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Comfort perception and its influence on Energy Consumption in Social Housing in Hot Dry Climates

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RESUMEN

Esta tesis explora la relación entre la percepción del confort térmico y el consumo de energía a través de los elementos o circunstancias que motivan a un individuo a realizar una acción para la búsqueda de la adaptación hacia un estado de confort y que finalmente, dicha acción pudiera consumir energía. El análisis se realizó en a un grupo de habitantes de la vivienda de interés social, en un clima cálido seco en México. La primera parte de la investigación se centra en la búsqueda y clasificación de variables que influyen en la construcción de la percepción del confort, desde generalidades como variables climáticas, variables de los edificios, hasta características particulares del individuo en relación al cuerpo humano, así como variables relacionadas con la dimensión psicológica. De la diversidad de variables encontradas, se seleccionaron solo aquellas con información disponible para su evaluación y luego entonces correlacionar sus valores con las probabilidades de realizar una acción específica para la adaptación según las particularidades del contexto analizado. Además para este fin, se programó una hoja de cálculo para automatizar el proceso de definición de la probabilidad de acción, la cual podría utilizarse para el futuro análisis de otros grupos específicos. Finalmente, en base a los valores de probabilidad de acción se calcularon los consumos de energía encontrando que las variables con mayor influencia son de carácter psicológico como la preferencia y actitud frente a la situación.

Palabras clave: consumo de energía, percepción del confort térmico, vivienda de interés social, clima cálido seco.

ABSTRACT

This thesis explores the relationship between the perception of thermal comfort and the energy consumption. This association is given by settings that motivate individuals to perform an action to change current environmental conditions to reach thermal comfort. The analyzed groups were people living in social-dwellings in a hot-dry climate in Mexico. The first part of the research was the classification of variables, which influence the perception of thermal comfort. These variables go from very general aspects like climate and building features to more particular qualities as context characteristics and body's individualities including psychological variables. From the resulting group, only selected those variables with available information of the behavioral responses, which are affected by the particular contextual characteristics, were selected. The analysis provided values to calculate action tendencies, finally resulting in a factor (per available device) to estimate energy consumption. Besides, a spreadsheet to perform action tendency calculations automatically was generated. Finally, based on the values of probability of action, the energy consumption was calculated. These results made clear, that the variables with the greatest influence are of psychological nature, such as preference and attitude towards the situation.

Key words: energy consumption, thermal comfort perception, dwellings, and hot-dry climate.

ZUSAMMENFASSUNG

Die vorliegende Arbeit untersucht die Beziehung zwischen der Wahrnehmung thermischen Komforts und dem Energieverbrauch. Es werden Elemente oder Umstände analysiert, die ein Individuum motivieren, eine Aktion auszuführen, die die aktuellen Umgebungsbedingungen ändert, um thermischen Komfort zu erreichen. Die analysierte Gruppe waren Menschen, die in sozialen Wohnungen in einem heiß-trockenen Klima in Mexiko leben. Der erste Teil der Forschung betrifft die Klassifizierung von Variablen, die die Wahrnehmung von thermischem Komfort beeinflusst. Diese Variablen reichen von ganz allgemeinen Aspekten wie Klima- und Gebäudeeigenschaften bis zu spezifischen Variablen in Bezug auf den menschlichen Körper, sowie im Zusammenhang mit der psychologischen Dimension. Aus der resultierenden Gruppe wurden nur diejenigen Variablen mit verfügbaren Informationen der Verhaltensreaktionen ausgewählt, die von den jeweiligen Kontextmerkmalen betroffen sind. Dies, lieferte Werte zur Berechnung von Aktionstendenzen, was schließlich zu einem Faktor (pro verfügbarem Gerät) zur Schätzung des Energieverbrauchs führte. Außerdem wurde eine automatisierte Kalkulationstabelle zur Durchführung von Aktionstendenzberechnungen generiert. Schließlich wurde auf der Grundlage der Werte der Aktionswahrscheinlichkeit der Energieverbrauch berechnet. Die Ergebnisse machen deutlich, dass die Variablen mit dem größten Einfluss auf den Energieverbrauch von psychologischer Natur sind, wie Präferenz und persönliche Einstellung zu der gegebenen (thermischen) Situation.

Schlüsselwörter: Energieverbrauch, thermische Komfortwahrnehmung, Wohnungen und heiß-trockenes Klima.

I. Introduction

Nowadays people live longer but not necessarily better, in this regard, the concept of well-being has been gaining importance [1]. The comfort is within the structure of the well-being, which is shaped by the dynamic of social and cultural constructs, leading to the understanding of different meanings of it [2], [3]. Therefore, comfort in buildings can be understood as the subjective understanding of occupants to the current indoor environmental conditions. Moreover, the built environment is the main human context in which most of the modern world´s activities are developed and these activities may involve the use of energy to accomplish human needs and expectations, as for instance, comfort provision. Thereby, this thesis explores the relevance of the subjective relationship between inhabitants and thermal comfort as a key to energy efficiency in buildings.

The implementation of standards is a common strategy to control the intensive and inefficient use of energy in buildings. This approach makes necessary to understand both, the environmental conditions and the control of the systems under which conditions the building will perform. All these predictions can be simulated and are used to take designer's decisions. While this process is acceptable for controlled environments as those with air conditioning system, standards present problems to predict occupant responses [4] basically because building design framework has been reduced to rigidity measurable parameters, such as a pre-established comfort range.

If many type of climates can cause many indoor comfort conditions, variations in cultures defined by diverse lifestyles and beliefs, should also affect comfort [5]. It is evident that there exists a gap of information between thermal comfort perception and how standards and assessment systems are predicting far from reality.

Therefore, the challenge is to ensure thermal comfort based on adaptation rather than standardization and use of mechanical systems. Adaptation can only be successful if we develop a better understanding of human behavior in the different settings of everyday life [3]. Only then, will be possible to develop adequate assessment tools to provide better solutions to designers and ensure sustainable built environments to inhabitants.

I.1. Justification

Natural resources are the main source for energy production and, at the same time, energy is a necessary condition for economic growth, which is essential to the development and use of almost all goods and services of the modern world [6]. Energy production and how it is used generate an environmental impact associated with greenhouse emissions that contribute to climate change and pollution. Hence, strategies to change current patterns of production and energy consumption are required.

The built environment is the main human context and an indoor space is an area in which most of us spend most of our lives performing many of the modern world's activities [7]. These activities may involve the use of energy to accomplish human needs and expectations. In this context, the issue of thermal comfort becomes relevant, since it is one of the main requirements in building to be habitable. A significant increase in energy use is related to the use of heating, ventilation and air conditioning systems (HVAC), accounting for about half of the total of energy consumption in buildings in developed countries [8].

In developing countries this understanding is especially important, for instance Mexico, where hot dry and hot humid climates represent around 70% of the territory [9] and 35% of housing is built for low-income families; it is estimated that the number of housing units will reach nearly 50 million by 2030 [10]. Moreover, Mexican standards are primarily designed for buildings functioning with air conditioning systems. This situation causes social and economic problems for inhabitants, as well as deficiencies due to the improper functioning of the dwellings associated with thermal comfort [11].

In Mexico, the *National Energy Balance* of 2015 [12] exposes that transport sector consumes the major part of the energy produced with 46.4%, followed by industrial sector with 31.4% and Residential/Commercial/Public (RCP) sector with 18.7%. In the RCP sector, housing consumption represents 81.84% of the total, in which 33.6% is electricity; and 44% is HVAC systems in the residential sector.

Based only on the principle of thermal neutrality and regardless of the context or the nature of the design problem, standards disregard the more dynamic, experiential qualities of the indoor environment [4]. As a consequence, there is an excessive use of mechanical devices and insulation materials to achieve standardized thermal comfort expectations.

I.1.1. Energy conservation, climate change, and comfort

Taleghani [13] argues that the widespread acceptance of air conditioning has been one of the most unfavorable aspects of modern development. Today, vast quantities of energy are consumed in buildings related mainly to heating and cooling indoor spaces to achieve standardized thermal comfort expectations. In general terms, human activity and their search for comfort can cause environmental impact rising temperatures, subsequently the higher temperatures, the higher will be the use of air-conditioning. Under these conditions, Nicol & Humphreys [14] consider that the provision of comfort has a major role to play in energy consumption and carbon dioxide emissions.

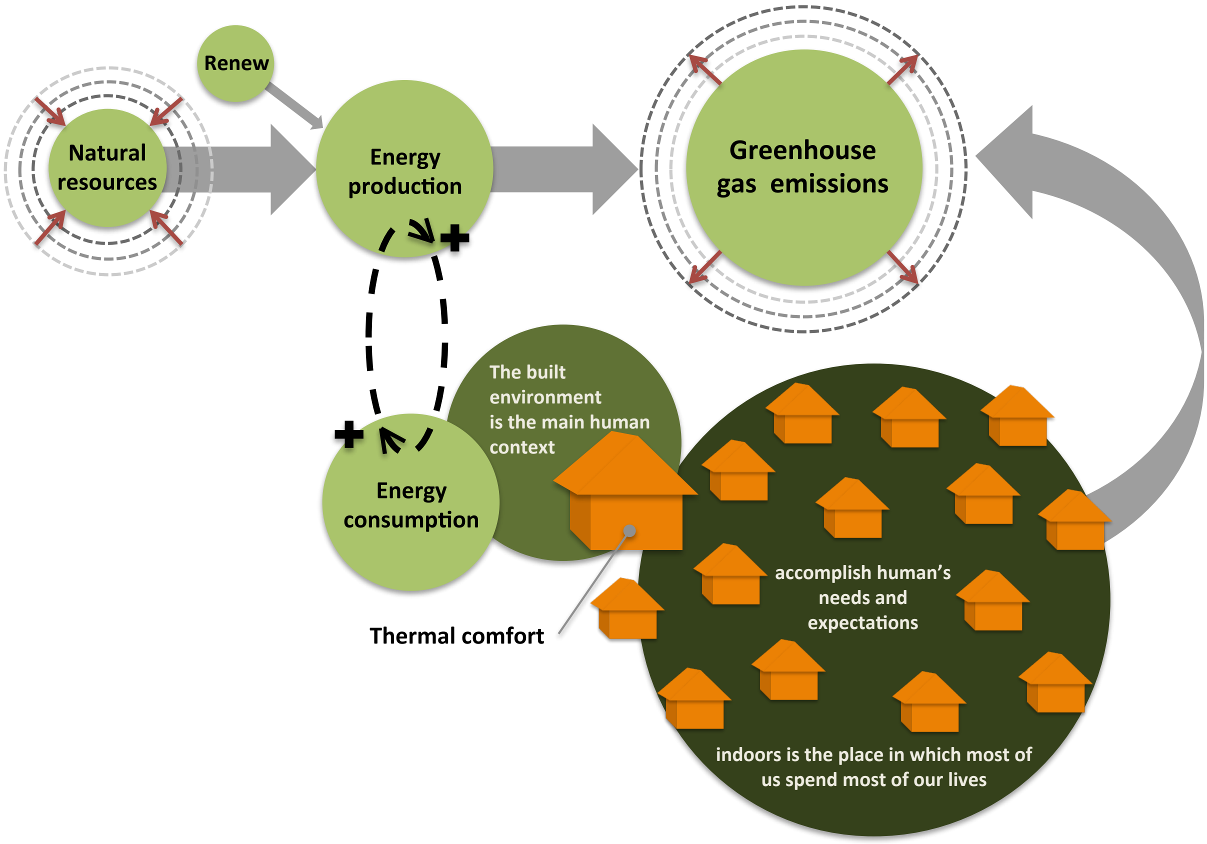


Figure 1 - Environmental impact associated to Thermal Comfort
Diagram by author

Natural resources are the main source for energy production. Moreover, energy is a necessary condition for economic growth, essential in development and use of almost all goods and services of the modern world [15]. Yet, energy production and how it is used generate an environmental impact associated to greenhouse emissions that contribute to climate change and pollution. In addition, indoors is the place in which most of us spend most of our lives and develop our activities [7]. In this context, the issue of thermal comfort becomes relevant, since it is one of the main conditions required in buildings in order to be habitable. See **Figure 1**.

Within the Conference of the Parties (COP) framework, Mexican Government has a compromise to cooperate in the struggle against fast global warming. According to the Ministry and Natural Resources (in Spanish: *Secretaría del Medio Ambiente y Recursos Naturales*, SEMARNAT), the forecast is a 50% of reduction until 2050 (compare to 2000). In order to reach this objective, Mexico has adopted several lines of action and one of them is the sustainable housing regarding total consumptions of energy, water, and gas. To this, the main strategy is the implementation of NAMAs (Nationally Appropriate Mitigation Actions) with a focus on low-cost dwellings [16]. Mexican-German NAMA Program is a part of the International Climate Initiative (IKI) leading by the German Development Cooperation (in German: *Gesellschaft für Internationale Zusammenarbeit*, GIZ).

Moreover, not only structural changes should be made, but also it is essential that energy users adopt a wider willing to tolerate temperatures variations and introduce more relaxed norms concerning comfort [8]. Also, the studies of thermal comfort should expand their focus over individual control to explore the possibilities of social conventions and designing for cultural variability [3].

