameters
Thermal comfort and visual interaction: a subjective survey. (D'Ambrosio Alfano et al., 2019)	5	Visual contact, light
Thermal Comfort and the Heat Stress Indices. (Epstein & Moran, 2006)	764	Outdoor air temperature, metabolic rate, clothing, weight, indoor air temperature, relative humidity, radiant temperature, air velocity
Practical evaluation of the thermal comfort parameters. (Markov, 2002)	37	Outdoor air temperature, metabolic rate, clothing, weight, indoor air temperature, relative humidity, radiant temperature, assimetry
Thermal comfort models: A review and numerical investigation. (Cheng et al., 2012)	242	Outdoor air temperature, metabolic rate, indoor air temperature, relative humidity, radiant temperature, air velocity
A method to weight three categories of adaptive thermal comfort. (J. Liu et al., 2012)	80	Outdoor air temperature, sex, metabolic rate, contribute, thermal history, time of stay, expectations, indoor air temperature, relative humidity, radiant temperature, radiant temperature, air velocity, adaptability of the space
Impact of Social Network Type and structure on modeling normative energy use behavior	56	Interpersonal relationship

interventions. (Anderson et al., 2014)		
Heritage buildings and energy performance: Mapping with GIS tools. (Fabbri et al., 2012)	100	Architectural parameters
Characterizing the household energy consumption in heritage Nanjing Tulou buildings, China, A comparative field survey study. (Li et al., 2012)	37	Outdoor air temperature, expectations, indoor air temperature, adaptability of the space
Thermal comfort in open spaces. Comparison of models and their application in cities in arid areas. (Angélica Ruiz & Correa, 2009)	52	Outdoor air temperature, metabolic rate, clothing, weight, indoor air temperature, relative humidity, radiant temperature, air velocity
Zona variable de confort. (Variable de Confort Térmico & Propuesto, 2002)	36	Sex, age, metabolic rate, weight, contribute, thermal history
El confort térmico adaptativo. (Blender, 2015)	4	Outdoor air temperature, age, sex, metabolic rate, clothing, weight, contribute, thermal history, time of stay, expectations, visual contact, indoor air temperature, relative humidity, radiant temperature, architectural parameters, adaptability of the space
Evaluation of thermal comfort in enclosures of 10 public buildings in Chile in winter. (Molina & Veas, 2012)	17	Sex, age, metabolic rate, weight, contribute, thermal history
Physical foundations and methods of evaluation of climatic comfort in human bioclimatology studies. (García, 2003)	9	Sex, age, metabolic rate, clothing, weight, contribute, thermal history, indoor air temperature, indoor air temperature

Table 18. Articles, citations and factors.