I.2. Objectives

General Objective

To analyze thermal comfort perception as a social construction that influences energy consumption through behavior in social housing in hot dry climates.

Specific Objectives

- To determine a set of variables that influence thermal comfort perception.
- To examine the relation between comfort perception and behavioral responses.
- To calculate user's influence on energy consumption according to their comfort perception.

I.3. Methodology

The first objective of this thesis is to determine a set of variables that influence thermal comfort perception, to this, it will be carried out a literature review to analyze generalities regarding the concept of comfort including theories based on the two dominant models: the thermal balance and the adaptive approach. This discussion based on relevant literature will make possible the identification of characteristics that influence thermal comfort perception describing the interaction among variables. This approach and its results are fully explained in section IV.

The second objective of this thesis will be addressed through a correlational analysis between variables and the prediction of user's responses in regards to thermal comfort adaptation. This will be accomplished in two phases. In the first phase, we define a state prior to make a decision in so far as changing or not current environmental conditions. This state will be determined by means of the thermal comfort perception according to real data. The method used is based on the analysis developed by Matias [17] and adapted to the analyzed context. Besides, neutral temperatures and comfort ranges will be defined according to the method used by Gomez-Azpeitia [18] in his analysis *Extreme Adaptation to Extreme Environments in Hot Dry, Hot Sub-humid and Hot Humid Climates in Mexico*. All details of procedures and results are in section V, and information regarding the universe of study and data collection are specified in section III.

The second phase involves behavior. We want to know how this concept is understood and its relevance to energy consumption, including how to define a tendency to perform an action. The method for prediction is an adaptation based on the methodology proposed by von Grabe [19]. The procedures, details, and results of this second phase are shown in chapter VI.

Finally, the third objective of this thesis is to calculate user's influence on energy consumption according to the action tendency defined by the impact of specific variables, or a combination of variables. Therefore, different rates of energy will be consumed according to the specific characteristics of the users. In addition, to perform the analysis, it has been built a spreadsheet table to calculate neutral temperatures, comfort ranges, and action tendency according to data from field surveys. Through this simple tool, it would be easier to compare and analyze the impact of each variable on energy consumption. Process and results are shown in section VII, VIII and IX.

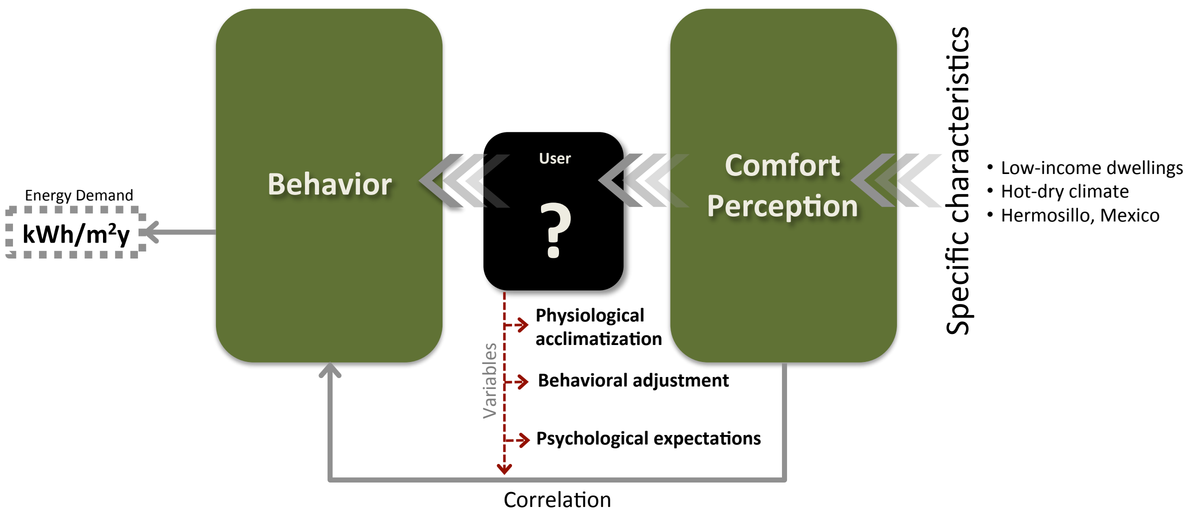


Figure 2 - Methodology diagram

Proposed methodology. Diagram by author

II. Comfort

II.1. General concept of comfort

The first resource to define comfort is a dictionary in which indicates that the word *comfort* is a noun that comes from the Latin *comfortis*, which means "strong, to strengthen". This etymological origin might be centered on the state, process or outcome that helps a person to feel stronger, supported or empowered [1]. The modern definition in the Oxford dictionary describes comfort as *the pleasant and satisfying feeling of being physically or mentally free from pain and suffering or something that provides this feeling* [20]. In this sense, the dictionary's definition is already placing the concept into a mixed objective-subjective meaning, where pleasure and satisfaction or pain and suffering are a consequence or interpretation of a feeling. But what is satisfying or pleasant for somebody?

It is well known that feelings are emotional stages, and from an objective point of view, it is believed that emotions are generated from a physical source called limbic system (located in the brain). These structures register the levels of chemicals in response to certain conditions the person is experiencing [21]. For example, the body produces a higher level of serotonin than normal, when the individual is experimenting love or the effect of some drug. The resultant feeling is the one we associate with a meaning defined by personal interpretation, which is a subjective understanding as a result of the socially, culturally and collectively negotiated experiences [3].

Evidence has shown that, besides being subjective, these meanings can change over time. An example of this can be found in John E. Crowley´s book *The Invention of Comfort* [22], where he explains the origin of our modern understanding of comfort. In the first chapter, he mentions that the medieval definition of domestic amenities would provide harmonious environment in hopes of a royal visit, giving total importance to social status over personal physical comfort, which lacked priority as a value or a problem. On the other hand, a medieval articulation of discomfort emphasized dirtiness because it implied disrespect, instead of being a matter of health and hygiene, which according to modern basic needs would be more important. Chappells and Shove [23] give another example, and describe the malleability of what people take to be appropriate and necessary comparing two opposite examples. The first one says that in the United States, at the beginning of the 20th century, campaigners argued that outdoor fresh air should provide healthy bodies and minds to school children. This is contradictory to the second example; where the idea from those who currently design and specify air-conditioned offices argue that productivity can be achieved by limiting exposure to the outdoor elements.

Thus, the construction of the concept of comfort came from the historical evolution of society and technology. Its appraisals and expectations can change according to what people consider necessary due to cultural history and practices, shared conventions, social conditions and deeply rooted understanding of what is normal and proper in specific places [3], [4], [8], [17], [23]–[25]. Moreover, institutions, policies or any other system force such as the market can also outline the understanding of the concept. All these features construct a multidimensional framework in the aim for well-being, as it needs to fulfill conditions of both **comfort meaning** and **comfort values**.

The concept of comfort can be understood as the state of being strengthened by having covered physical, psycho-spiritual, socio-cultural, and environmental needs [1]. These needs will not only change through time but also will depend on place, season and culture, turning comfort into a highly negotiable concept [23], [26].

II.2. Architecture and comfort

Architecture aims to create the main human environment through the design of spaces and, from the most basic concept, it provides shelter to their inhabitants. What is more, the human environment is dynamic, evolutionary and must ensure human well-being [3]. To that order, essential characteristics are required as **functionality** in its wider sense and the capability to **provide comfort**, finally leading to the well-being.

The functionality in the practical sense is referred to an inherent feature of buildings, defined according to the indoor activities that will be performed. Functionality is reflected in the morphology of the building and it could be modified but only over time. For instance, the functional structure of a house, an office or a hospital is different from each other basically due to user's needs and, therefore, user's activities become different. If a building needs changes over time due to needs and activities, the morphology can also change in order to readapt or completely switch to another type of building. In such manner, for example, an old house can be readapted to an office building.

It is well known that the dimension of comfort in the built environment can be expressed through issues of thermal, visual, acoustic, and air quality. Comfort in any of these dimensions is defined by the needs and expectations of the inhabitants, and to some extent can be inferred from the functional structure of the building. For example, offices lighting requirement is different from a living room lighting in a house, and also differs from the lighting conditions in a surgery room of a hospital, mainly because of the activities performed in the area. If the needs are different, the expectations will also be dissimilar.

The conception of the architecture as a solution for the well-being through the planning of the human environment goes further than the interaction of the two mentioned characteristics: functionality and comfort. However, the objective of this thesis centers specifically on the understanding of comfort as a motivation to human interaction with the environment and its implications. The challenge is how to understand human-environment relation and how to generate a valid approach to propose accurate solutions, ensuring not only human well-being but also the conservation of natural resources. From the most conventional demands of clients such as cost minimization, efficiency, functionality, aesthetics, status, and prestige, the challenge for today's architects is evidently great [3].

II.3. Thermal comfort models

The research field related to thermal comfort is very varied, from climatology and building design, through simulation and the physics of clothing, to physiology and psychophysics [5]. Thus, thermal comfort has been widely described based on different perspectives. In terms of indoor thermal comfort, the current discussion centers mainly on two opposite approaches: quantitative approach, in which thermal comfort is looked upon as a state of thermal neutrality [27] designed mainly for HVAC spaces; and qualitative approach, which parts from a conception of thermal comfort as a complex cultural construction [28].

II.3.1. Quantitative Thermal comfort

The first approach can be described as one that deals with quantitative models based on the heat balance of the human body. In 1969, Baruch Givoni defined the thermal sensation concept as the perception of heat or cold from the neuralgic activity nerve originated in the skin that acts as a thermal receptor. In 1970, Fanger[27] developed a quantitative model which is based on the steady state approach deducted from laboratory experiments and climate chambers. Fanger asserts that comfort values are defined by physiological body reactions caused by the physical phenomenon of the heat exchange between body and environment [4]. In other words, when the human body does not gain or lose heat, the balance shows a zero value, in this case, people are experiencing thermal sense of comfort. When the heat balance shows a negative value, the body is experiencing cold and, a positive value corresponds to a sense of heat. Fanger proposed a model to predict the mean thermal sensation and the percentage of dissatisfaction from a group of people. These values are represented by the index PMV-PPD (*Predicted Mean Vote and Predicted Percentage Dissatisfied*). PMV represents a standard scale for a group of building occupants and the values are given by four environmental variables: air temperature (t_a), indoor mean radiant temperature (t_{mrt}), indoor air velocity (v), indoor air humidity (p_a); and, two personal variables: activity level or metabolism (M),,and clothing insulation (I_{cl}) (see Equation 1). The percentage of people dissatisfied is defied by an empirical relationship between PMV and the PPD (see Equation 2).

Equation 1

$$PMV = f(t_a, t_{mrt}, v, p_a, M, I_{cl})$$

Equation 2

$$PPD = 100 - 95 \times \exp\left(-0.03353 \times PMV^4 - 0.219 \times PMV^2\right)$$

PMV-PPD method has been the basis of the ISO 7730 (1984) and ASHRAE 55-1992 and some other international standards [8], [29].

According to quantitative models, comfort ranges are almost universal since differences regarding national origin, sex, age and daytime are not significant [4]. Different studies have compared thermal sensation responses of individuals from different countries applying quantitative models. These studies concluded that quantitative models do not adequately describe the comfort conditions of "real" people, especially in high temperature and high humidity conditions underestimating their adaptive capacity [30] and over predicting results by unnecessary cooling in hot climates and unnecessary heating in cooler regions [8]. Therefore, after almost half a century of popularity, these quantitative models have lost acceptance and from the last 20 years there have been some research regarding the implications of thermal comfort standards. However, it is necessary to mention that quantitative models are very applicable to controlled environments such as those with cooling and/or heating systems. Contrasting, in naturally ventilated buildings (NVB) comfort temperature increases significantly in warmer climates, and decreases in colder climates [31].

II.3.2. Adaptive Thermal comfort

The second approach is the qualitative or adaptation model, which is based on the adaptive principle and it conceives thermal comfort as a state of mind. *"If a change occurs such as to produce discomfort, then people can react in ways which tend to restore their comfort"* [32]. Thermal perception is affected by circumstances beyond heat balance in the human body involving subjective variables. According to Brager and de Dear, 1998 [4] three inter related aspects are important to consider in adaptive models: psychological, behavioral and physiological. Therefore, thermal adaptation models are a complex interacting system, which reflects the beliefs, values, expectations, and aspirations of those who construct them [33]. The adaptive hypothesis states that thermal comfort perception is reached by matching the actual conditions in time and space, as well as the expectations of what the indoor climate should be as a result of current and past thermal experiences as well as cultural and technical practices [4].

Unlike laboratory experiments and climate chambers of the classic steady-state model, the adaptive model is based on field studies comparing variables with linear regressions, as for instance indoor operative temperatures and prevailing outdoor temperatures. This model is commonly used in natural ventilated building (NVB) and mix-mode buildings and it has been included in some standards as ANSI/ASHRAE 55-2004 and EN 152515.

A review by Yang [8] exposes a summary with different field surveys comparing the findings with thermal comfort standards. From these examples, we can highlight those related to residential buildings. As for instance, using an adaptive model in Nigeria, it was found that physiological and adaptive factors are equally important in the perception and interpretation of thermal comfort defining a comfort range 2 or 3 °C less than that suggested by the ASHRAE standard, probably due to higher relative humidity [34]. An other example takes place in India, where a temperature range based on the adaptive model was defined from 26°C to 32.5°C, far higher than the Indian Standard 23–26 °C [35].

According to Chappells & Shove, 2005 [23], both described comfort theories, the steady-state and the adaptation model have quite different consequences for energy and environmental policy positions.

II.4. Policies, standards, and comfort

Some evaluation parameters can be deducted from the conventional structure of the relationship between functionality and comfort, including other quantifiable building's characteristics. All these serve as a guide for designers as well as a reference for regulatory authorities in order to assess whether 'acceptable' conditions have been provided within spaces [36]. The assurance of comfort and well-being has been an institutional task that usually goes through policies and standards which are translated to designing, management or operation strategies to make them applicable to specific building types and usage. Nevertheless, comfortable conditions are not solely an intrinsic characteristic of the building, and they are not possible to predict only by generalities but also foreseen by the understanding of the inhabitant. Here it is when the variability of each resident regarding needs, preferences, physical conditions, past experiences, and many other variables turns comfort understanding into a complex structure which is highly dependent on specific contextual conditions, including time. Moreover, this variability grows within collectives, where the comfort can be modified due to the relationship between inhabitants, where individuals may reinforce or compromise the comfort of others [37]. These associations also include other elements from different values such as education, religion, morality, privacy, austerity, and so on. Additionally, comfort issues are learned from the experiences of everyday life, and are constantly redefined by the relationship between the human body and the immediate physical environment, all involved in the evolution of architecture and technology [3][8].

Taking into consideration all that influence the perception, the multidimensional framework of comfort has been forced to fit into very general standards that do not address specific and dynamic conditions. This situation is usually reflected in the building planning approach where designers and later building management rely on precise specifications to maintain "acceptable" indoor conditions. In other words, solutions are given only by the determination of some environmental settings as a fixed range of temperature or a particular lighting level. There is no differentiation among user's particularities, their social conditions, preferences or cultural practices: the variability due to different preferences and expectations among inhabitants is completely absent. In addition, the most common way to meet and maintain these requirements is with the use of mechanical control increasing utilization and loyalty to systems as air-conditioning [29], [37] and therefore energy consumption. And the effect becomes exponential when we realize that most activities in the modern world are developed in the built environment and the fact that indoors is the place in which most of us spend most of our lives [7].

Traditionally, architecture has been adapted to the local environmental conditions and lifestyles. In the desert, for example, traditional houses were built with wide clay walls to slow down the heat transfer from outside to inside. Also, high ceilings allowing the physic phenomenon of the heat transfer by convection, where the cold air goes down and hot air goes up due to the densities differential. Additionally, exterior wall colors commonly were clear as sand, ensuring enough reflection to avoid overheating. Also, using small windows as a strategy to avoid overheating by the sun, the crossed ventilation, and other techniques were implemented.

At present, architecture in cities has been changing due to conventional client demands. Far from a discussion of aesthetics and technology, the globalized architecture in cities has resulted as an excellent example of uniformed and standardized solutions for a problem that is multifaceted and multidimensional. It would not be hard to find an office building with glass and metal walls and seal windows in a hot climate. In this situation, and to avoid the unavoidable overheating due to the transparent and thin walls, air conditioning would be turned-on to maintain a fixed temperature to accomplish the "acceptable" conditions. However, the higher the temperature differential between indoors and outdoors is, the higher the amount of energy would be consumed.

ASHRAE 55-2010 is an internationally well-known thermal comfort standard proposed by The American Society of Heating, Refrigerating and Air-conditioning Engineers. One of the standard's objectives is to predict comfortable temperatures, and for that, is used the PMV equation. The standard suggests two acceptable ranges, one with 80% and another with 90% of acceptance among inhabitants. This variation is defined using the neutral temperature obtained by the PMV equation plus a deviation of ±3.5◦C or ±2.5◦C respectively. According to the description by Yang [8] regarding the operative temperatures defined by ASHRAE Standard 55, comfort zone is positioned from 20 °C to just over 27 °C approximately. Contradictory to this values, a survey of 34,000 people inhabiting US office buildings reported 42% of dissatisfaction, 19% were neutral, and only 6% considered themselves very satisfied [38].

Another example is the European Standard EN15251 for non industrial buildings described by Taleghani [13] and Attia [39]. They mention that this standard establishes comfort parameters depending on the type of system used to provide comfort; proposing different adaptive algorithms for different European countries; and different categories according to user's expectations, thus providing different ranges of acceptability. Nevertheless, this standard was designed exclusively for Europe and would not be useful for Latin America or Mexico. Also, the resulting values form these exposed standards differ from each other. Attia [39] compared the influence of different thermal comfort models for zero energy buildings in hot climates by simulation. The results showed that the percentage of energy consumption is different according to ISO 7730 compared to EN 15251, ASHRAE 55 varying up to 16.0%, 21.0%, and 24.7%, respectively.

Regarding Mexico, the Government has established a range of efficiency standards for buildings and their components, formulated a building energy code, which works as a model for local authorities, but the implementation of efficiency policies in the buildings sector is complicated by the devolved policy responsibility to local jurisdictions. Limited resources and capabilities in local municipalities mean that only a limited number of cities have adopted such building energy codes

There are several Official Standards for Energy (NOM-ENER), but none of them are exclusive to comfort. The most applicable standards are NOM-008-ENER-2001 [40] for non-residential buildings and, the NOM-020-ENER-2011 [41] for residential buildings. The objective of these two norms is to estimate the energy demand and then to limit energy consumption regarding HVAC. Estimations are defined regarding the heat gains through building envelope according to the heat transfer values of materials; therefore, all insulating materials have a great relevance over final results. In other words, the less the heat transfer between outdoors and indoors is, the less energy would be invested to heat or cool indoor spaces. According to NOM-08 and 20 calculations, with the temperature average of a particular location, characteristics of building envelope and the indoors operative temperature, it is possible to calculate how much energy would be invested in a house to reach the standard temperature. With the results, it is defined if a house is efficient or not and how efficiency.

Mexico has implemented some programs to decrease energy demand from residential buildings and for the worker part of the population. The National Commission of Housing is the responsible for the housing sector (in Spanish: *Comisión Nacional de Vivienda*, CONAVI) and the Institute of the National Fund for Workers' Housing (in Spanish: *Instituto del Fondo Nacional de la Vivienda para los Trabajadores*, INFONAVIT) started in 2007 as a joint effort to foster the construction of houses with energy-efficient and water-saving technologies. They have also raised general public awareness of the importance of reducing energy and water consumption. In 2010 CONAVI updated the voluntary regulation for residential construction (in Spanish: *Código de Edificación de Vivienda*, CEV), including energy conservation strategies, and established financial incentives for those developers who follow it [42]. This means that housing energy efficiency in Mexico is optional.

The fixed comfort range for housing is between 20°C and 25°C and it can be extended to 27°C if air speed increases whit the help of fans [43], regardless any other setting such as social condition, preferences, season or type of climate, buildings, among others. Moreover, no particular studies or surveys for Mexican population were developed to define this comfort criterion. It means that in any of the seven types of climates prevailing in Mexico according to National Institute of Statistic and Geography INEGI (in spanish: *Instituto Nacional de Estadística y Geografía*, INEGI), the same considerations should provide “acceptable” environmental conditions. Clearly, hotter climate means that monthly temperatures will require a higher amount of energy to reach thermal comfort compared with a cooler climate. Under this panorama, some questions come up. What happens to the comfort of housing that does not have any mechanical system? What happens to inhabitants that cannot afford the energy cost due to socioeconomic conditions? Are they living far from well-being? How far are standards to be a reliable parameter of comfort and well-being? How can we ensure the well-being of people living in low-cost dwelling in a hot dry climate? And how much can affect this gap to energy conservation negatively?

It has been proved that at the extreme environmental conditions people can be comfortable in indoor temperatures as low as 10°C and as high as 35°C or more [26]. It seems that the need for air-conditioning is a political necessity and it is not a natural consequence of the human condition [7]. It is instead an unsustainable requirement developed according to institutional or organizational rules naturalized and reproduced to reinforce the need for mechanical control [3], [24].

III. Universe of Study

III.1. Location and climate

The sample analyzed is located in the city of Hermosillo, Sonora with a local population of approximately 884, 273 [44] in the northwest region of Mexico with 29° 05’ North latitude and 110° 58’ West longitude and height above sea level is 282 meters. According to INEGI (National Institute of Statistic and Geography), the climate is classified as very dry [9] and labeled as BWh by the Köppen-Geiger climate classification, meaning that Hermosillo has an arid climate (B) very dry (W) and hot temperatures (h) [45]. Hermosillo city has a mainly tendency to high temperatures. However, this climate presents a considerable variation of temperatures among seasons, from 4°C minimum average during winter to 42°C maximum average during summer. According to Marincic, 2012 [46], daily summer temperatures can vary from 15°C to 21°C as minimum average and 40°C to 45°C as maximum average with high solar radiations levels and clear skies with relative humidity between 15% and 50%. During summer, the wind comes from the south with average temperatures between 30°C to 35°C. From June to September maximum air temperature exceeds 38 °C and in extreme cases can reach up to 50°C [11]. In July of 2014, Hermosillo registered a temperature of 49.5°C becoming the hottest city in the world of that season [47]. In the other hand, most winters register minimum temperatures from 0 to 7°C and maximum between 25 and 30°C being January the coldest month. In **Figure 3** the blue cells are contained average temperatures under 20°C; the green cells contain temperatures higher than 20°C and under 30°C; the red cells contain temperatures higher than 30°C. The higher temperatures are registered during the midday and from June to October, reaching temperatures up to 42.20°C on average.

Hour/Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DIC
1	8.17	9.60	9.67	11.47	13.03	20.01	24.85	24.02	25.35	19.00	11.02	9.43
2	7.16	8.61	8.60	10.27	11.91	19.05	24.02	23.17	24.56	18.06	9.98	8.48
3	6.16	7.62	7.52	9.08	10.80	18.08	23.18	22.32	23.77	17.12	8.94	7.53
4	5.41	6.88	6.71	8.19	9.97	17.35	22.55	21.68	23.18	16.41	8.16	6.82
5	4.65	6.14	5.91	7.29	9.13	16.63	21.93	21.04	22.59	15.71	7.38	6.11
6	3.90	5.40	5.10	6.40	8.30	15.90	21.30	20.40	22.00	15.00	6.60	5.40
7	4.90	6.39	6.18	7.59	9.41	16.87	22.14	21.25	22.79	15.94	7.64	6.35
8	6.16	7.62	7.52	9.08	10.80	18.08	23.18	22.32	23.77	17.12	8.94	7.53
9	10.43	11.82	12.09	14.15	15.53	22.19	26.73	25.94	27.12	21.11	13.36	11.56
10	18.21	19.48	20.43	23.39	24.15	29.69	33.21	32.54	33.23	28.40	21.42	18.91
11	22.73	23.93	25.28	28.75	29.15	34.05	36.98	36.38	36.78	32.63	26.10	23.18
12	25.24	26.40	27.97	31.73	31.93	36.47	39.07	38.51	38.75	34.98	28.70	25.55
13	27.24	28.37	30.12	34.11	34.15	38.41	40.74	40.21	40.32	36.86	30.78	27.44
14	29.00	30.10	32.00	36.20	36.10	40.10	42.20	41.70	41.70	38.50	32.60	29.10
15	28.00	29.11	30.92	35.01	34.99	39.13	41.36	40.85	40.91	37.56	31.56	28.15
16	26.99	28.12	29.85	33.82	33.88	38.16	40.53	40.00	40.12	36.62	30.52	27.20
17	24.23	25.41	26.89	30.54	30.82	35.50	38.23	37.65	37.96	34.04	27.66	24.60
18	21.22	22.44	23.66	26.96	27.48	32.60	35.72	35.10	35.59	31.22	24.54	21.75
19	17.96	19.23	20.16	23.09	23.87	29.45	33.00	32.33	33.03	28.16	21.16	18.67
20	14.69	16.02	16.67	19.21	20.25	26.31	30.29	29.56	30.47	25.11	17.78	15.59
21	13.19	14.54	15.05	17.43	18.59	24.85	29.03	28.28	29.29	23.70	16.22	14.17
22	11.43	12.81	13.17	15.34	16.64	23.16	27.57	26.79	27.91	22.05	14.40	12.51
23	10.18	11.58	11.83	13.85	15.25	21.95	26.53	25.73	26.93	20.88	13.10	11.33
24	9.17	10.59	10.75	12.66	14.14	20.98	25.69	24.87	26.14	19.94	12.06	10.38

Figure 3 - Annual temperature matrixes

Figure by author, data source: Meteonorm

III.2. Data

The School of Architecture and Design from the University of Sonora (UNISON) provided the data for this analysis. The field surveys were collected under the project "*Comfort and thermal energy efficiency in low-cost dwellings in Mexico: regions of warm dry and warm humid climates*". This project was lead by Dr. José Manuel Ochoa de la Torre and supported by Mexican Federal funds from the National Housing Council (CONAVI) and the National Council of Science and Technology (in Spanish: *Consejo Nacional para la Ciencia y Tecnología*, CONACyT).