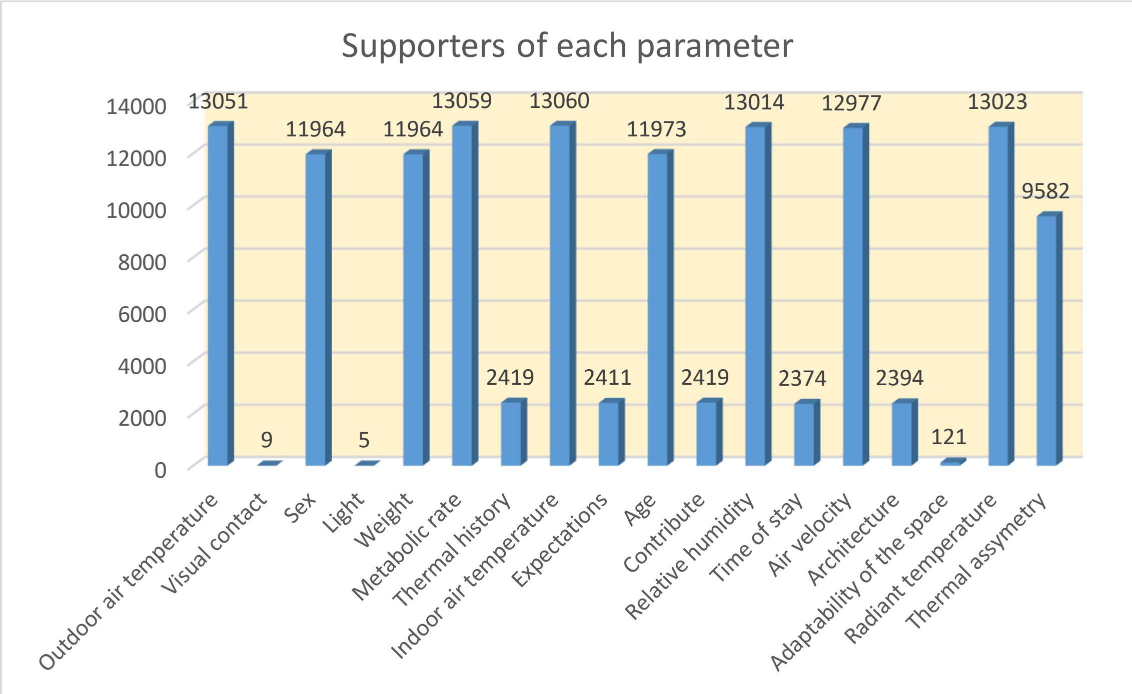

Figure 22. Supporters of each parameter mentioned on the thesis.

Figure 22 shows which are the most cited factors in the study of human thermal comfort. It should be noted that the fact that it is more often cited does not necessarily mean that it is more influential than others. As can be seen, the most frequently mentioned factors are those that have historically been found to influence thermal comfort, which are those named by P.O. Fanger in his PMV model. The factors that have been named later by the adaptive model are listed on a second level. The third level are factors which have been investigated in recent years.

There are some parameters that are dependent on others, and therefore when one is mentioned, the other is being mentioned. This is the case of age, sex and weight, which are totally related to the metabolic rate, so the previous graph could be corrected, although only the metabolic rate should be considered as the main parameter because it is the one that directly relates to the others.

What we can say is that there are many methods and models, not only are there valid ones, nor those who are better or better than others, but there are those who better represent reality in given circumstances than others, and vice versa. The circumstances depend on the location or configuration of the space being studied.

In addition to the validity of many models, the Fanger model, based on PMV and PPD, is currently the most used mathematical model and has had the greatest influence on the study of thermal comfort, especially in indoor environments. This is why there have been many studies dedicated to validate this model and others, and this is the one that has been validated in more studies.

From the 90's onwards, studies have been carried out where users are considered to be active in respecting the thermal environment, i.e. where they have certain personal control, and therefore increase their acceptance. At the same time, the variability of comfort in real time, both for external and internal conditions, begins to be considered.

This is how the basis for the creation of adaptive and variable models will be established, in which the conditions of the local climate and time are present and are more precise for particular cases.

A favorable factor for the study of the quantification of thermal comfort is that the last century has seen the creation of very precise measurement devices, which have improved the precision of the proposed models.

When dealing with a technological and scientific subject, it is possible to affirm that there will not exist anymore a model that describes the thermal comfort with total accuracy, since it is demonstrated that the perfection does not exist. However, the level of precision at which the different models arrive is considered valid with a very small margin of error. These errors are serious, for example, when one says that all users are comfortable and a very small percentage of them feel that they are not getting enough sleep, but this percentage is small and the error does not have severe consequences.

During the last decades it has been proved that there are many parameters that influence the thermal comfort, and so it is considered that it has not reached a modeling that describes in a very accurate way the reality of each person, There have been models (published by ASHRAE) that can guarantee comfort conditions for a high percentage of the occupants, but it is considered that it is still possible to create more complete and precise models, and this can be done using the new computerised calculation methods. And it has been observed that new technologies are going to play a fundamental role in the field of thermal comfort in the coming years.

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