The description methodology for data collection, including questions regarding thermal comfort perception, and definition of comfort range and neutral temperature are described in the articles: *Adaptive Thermal Comfort for Occupants of Low-Cost Dwellings in a Hot Dry Climate,* by Marincic, Ochoa, Alpuche and Gómez-Azpeitia (2012) [46]; *Extreme Adaptation to Extreme Environments in Hot Dry*, *Hot Sub-humid and Hot Humid Climates in Mexico*, by Gomez-Azpeitia, Bojórquez-Morales, Ruiz, Marincic, González and Tejeda (2014) [18]; and *Confort Térmico Adaptativo Dependiente De la Temperatura y la Humedad*, by Marincic, Ochoa and del Río (2012) [48]. These articles are some of the products of the mentioned project.

The objective of the field survey was to analyze inhabitant's thermal sensation in their own environment, including the actions they take to achieve thermal comfort. The data collection consists of a survey through a questionnaire designed specially fort this purpose. Survey was randomly applied to households regarding indoor thermal comfort including their physical characteristics, indoor and outdoor weather conditions in the moment of the questionnaire as well as the gathering of information regarding building features. 150 surveys were carried out during summer and 150 during winter. The methodology was carried out according to ISO 7730 and ISO 10551 standards. At the same time, indoor environmental conditions as dry bulb temperature, wet bulb temperature, black globe temperature, relative humidity, and wind speed were considered and registered with the data logger *QUESTemp° 36* thermal environmental monitor.

III.2.1. Population

Questionnaires were applied to healthy people without any particular condition such as pregnancy or menstrual period, except obesity, where 56% of the analyzed population presents this condition. The ages of surveyed people were between 11 and 61 years old, and approximately 60% were women and 40% men. Clothing insulation level, type of activity performed right before the survey and acclimatization time were also measured.

Self-evaluation characteristics also were measured as sensation of thermal conditions, humidity, ventilation and sensations during the night. Regarding the preferences; there were considered temperature and ventilation, and other considerations as the tolerance and acceptance of the environment.

III.2.2. Context

The sample was selected from low-cost housing developments in Hermosillo, Sonora. The INFONAVIT supports this housing for workers who are not appointed for a bank mortgage. The income level of the analyzed households amounts reach to 387.90 € per month. According to the National Population Council (in Spanish: *Concejo Nacional de Población*, COESPO) 64% of population concluded basic education and the average number of people living in this type of housing is 3 to 4 individuals, 3.5 as average according to INEGI [49] and mainly formed by young couples.

According to Marincic [48] water scarcity is a common problem, since precipitation is less tan 300 mm per year, and because of it, water supply is controlled depending on the time of the day and the zone of the city. Moreover, pollution by dust is a common characteristic of this zone of the city.

III.2.3. Building

The analyzed type of housing is small; around 33.5 to 39 m^2. Additionally, each house is isolated from the rest of the buildings. In other words, none of the small houses share walls with another meaning a negative impact regarding the indoor overheating that affects comfort. Usually, these housing developments are constructed in series with low-quality materials, or at least, not adequate to the local environmental conditions. The thermal envelope is built with thin concrete hollow block walls and without insulation and the roof is a precast beam and polystyrene vaults without any extra insulation causing problematical thermal bridges. The most common orientation is north-south and windows do not have any shading devices.

In extreme climate conditions, as we see in Hermosillo, the use of mechanical systems as cooling is widespread. However, the use of these systems implies high-energy consumption, and commonly the population with lower incomes cannot afford it. This variable was also documented.

III.3. Collected variables

Data were collected through questionnaires divided into six groups. The first two clusters are regarding personal data as name, address, hour of start and end of the surveys, and some other general details. The third group of questions concerns the control of devices. In **Table 1** is presented each type of device and the percentage of its existence. The fourth group inquiries about inhabitant characteristics as gender (**Table 2**) and age (**Table 3**), as well as activities performed right before the survey (**Table 4**) and clothing type (**Table 5**). Measurements of weight and height are presented as Body Mass Index in **Table 6**.

Concerning group number five, questions are about indoor environment perception including sensations and preferences regarding temperature, humidity, and air velocity as well as acceptance and personal tolerance. To describe thermal sensation the question was “How do you feel at this exact moment?” Alternatives to answer were limited to seven points in two-pole scale values from -

3 to 3, where 0 means completely comfortable, -3 means totally out of comfort by cold and 3 means totally out of comfort by hot sensation. Preference was acquired by the question: At this exact moment, how would you prefer to be? Evaluated with the same seven points in two-pole scale criteria. The acceptance of the thermal environmental conditions was assessed with the question: How do you qualify the climate inside your home? Valuated with two points, one means acceptable and two means unacceptable. Finally, to assess tolerance, the question was: How well are you bearing the climate inside your home at this exact moment? The options include five points, from 0 to 4; where 0 means perfectly tolerable and 4 means extremely intolerable, see **Table 7**.

Finally, in the sixth group, environmental data were collected including characteristics as temperature (°C) of dry and wet bulb, relative humidity (%), radiation (globe temperature, °C) and air speed (m/s). At the same time, outdoor environmental conditions were obtained from the meteorological station of the Energy, Environment, and Architecture Laboratory at the University of Sonora (LEMA). Respective averages and deviations can bee seen in **Table 8**.

Other questions, initially not included in the field survey, have been incorporated to give values to other concepts as the perceived control (concept explained in section VI.2.1.2.2) based on ASHRAE RP-884 ADAPTIVE MODEL PROJECT [50]. The question about heating control was eliminated because there's no record of its existence and the question about the evaporative cooling system was included. Additionally, there are included questions regarding possibilities to modify their clothes, activity, and schedules, see **Table 9**. Answers to this set of questions are assumed as "yes" except number 10; these assumptions are further discussed also in the section VI.2.1.2.2.

Table 1 - *Control of devices - Existence*

Device	Existence
None	17.48%
Air conditioning	13.29%
Fan	36.66%
Evaporative cooler	52.45%
Heating	0%

Table 2 - *Gender*

Female	Male
64.34%	35.66%

Table 3 - *Age*

10-20	21-30	31-40	41-50	>51
27.27%	37.06%	25.17%	8.39%	2.10%

Table 4 - *Intensity of activity*

Intense	Moderate	Passive
10%	30.07%	62.94%

Table 5 - *Clothing*

Very light	Light	Normal	Sheltered	Very Sheltered
53.85%	44.06%	2.06%	0.00%	0.00%

Table 6 - *Body Mass Index*

Underweight	Normal	Overweight	Obesity
3.50%	33.57%	41.26%	21.68%

Table 7 - *Questions and values regarding environmental perception.*

	Scale	-3	-2	-1	0	1	2	3	4
Sensation	Thermal	**How do you feel in this moment?**							
		Very cold	Cold	Cool	Neutral	Warm	Hot	Very hot	------------
	Humidity	**How do you feel humidity in your skin in this moment?**							
		Very humid	Humid	Some humidity	Neutral	Some dryness	Dry	Very dry	------------
	Ventilation	**How do you feel ventilation in this moment?**							
		------------	------------	------------	------------	Too much	Moderate	Light	Nothing
	Night	**How did you feel last night while you slept?**							
		Very cold	Cold	Cool	Neutral	Warm	Hot	Very hot	------------
Preference	Temperature	**How do you prefer to feel in this moment?**							
		Much cooler	Cooler	Slightly cool	No change	Slightly warmer	Warmer	Much warmer	------------
	Ventilation	**How would you prefer ventilation in this moment?**							
		------------	------------	------------	------------	More	No change	Less	------------
	Acceptance of the environment	**How do you evaluate the environment inside your house?**							
		------------	------------	------------	------------	Acceptable	Unacceptable	------------	------------
	Personal tolerance	**How tolerable is the environment of your house in this moment?**							
		------------	------------	------------	Perfectly tolerable	Tolerable	Lightly intolerable	Intolerable	Extremely intolerable

Table 8 - *Indoor environmental conditions*

	Temperature (dry bulb)	Temperature (wet bulb)	Radiation (Globe temp)	Relative Humidity	Wind speed	Outdoor temperature
Average	33.7 °C	26.00 °C	34.5°C	41%	.3024 m/s	38.6 °C
Deviation	2.9	3.6	3.1	10	.2265	-

Table 9 - *Perceived control*

	Question	Answer
1	Can you open/close windows?	1=yes
2	Can you open/close external doors?	1=yes
3	Can you adjust thermostats (a/c)?	1=yes
4	Can you adjust turn on/off evaporative cooling?	1=yes
5	Can you adjust local fans?	1=yes
6	Can you adjust curtains/blinds?	1=yes
7	Can you adjust local fans?	1=yes
8	Can you change your clothes?	1=yes
9	Can you change your activity?	1=yes
10	Can you change your schedule?	0.3=no

IV. Variables Influencing Thermal Comfort Perception

IV.1. Literature review

Even though, current discussion regarding thermal comfort models clearly complement each other to solve weaknesses in the approach and eventually are able to account for both the thermal and non-thermal influences on occupant response in real buildings [4]. In other words, it is necessary to construct a more flexible interpretation of the energy balance between the human and its environment in order to develop a holistic point of view concerning how comfort is perceived and how it can be achieved. But, what characteristics could interact and influence in this approach?

The first step to define the influencing variables over thermal comfort perception was the analysis of relevant literature. To that, it was necessary to split the search into two phases. The first one was focused on comfort from the socio-technical point of view with the aim of answering: what is comfort in the modern life? The following key words were used to select the appropriate literature: comfort provisioning, well-being, building's inhabitants, social convention and climate change. The second phase was focused on applied knowledge in the field of study with the aim of answer the question: how thermal comfort is studied? The searching was delimitated by the following key words: thermal comfort, built environment, thermal adaptation, energy efficiency, thermal sensation, acceptability and preference, occupants' perception and comfort standards. Additionally, it was only included literature as reviews regarding thermal comfort approaches, experiments in controlled environments and field studies in residential buildings, offices or schools, and it was not include any studies concerning outdoor and semi-outdoor spaces.

The second step consisted in the organization of all variables found into general groups. During the review, it was clear that some variables belong to characteristics related to the unconscious reactions of the human body to the environment and conscious individual actions. In this sense, the first group is called ***Human Body***. All these human body or individual characteristics are embedded in specific circumstances as social conditions or cultural practices; this type of variables is grouped under the ***Context*** classification. At the same time, and as mentioned before, modern human activities are developed indoors mainly, therefore, building characteristics have a major influence over thermal comfort provision; the third group of variables is named ***Building***. Lastly, the three previous groups are suppressed to local environmental conditions; therefore the name of the fourth group is ***Climate***. Besides, these actions happen in a specific space and time, so the model is considered to be dynamic, flexible and under constant change.

In addition, in this thesis we propose to cross transversely the four groups by the ***behavioral actions*** proposed by Brager & de Dear, 1998 [4]. These behavioral actions are classified as ***physiological acclimatization, behavioral adjustments*** and ***psychological expectations.***

Physiological acclimatization is the result from the exposure of the human body to the environmental factors; this aspect belongs only to the human body itself. The *behavioral adjustments* include all modifications that a person might be able consciously or unconsciously to make in order to modify the body's thermal balance. These modifications are personal and collective decisions are constructed by available possibilities. Additionally, three modes of behavioral adjustments are distinguished: *personal adjustment* when changing personal variables; *technological or environmental* adjustment, for instance when one's control is available, such as opening or closing windows or shades; and *cultural adjustments* that include scheduling activities, adapting dress codes, among others. Finally, in the description of the *psychological expectations*, Brager & de Dear [4] included the effect of cognitive and cultural variables, where habituation and expectation may change one's perception due to past experience and past expectations.

The third and last step was to describe a possible interaction among these groups of variables found.

Figure 4 represents the comfort perception, which is defined by the intersection of the four general groups of variables, at the same time, it was intersected by the behavioral actions: psychological expectations, behavioral adjustments and physiological acclimatization. All these interactions happen in space and time. For a better understanding, this interaction is better described in the next two sections.

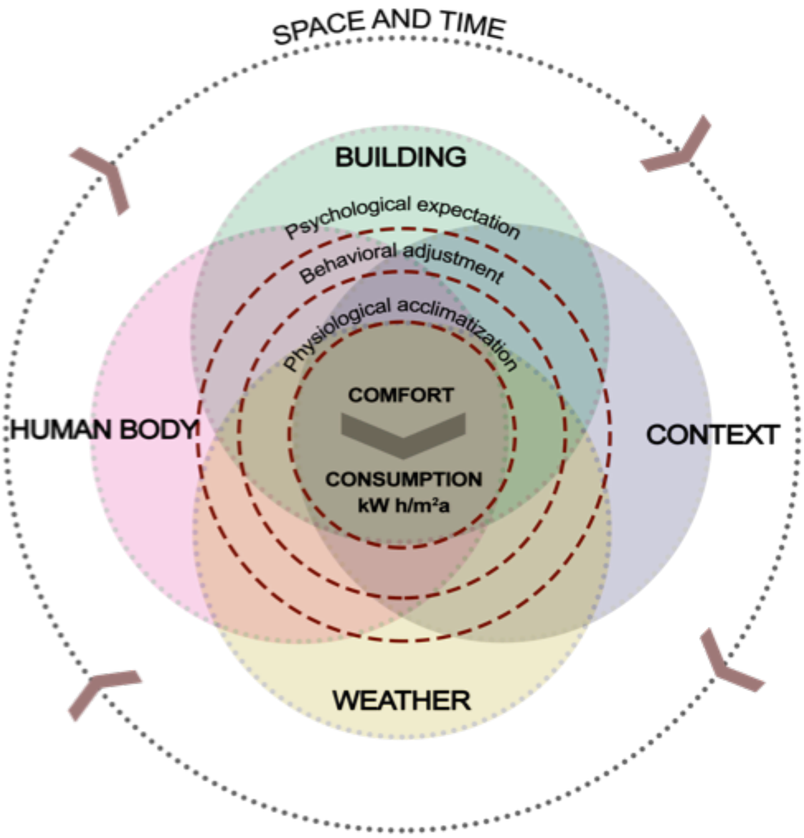


Figure 4 - Variables influencing the thermal comfort perception
Diagram by author

IV.2. The four main groups of variables: Human body, Context, Building, and Climate

During the literature review, the variables mentioned by authors were identified and then organized into groups according to general characteristics.

Human Body

The first group is called *Human Body* and includes all variables related to individuals, from human body's characteristics to particular and subjective considerations. The first adaptation of the human body itself is caused by metabolism. According to Brager [4], he classifies this process as a *physiological acclimatization*. The metabolic effects are a consequence of heat exchange between human body and the environment mainly by radiation and convection. In other words, when environment temperatures are higher than the human body, heat cannot be dissipated and thermal discomfort starts [51], additionally, the metabolic rate varies with the activity level [52]. From this physiological point of view, it would be also possible to expect other characteristics as age, gender, and body fat, among many others. For instance, older subjects may prefer to keep warmer as a consequence of the differences in the thermoregulation system due to the morphological characteristics, the differences in fitness levels, and the debilitating effects that come along with ageing [29], [52]–[55]. Another example could be the gender of the individual, in this context, it influences morphological differences; women normally have a smaller average body size, lesser muscle mass, and a higher surface area to mass ratio affecting heat balance and also causing differences in thermoregulation and thermal perception [13], [25], [29], [51]–[55]. The most mentioned variables regarding physiological acclimatization are: height, gender age and metabolic rate. In general, variables were found regarding the physiological acclimatization of the human body as listed in **Table 10**.

In other level of variables, the Human body can be understood as one person: an individual. In this sense, the individual can consciously perform behavioral adjustments and be able to make changes in order to modify the body's thermal balance. These modifications are possible only if there exists any possibilities available. The individual decides to take action on and this can be performed immediately. The amount of clothing resistance will increase or decrease heat transfer between body and environment [4], [8], [13], [25], [29], [51], [52], [54]–[57]. The type of activities or the vigor performing an activity can also influence thermal perception because it modifies metabolic rate [8], [13], [51], [54]–[57], we can immeadilty change the vigor of an activity, but metabolic rate will deacrease slower. We can take inmediately action on changing activity but we can not do anything regarding metabolic rate.

Regarding psychological expectations, our thermal perception is not only formed by physical features, but also based in past thermal experiences [4], [8], [25], [29], [37], [52]–[55] and the expectations on future [4], [8], [13], [23], [25], [54], [57]. Tolerance and attitude, also learn from past experiences, can affect the understanding of given environmental conditions [4], [8], [17], [25],

[29], [54], [57]. Alliesthesia is a less studied concept that describes the dependence of sensations as a descriptive assessment, and pleasures as emotional description, [25], [29], [53], [57].

Table 10 - *Human Body Variables*

Physiological acclimatization	
Variable	**Source**
Body mass (weight and height)	[25], [29], [55]
Gender	[13], [25], [29], [51]–[55]
Age	[29], [52]–[55]
Metabolic rate	[4], [13], [29], [52], [53], [55]–[57]
Body fat	[53], [55]
Heat exchange / storage	[8], [13], [51], [56]
Skin temperatures	[29], [51], [53]
Skin moisture	[29], [51]
Skin area	[29], [53], [55], [56]
Respiration	[13]
Sweeting	[51], [53], [54], [56]
Acclimatization	[13]
Genetic adaptation	[4]
Mental stress	[4]
Behavioral Adjustments - Personal	
Variable	**Source**
Type of activities	[8], [13], [51], [54]–[57]
Moving to different location	[54]
Clothing	[4], [8], [13], [25], [29], [51], [52], [54]–[57]
Posture	[4], [57]
Eat/drink hot/cold	[4]
Time of exposure	[53]
Psychological expectations - personal	
Variable	**Source**
Tolerance	[17], [25], [54]
Attitude	[4], [8], [29], [57]
Preferences	[4], [17], [29], [58]
Expectations	[4], [8], [13], [23], [25], [54], [57]
Thermal experiences	[4], [8], [25], [29], [37], [52]–[55]
Spirituality and Morality	[3]
Privacy	[3], [37]
Alliesthesia,	[25], [29], [53], [57].
Sentation	[56], [58], [59]
Acceptability,	[58]
Aspitrations	[23]
Religus	[52]

Context

Not only individual meanings determine comfort perception. The second group, *Context,* presents all the characteristics of the socio-technical and socio-economic framework conditions. In this group we analyze the common understanding of what is normal and proper defined by social conditions, education level, economic status, culture, religion, education, experience and so on. These expectations tend to mediate our perception of the thermal environment [8]

In *Field studies on human thermal comfort*, Mishra [25] cited some results as an example of non-thermal influences on occupant's responses. He mentioned that according to a field survey performed in Hyderabad, India, it was found that subjects from higher economic groups are more dependent on mechanical strategies as air-conditioning while neglecting adaptive measures as other social groups, moreover, it was also found that comfort votes were more favorable in residences where owners lived compared to residences with housing tenants. Mishra [25] also mentioned a study in Thailand, where it was found that subjects with higher education voted at higher values of thermal sensation. In addition to above, Nicol [57] declares that provision of comfort is also given by possibilities provided and defined by building type, which can be described by contextual characteristics, for instance, the possibilities to control the environment regarding policies of management, or economical possibilities, where there is a dress code depending on the type of building such as a house, offices or a church, and so on. **Table 11** shows gathered variables defined by specific characteristics of context in three levels; the general characteristics, behavioral adjustments and those that affect psychological expectations.

Building

The third group is *Building* and it comprises all technical specifications. These characteristics are completely predictable and controllable, for instance, heat transfer of materials, the influence of geometry, influence of orientation and design over indoor environmental conditions, and so on. Additionally, through the use of software, this group was easily assessed. A correct use of these resources may provide a good design and therefore acceptable comfort conditions. Thus, since buildings provide indoor environmental conditions, the objective now is to identify which of these given characteristics affect comfort thermal perception. According to the literature review, most relevant indoor environmental characteristics are temperature, humidity, air velocity, and mean radiant temperature [13], [17], [29], [51], [54]–[56]. This result was expected since these variables were included in adaptive models and the PMV equation, which is the base for several standards as described in section II.4. Other variables as asymmetry or thermal cycles of temperatures would impact individual evaluation of a common space and may increase negatively evaluations of thermal conditions [53], [55], [56].

Regarding behavioral adjustments, buildings can provide technological or environmental adjustments such as windows, shades, natural ventilation and so on. In some cases, these adjustments may involve energy consumption such as the use of cooling or heating systems. The influence of these devices depends first on the availability and secondly on accessibility to control them [4], [13], [14], [29], [53], [55], [57].

The psychological expectations in buildings refer to expectations related to past experiences and can vary according to the type of building, for example, between a house and a hospital, or the available technology in a building, for example, between a NVB and a building functioning with HVAC [3], [55]–[57], [60]. All variables are present in **Table 12**.

Climate

Finally, the fourth group belongs to *Climate* conditions. This variable is uncontrollable but most of the time predictable and besides, it is an important consideration in the definition of comfort standards. The energy demand of a building regarding thermal comfort can be defined only if the climate characteristics are considered. Table 13 shows climate conditions that affect comfort inside buildings according to what was found in literature review.

Table 11 – *Context Variables*

Variable	**Source**
Social conditions	[4], [8]
Education level	[25], [52], [54], [60]
Economic status/condition/incomes	[4], [25], [29], [52]
Environment charact. (Noise, poluttion, dust)	[60]
Owned or rented	[25]
country of origin	[60]
Behavioral Adjustments - cultural	
Variable	**Source**
Dress code	[4], [8], [57]
Schedules	[4]
Energy guide lines	[8], [29], [57]
Cultural practices / habits	[3], [4], [8], [17], [23], [25], [51], [52]
Social norm / shared convention / organizational	[3], [8], [23], [37], [51], [52]
Lifestyles - belifs	[8], [23], [25]
Relation between inhabitants	[37], [60]
Psychological expectations - cultural	
Variable	**Source**
Safety perception	[3]
Historical evolution of architecture	[3]
Historical evolution of technology	[3]

Table 12 – *Building Variables*

Variable	**Source**
Furniture	[4]
Indoor temperature	[13], [17], [29], [51], [54]–[57]
Indoor humidity	[13], [29], [51], [54], [56]
Indoor air velocity	[13], [17], [29], [51], [52], [54]–[57]
Indoor mean radiant	[13], [17], [29], [51], [52], [54]–[56]
Asymmetry	[53], [56]
Cylces and drift	[53], [55]
Discharge angle of air conditioners	[54], [55]
Thermal storage	[13], [51]
Typology (country solutions)	[17]
Behavioral adjustments – technological or environmental	
Variable	**Source**
Windows	[8], [52], [53]
Ventilation/air movement	[55], [57]
Fans	[8], [52], [53], [55], [57]
Cooling	[8], [57]
Heating	[53], [55], [57]
Blinds/Shades	[14], [53]
Control / adaptative oportunity	[3], [4], [13], [29], [36], [37], [52], [53], [55], [57]
Psychological expectations - technological or environmental	
Variable	**Source**
Type of building	[55]–[57], [60]
Austerity	[3]
Efficiency	[3]

Table 13 – Climate Variables

VARIABLE	**SOURCE**
Season	[13], [17], [25], [51], [53], [55], [57], [60]
Temperature	[13], [29], [52], [55], [60]
Air speed	[8], [25], [52]–[54]
Humidity	[8], [25], [29]
Relative humidity	[52]
Radiant Temperature	[8], [52]
Solar radiation	[13], [29], [54]
Air temperature	[8]
Climate change	[8]
Atmospheric pressure	[55]

Finally, and according to the objective one, all variables already described are arranged all together in **Table 14**. Variables are within the four main groups and crossed transversely by *behavioral actions (physiological acclimatization*, *behavioral adjustments* and *psychological expectations).*

Table 14 - First group of Variables found from literature review

Human Body	Context	Building	Climate
Physiological acclimatization			
Body mass	Social conditions	Furniture	Season
Gender	Education level	Indoor temperature	Temperature
Age	Economic condition	Indoor humidity	Air speed
Metabolic rate	Environment charact.	Indoor air velocity	Humidity
Body fat	Noise	Indoor mean radiant	Relative humidity
Heat exchange	Pollution	Asymmetry	Radiant Temperature
Skin temperatures	Dust	Cycles and drift	Solar radiation
Skin moisture	Owned or rented	Discharge angle of air conditioners	Air temperature
Skin area	Country of origin	Thermal storage	Climate change
Respiration		Typology (country solutions)	Atmospheric pressure
Sweating			
Acclimatization			
Genetic adaptation			
Mental stress			
Behavioral Adjustments			
Personal Adjustments	***Cultural Adjustments***	***Technological adjustments***	
Type of activities	Dress code	Windows	
Moving to different location	Schedules	Ventilation/air movement	
Clothing	Energy guide lines	Fans	
Posture	Cultural practices / habits	Cooling	
Eat/drink hot/cold	Social norms/shared convention/organizational	Heating	
Time of exposure	Lifestyles - beliefs	Blinds/ Shades	
	Relation between inhabitants	Control / adaptive opportunity	
Psychological expectations			
Personal Expectations	***Cultural Expectations***	***Technological Ad.***	
Tolerance	Safety perception	Type of building	
Attitude	Historical evolution of architecture	Austerity	
Preferences			
Expectations	Historical evolution of technology	Efficiency	
Thermal experiences			
Spirituality			
Morality			
Privacy			
Alliesthesia			
Sensation			
Acceptability			
Aspirations			
Religious			

IV.3. Variables interaction

According to the findings described in the last topic, **Figure 5** presents all the variables highlighting the three behavioral actions (***physiological, behavioral and psychological***) throughout the main groups **(body, context, building and climate**). In this figure, it is also noticed three levels from the top to the bottom, comprising from general characteristics to a very specific individual background. These levels are also classified regarding to long-term or short-term impact over comfort. Top and bottom levels are modifiable variables only by the long-term. This long-term state provides constant settings or situations, but nevertheless it shows dynamic flux (for example, a social context always evolve). Hence, these characteristics represent the structure of the system. Contrary, middle level contains modifiable characteristics in short-term that affect the system immediately and are performed by behavior; therefore, we encounter human action in middle level.

Regarding to variables interaction, each group can affect others, even among levels from the same or different group. Interaction can be so complex that the relation among all variables would be different depending on a given situation and time. Either way, the general functioning of the system can be described in **Figure 5**.

In this diagram (**Figure 5**), the climate is the greater force affecting on a unidirectional basis the entire system and it would be impossible to modify its given conditions. The influence of climate over buildings is determined by characteristics such as materials, orientation, geometry, and so on, and at the same time, these features generate environmental conditions in indoor environments as for instance temperature or humidity. The possibility to modify these building's conditions is only in the long term and maybe decided by other reasons as economical factors instead of a temporary comfort stage. Technological or environmental adjustments are the interface for inhabitants, and it can be modified by individual or collective action (decision or criteria). These adjustments provide possibilities to modify the system by interaction. Once users have made a modification, the building will respond changing the environmental conditions. If the comfortable condition is reached then interaction will be finished; if this does not happen then users will search for another option (fed loopback) until desired comfort condition is reached. Only through this part of the system would be possible to consume energy and it depends on building opportunities.

Regarding to the top level of the context group, this can affect personal, cultural and technological adjustments. These context variables are modifiable only in the long term, however in contextual situations as in developing countries individuals normally cannot modify them. In addition, cultural adjustments affect directly to technological and environmental adjustments.

In the human body group, top variables named as physiological acclimatization affect directly to personal adjustments and backwards. Meanwhile personal adjustments are completely controllable by individuals; physiological acclimatization is a consequence of a personal adjustment and it is not controllable. In other words, people act and the body reacts. Actions are controllable and immediate but reactions are uncontrollable and slower. As for instance, the type of activities can define the metabolic rate, in this sense, an individual can decide to decrease or increase vigor activities immediately but the body response will be slower.

In the bottom level, physiological expectations are influenced unidirectional by the entire system. This level is the individual background fed by past experiences regarding climate, buildings, context and the body itself. This level provides to the individual cognitive knowledge to define a motivation to change current conditions and to perform an action or not. The value (or meaning) of the variables contained in this level occurs in different time; there is an existing gap of time between variables affecting current situation and the variables involved in psychological expectations. Finally, in this level, the individual (the human body group) is the only way out for the influence of these psychological variables. In other words, only by individual actions physiological expectations are expressed. This level is not immediately modifiable, it is part of the structure, moreover, it is constantly evolving.

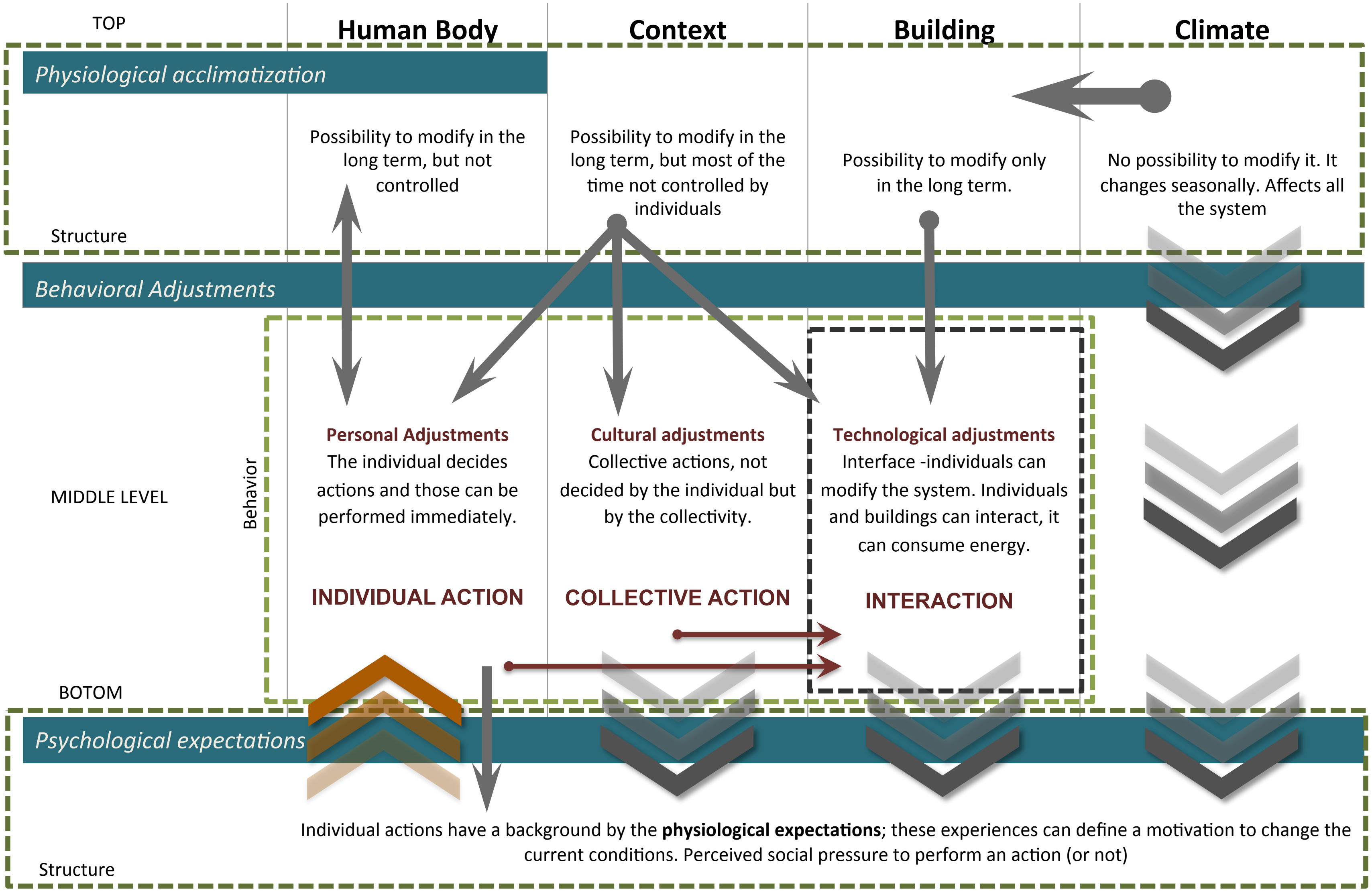


Figure 5 – Variables Interaction
Diagram by Author.

IV.4. Derivation of variables

After the literature review presented in section IV, it is now necessary to apply a criteria to choose which variables are suitable to develop a correlation analysis among real data, comfort perception, and energy consumption. The derivation of variables in this work has been based on the criteria used by Yang [61] in the article *"A method of identifying and weighting indicators of energy efficiency assessment in Chinese residential buildings"*.

The first filter is the feasibility of variables. This criterion is about the possibility to evaluate variables or the availability of the information. In this case, the greater limitation is technical. Since this research work has been developed whit no financial resources, data from field surveys were originally designed for other objectives. Therefore, it does not exist some specific information, for example, body fat, drinking cold or hot beverages, relation between inhabitants, also variables regarding the building as thermal asymmetry, furniture characteristics, etc. In addition, some variables or interaction among variables possess an inherent high complexity limiting the capacity to analyze them and/or are out of the scope of the thesis objectives. Some examples are the variables involved in human heat transfer or building's materials heat transfer. These examples are complex systems by themselves.

The second filter is completeness. In order to perform an accurate impact of variables, values must be quantitatively or qualitatively measurable; therefore, information must come from reliable sources. The first source is field survey data (described in section III.2); second source from official sources as government reports; and third from reliable literature sources as field studies in dwellings in hot dry climates. Finally, the last source comes from personal observation. Whatever the case, it will be indicated.

The third filter is the effectiveness of data. In this research is believed that all variables may impact final results, some more than others, but they all matter. If it were suspected that any variable would not have a considerable impact on results, it would be dismissed only after proved that the impact is minimal. Some examples of these would be safety perception, pollution, or external noise. Either way, in result's chapter, will be presented last version of influencing variables.

The final filter is the multi-attribute. According to this criterion, it is necessary to avoid those redundant variables to prevent double counting that affects final results. The final group of variables is presented in **Table 15**.

The final variables presented in **Table 15** were used to define objective two and three, and in the following chapters the process is described.

The final variables presented in **Table 15** were used to define objective two and three, and in the following chapters the process is described.

Table 15 - *Final set of variables*

Human Body	**Context**	**Building**	**Climate**
Physiological acclimatization			
	Social conditions	Indoor temperature	Season
Body Mass Index (Weight and height)	Economic status/condition/incomes	Indoor humidity	Temperature
Age	Environment characteristics	Indoor air velocity	Humidity
Gender		Indoor mean radiant	Relative humidity
			Radiant Temperature
			Solar radiation
			Air temperature
Behavioral Adjustments			
Personal Adjustments	***Cultural Adjustments***	***Technological adjustments***	
Type of activities	Schedules	Windows	
Clothing	Energy guide lines	Blinds/ Shades	
Acclimatization time		Fans	
		Evaporative Cooling system	
		Air-conditioning system	
		Ventilation/air movement	
		Control / adaptive opportunity	
Psychological expectations			
Personal Expectations	***Cultural Expectations***	***Technological or environmental***	
Tolerance	Safety perception	Type of building	
Attitude	Habituation		
Preferences			
Expectations			
Thermal experiences			
Sensation			
Acceptability			

V. Thermal comfort perception

Perception is the process of creating coherence from patterns of energy impinging on sensory organs allowing to the consciousness of objects, and also, the capacity to react differentially to them [56]. On one hand, **comfort perception** can be understood as the combination of **thermal sensation** of one's sensory perception of the surrounding thermal environment which describes the direction as hot or cold; and magnitude a little or a lot [58]. This is the representation of given conditions, which involves aspects as age, gender, clothing, acclimatization, and so on. On the other hand, **thermal preference** can be understood as the ideal condition if you could have exactly what you wanted, in other words is the liking or choice of one option over one or more other options [2], [58]. These preferences are determined by the psychological expectations as thermal experiences, expectations, attitude, etc.

In the next sections, will be explained how to evaluate thermal comfort perception according to thermal sensations and thermal preferences by means of the thermal comfort profiles. The resultant profiles, will provide a state prior to take a decision regarding to change or not current environmental conditions. In addition, will be explained how to calculate neutral temperatures which refers to the average indoor temperature corresponding to sensation responses in zero. And, the calculation of the comfort range temperatures according to real data. These two features will support to the description and understanding of thermal comfort profiles.

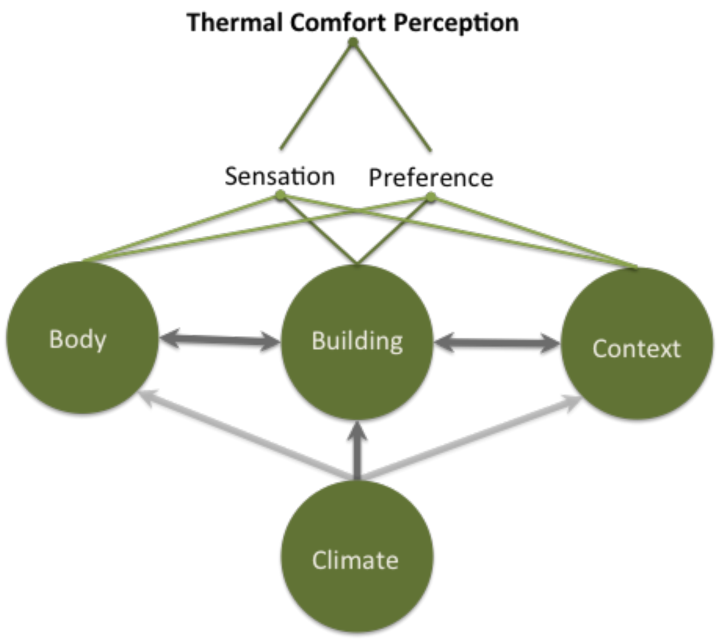


Figure 6 - Thermal Comfort Perception and its four main groups

Diagram by Author

V.1. Profiles of thermal comfort

A profile of thermal comfort can describe qualitatively current conditions regarding how inhabitants perceive their environment based on thermal sensation and thermal preference. About this adaptive approach, Matias [17] argues that thermal **sensation (*t*si)** and thermal **preference (*t*pi)** can mutually influence comfort perception, suggesting that the only sensation, regardless of what people would like to feel, could not be a sufficient explanation to define a thermal comfort state. For example, if a person feels neutral regarding its own sensation, but he or she would prefer to be cooler or warmer: would it be possible to consider this as a comfortable condition?

On the one hand, ***sensation*** **describes the direction and magnitude** of one's sensory perception of the surrounding thermal environment [58]. In the other hand, ***preference*** **describes what would be ideal** regardless of what it is felt [2], [58]. The values to assess thermal comfort perception according to the two parameters discussed here are obtained from the field survey according to the questions and the scale of judgment expressed in **Table 16** (explained in section III). This thermal comfort profile describes different levels of comfort giving different values to the different combinations of sensation and preference. According to Matias [17] method, this combination leads to four distinct profiles (see **Table 17**); if both answers are neutral (or equal to zero) the perception is completely comfortable. If one of them is different from zero, then the condition will be slightly comfortable (sensation ≠ 0) or slightly uncomfortable (preference ≠ 0) giving a higher influence to preference. This classification has been defined like this because even if the sensation were equal to zero, the individual would prefer another condition; therefore, he or she might consider the need to act on it. This evaluation can provide more flexibility and accuracy to the description of comfort.

Table 16 - *Seven points of judgment*

Vote	Sensation	Preference
	How do you feel at this exact moment?	**At this exact moment, you would prefer to be…**
3	Hot	Much warmer
2	Warm	Warmer
1	Slightly warm	Slightly warmer
0	Neutral	No changes
-1	Slightly cool	Slightly cooler
-2	Cool	Cooler
-3	Cold	Much cooler

In this table is presented the seven points of the comfort scale and questions regarding sensation and preference; both parameters used in the field survey. Source [62].

Table 17- *Thermal comfort profiles*

Profiles of comfort	Thermal	
	Sensation	**Preference**
Uncomfortable	≠ 0	≠ 0
Slightly Uncomfortable	= 0	≠ 0
Slightly Comfortable	≠ 0	= 0
Comfortable	= 0	= 0

Profiles of comfort proposed by Matias, 2009. Source [17]

In order to analyze comfort according to the objective of this thesis, we proposed a modification of the thermal comfort profiles by extending sensation and preference combinations (codes) and adding values, which will be used as weighting into the calculation of the action tendency in the next chapter. See **Table 18**.

Since our target climate is asymmetrical, values regarding sensation only go from zero to three; and preference values go from zero to minus three. An asymmetrical climate is when the responses of the seven points show a tendency toward only one extreme of the sensation scale [63] (or seven points of judgment, see **Table 16**). In this case, sensation tendency is towards the hot side; hence preference will go towards cold side. It has to be noticed that from original data, only one value was deleted because sensation and preference votes went to the same direction, which supposes a contradiction.

According to what it was said above, we can understand the code (0, -2; sensation, preference), meaning that the individual sensation is neutral with what she or he is feeling, but he or she would prefer cooler conditions; or (1, 0), meaning that the person is feeling slightly warm, but he or she prefers to stay on the same condition. In the first example, preference vote would also mean a **motivation** to perform an action, and in the second example the incentive is null. Therefore, according to the comfort profiles and values (see **Table 18**), the values assigned for these examples would be 1.6 and 0.2 respectively, having more importance code (0,-2) than code (1,0) regarding the probability to perform an action.

Due to the resources and methods used in this research, it is important to highlight the values assigned to each comfort profile are linear (see values in **Table 18**). In other words, answers values are equidistant from each other, assuming that all answers regarding comfort have the same impact. Would it be possible that the relation between temperature and comfort profile presents an exponential growth? Here the question will remain open to future research.

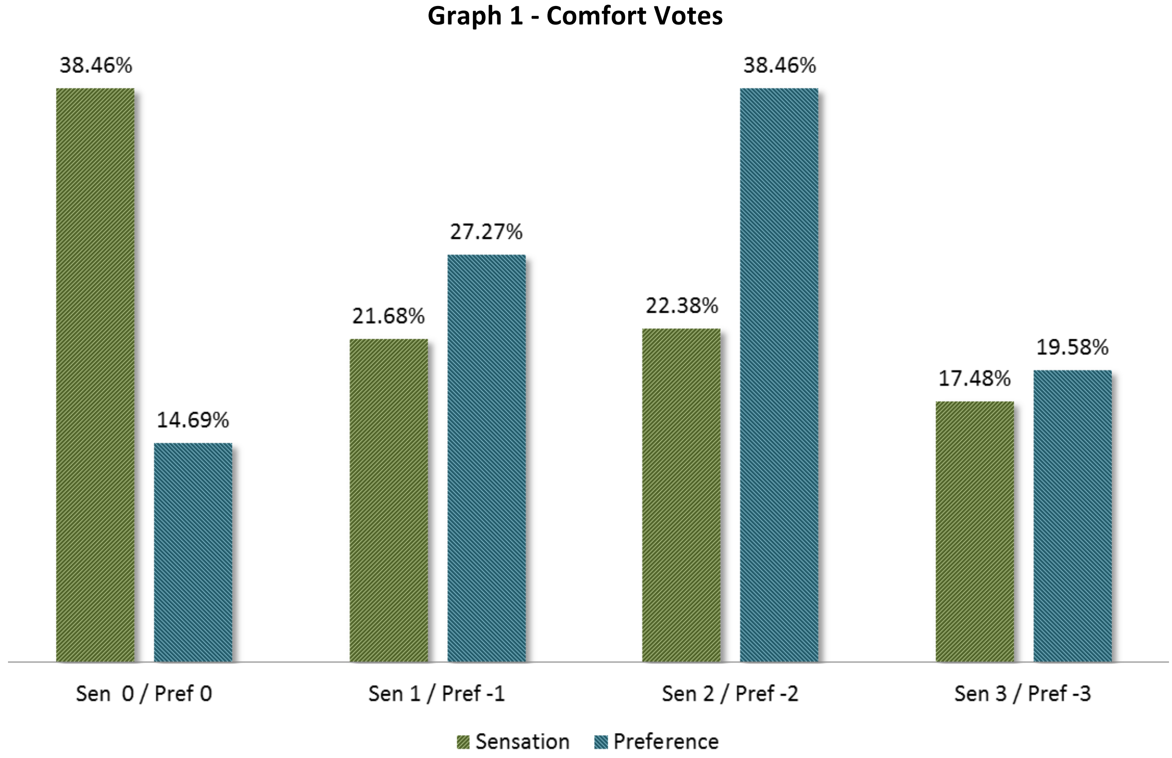
Finally, to each code correspond a name or status (see names in **Table 18**). Regardless of this name, what matters is the value; moreover, conditions of the profile can be deduced according to the code numbers. The aim of this profile is to define a prior state to make a decision.

Table 18 - *Comfort Profiles and values*

Value	Code: Sensation	Code: Preference	Status
0.0000	0	0	Comfortable
0.2000	1		Slightly comfortable
0.4000	2		Slightly comfortable
0.6000	3		Slightly comfortable
0.8000	0	-1	Slightly uncomfortable
1.0000	1		Uncomfortable
1.2000	2		Uncomfortable
1.4000	3		Uncomfortable
1.6000	0	-2	Slightly uncomfortable
1.8000	1		Uncomfortable
2.0000	2		Uncomfortable
2.2000	3		Uncomfortable
2.4000	0	-3	Slightly uncomfortable
2.6000	1		Uncomfortable
2.8000	2		Uncomfortable
3.0000	3		Completely uncomfortable

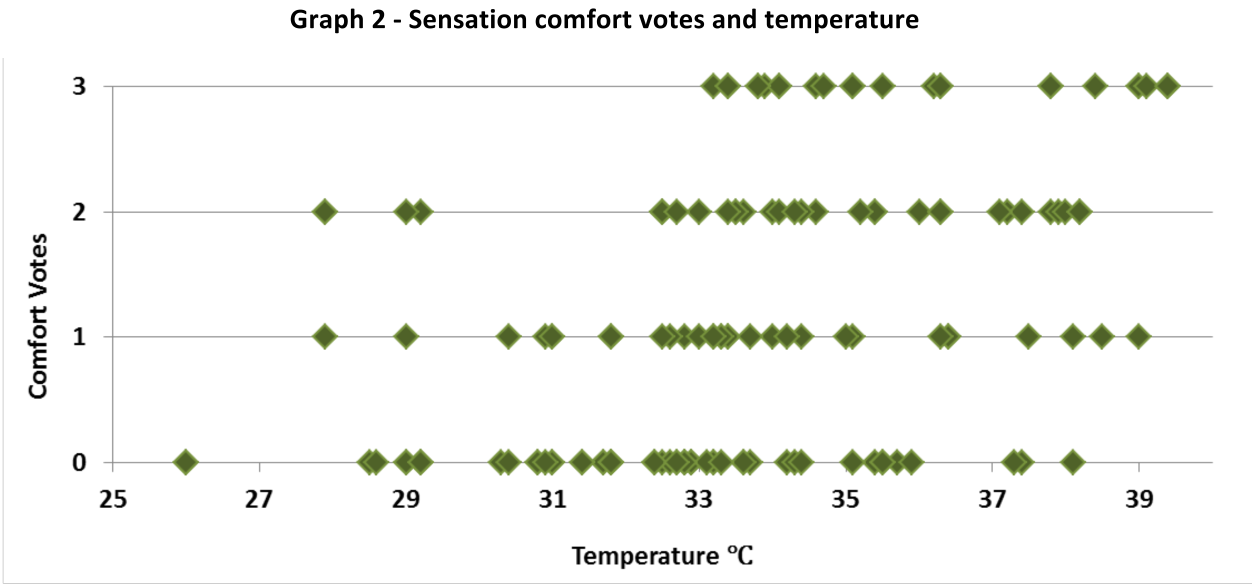
The following graphs present the field study responses regarding thermal sensation and thermal comfort including temperatures conditions.

Graph 1 represents answer percentages of the total data regarding thermal sensation and thermal comfort (to see questions attend **Table 16**). According to the results, 38.46% of the population declared to be neutral (sensation = 0) while another 38.46% stated a preference of -2. This means that little more than a third of the people felted neutral with current environmental conditions, but the same proportion would like to change it. It is a coincidence that these two percentages (sensation 0 and preference -2) are equal since the total answers of sensation and the total answers of preferences do not correspond to the same person.



Values from all data

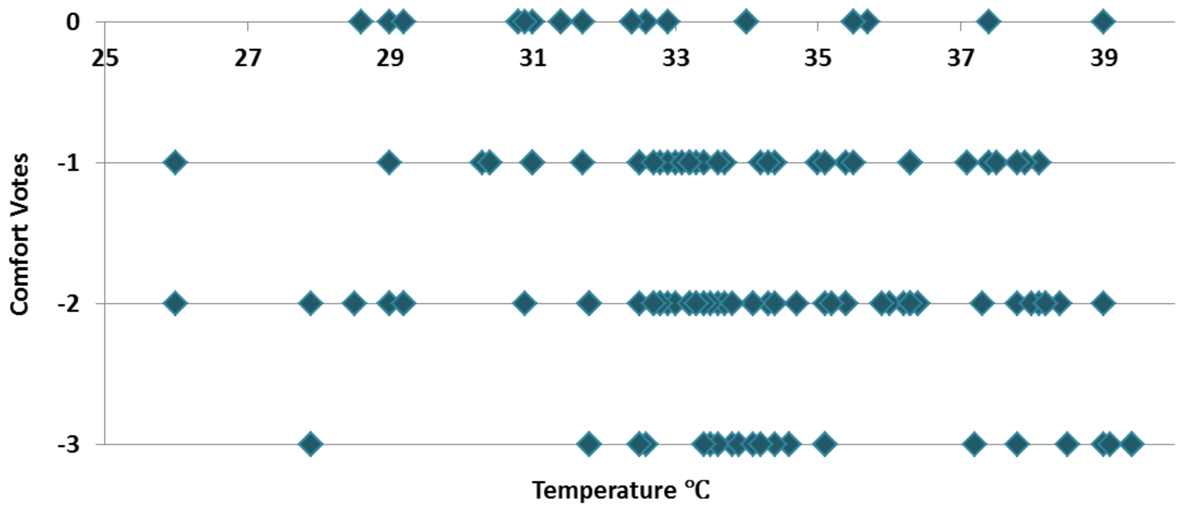
Graph 2 presents information regarding sensation votes and temperatures, all survey answers are placed between 26°C and 39°C although there is a clear tendency, the higher the vote is the higher the temperature goes.



Values from all data

In **Graph 3**, data remains more disperse, nevertheless the tendency is evident; the lower perception vote is the higher the temperature goes. So far, these results are just as expected.

Graph 3 - Perception comfort votes and temperature



Values from all data

Finally, **Figure 7** represents the comfort profile of the whole data. People feel slightly warm and would like to be slightly cooler at 33.7°C on average with a standard deviation of 2.9. Thus, according to the profiles, this is an uncomfortable condition and the corresponding value of the prior state to decide (explained in VI.1) is 1.00.

Sensation	Preference	
0	0	
1		
2		
3		
0	-1	
1		Uncomfortable
2		
3		
0	-2	
1		
2		
3		
0	-3	
1		
2		
3		

Figure 7 - Final Comfort Profile

Image from the spreadsheet indicating the comfort profile

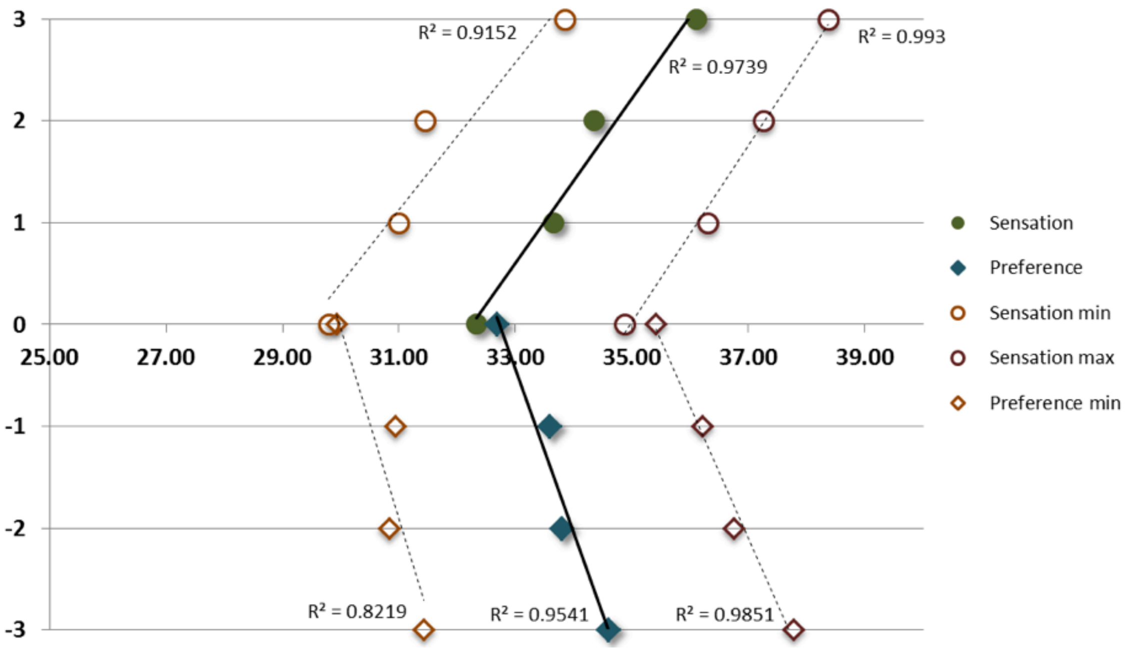
V.2. Comfort range and neutral temperatures

In this section, it will be defined the comfort range and the neutral temperature of data according to the methodology used by Gomez-Azpeitia [18].

The neutral temperature refers to the mean indoor temperature corresponding to sensation responses in zero. Besides, the comfort range is the interval of temperatures within votes from -1 (slightly warm) to 1 (slightly cool).

Thermal neutrality and comfort ranges are usually calculated by projecting linear regressions concerning thermal comfort votes and temperatures. However, according to Gomez-Azpeitia [18] the traditional method of lineal regression in asymmetric climates gives as a result unreliable data because these lines deviate towards the graph sector where there are no votes. The method ATSI developed by Gomez-Azpeitia and based on Humphreys [64] proposes to determine the average and standard deviation of each vote. Thus, instead of obtain a regression line from the seven points; the line is originated from the mean temperatures of each category. The neutral temperature is defined by the intersection of the regression line in the ordinate zero. To see Hermosillo's data attend **Graph 4**. Besides, the comfort range is given by ± one standard deviation for each category and by the intersection with ordinate. Moreover, the more inclined the slope line is; the wider the comfort range is (see **Graph 4**).

Graph 4 - Neutral Temperatures and Comfort Range



Hermosillo's data - Linear regression for sensation and preference - Definition of NT and Comfort Range

Graph 4 corresponds to the whole real data showing sensation and preference votes as opposite tendencies, and also a high dependency between votes and temperatures. The greater the temperatures are, the greater the sensation votes are and the same comportment for preference but in the opposite direction. Regarding Neutral temperature, individuals felt neutral (comfort profile 0, 0) at 32.30°C (**Graph 4**). The comfort range defined by sensation is between 29.62°C and 34.98°C, placing 60.14% of people in comfortable conditions (between votes -1, 1). According to the definition of comfort range, Gomez-Azpeitia [18] mentioned that this scope can be extended by defining limits whit ± two standard deviation instead of one. This means that the extended range would be from 26.94°C to 37.66°C. In this thesis, we decided to maintain the first limit (one standard); nevertheless, the spreadsheet (explained in chapter VIII) is able to calculate these values by selecting the number of standard deviation. Therefore, after accomplishing the objective of this thesis, it could be possible to continue analyzing variables influence over thermal comfort perception and its relation with energy consumption.

This information provides a panorama of how thermal comfort might be perceived and how it can be evaluated; at this point, and with the value of the prior state to decide (explained in section VI.1), the next chapter explains the methodology to define an action tendency.

VI. Behavior

According to Ajzen [65], the behavior is a function of salient information concerning the cognitive self-regulation process in a particular context. According to Matsumoto [2], the motivation is a mental force that leads humans to act or make an effort in the pursuit of a goal. In this thesis, we considered the motivation as the initial point of the behavior process followed by a personal appraisal of the given circumstances based on past experiences and leading in the construction of an intention. The intention is a central element in the Theory of Planned Behavior [65]. It explains the intention as the capture of motivational factors that indicates how hard people are willing to perform. After this personal analysis, individuals may continue with the evaluation of the available opportunities to change concerning to the specific conditions provided by the building, and thus reinforce the intention. Moreover, the individual has to evaluate the impact of the values attached to the possible actions to finally decide to perform an action or not. These values are given by particular cultural practices, expectations or experience. Finally, this behavior might cause energy consumption throughout the interaction with the technological elements. See **Graph 8**.

The chances to behave must be assessed in relation to a particular behavior of interest, besides the specified context must be the same as that in which the behavior is to occurs [65]. In accordance to this understanding, the context evaluation has a major importance since this one does not only supply environmental conditions to define a thermal comfort state but also provides the features to the possible modifications in order to change this ultimate state. Consequently, the accurate the context analysis is, the more chances to envisage the actions will be found and this would result into real opportunities to adaptation. In the following sections will be described and measured each context features including behavioral adjustments and the evaluation of local environment conditions counting a variety of influences to finally calculate an action tendency. This approach is mainly based on the method proposed by Von Grabe [19] in his original research article *"How do occupants decide their interactions with the building? From qualitative data to a psychological framework of human-building-interaction".* This study is based on *a solid, empirically proven psychological framework (expectancy-value, specifically instrumentality-theory.* There have been made some adjustments to make it more suitable to the study case and include some extra concepts to reaffirm relation between thermal comfort perception and behavior.

The **Graph 8** describes all process, from the evaluation of comfort to the final point, energy consumption. In the following sections will be described the process which throughout the evaluation of individual experiences over the given situation (instrumentalities, expectancies and potentials), including the evaluation of the environmental possibilities (operational expectancies, operational potentials and forces) and the impact of the significances (cost secondary cost and potentials) will finally lead in the action tendency. The feature number in the **Graph 8** (for example eq. 1) corresponds to formulas and scales to calculate action tendency specified on **Table 19**.

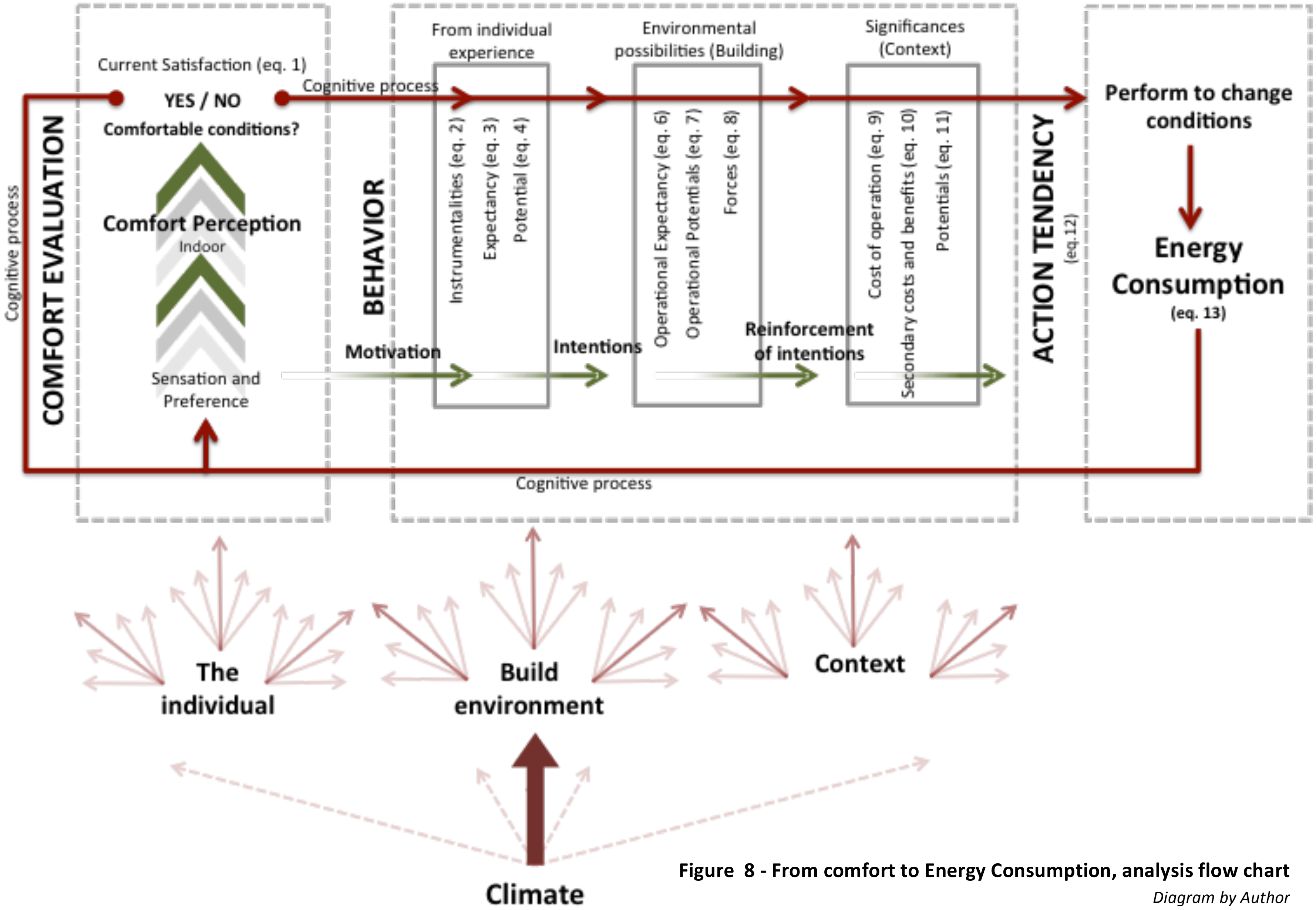


Figure 8 - From comfort to Energy Consumption, analysis flow chart
Diagram by Author

Table 19 – *Formulas and scales for action tendency*

	Feature and equation number	Formula	Scale
Previous state	1) Satisfaction	$Satisf$	0 to 3
Evaluation of adjustments	2) Instrumentalities	$I_{\Delta Env \rightarrow \Delta Satisf}$	-3 to 3
	3) Expectancy	$EX_{adj \rightarrow \Delta locEnv} = A_{locEnv \rightarrow \Delta locEnv} \times AD$	0 to 1
	a) Attitude for a change	$A = A_{locEnv \rightarrow \Delta locEnv}$	0 to 1
	b) Adjustments for adaptation	$AD = \left(\frac{a}{f_1} + \frac{pc}{f_2}\right)$	0 to 1
	4) Potential	$P_{locEnv} = \left(I_{\Delta Env \rightarrow \Delta Satisf}\right)\left(EX_{adj \rightarrow \Delta locEnv}\right)$	-3 to 3
Expectations to change	5) Expected maximal satisfaction	$Satisf_{MAx} = Satisf + P_{locEnv}$	0 to 3
Force to execute an operation	6) Operational Expectancy	$EX_{OP \rightarrow P_{locEnv}}$	0 to 1
	7) Operational Potential	$P_{OP} = EX_{OP \rightarrow P_{locEnv}} \times P_{locEnv}$	-3 to 3
	8) Forces	$F_{OP} = Satisf + P_{OP}$	0 to 3
Costs, secondary costs, and benefits of action	9) Cost of operation	$C_{OP} = C_{adm} + C_{uaf}$	0 to 3
	10) Secondary Costs and Benefits	$S_{AC} = \sum P_{OP}$	-3 to 3
	11) Operational Potential	$P_{OP} = EX_{OP \rightarrow P_{locEnv}} \times P_{locEnv}$	-1 to 1
	12) Action Tendency	$T_{AC} = F_{op} + C_{OP} + S_{AC}$	0 to 3

It has to be noted that we decided to use four decimals in all calculations since the scales are too small to see variations. The analysis that will be exposed in the following sections describes only summer season. Only in chapter VII will be included winter results since its impact is very low. Also, it has to be noticed that the main objective of this exercise is to define the energy consumption. And other strategies as changing clothing, opening and closing windows, among others have been included with the purpose of proving the effectiveness of the calculations.

VI.1. Prior state to decision

In order to calculate a tendency to perform a behavior; it is necessary, in the first place, to define self-perception of thermal environment. Thus, it is assumed that this condition, either positive or negative, provides a motivation to act or not. This condition is the starting point and it is called according to von Grabe [19] as the **prior state to decision**.

As explained in section V.1 the self-evaluation of the environment is determined by the sensation and the preference and is called thermal comfort perception expressed by the comfort profile. According to this value profile, we proposed to determine the value of the prior state to decision, which ultimately describes the satisfaction level ($Satisf$). This previous state can be understood and defined by the interaction of all variables involved in the four main groups that conform thermal perception. The values are given by climate characteristics as described in section III.1; building characteristics described in section III.2.3; social conditions as described in section III.2.2; and finally individual characteristics described in section III.2.1. **Figure 9** summarizes these general characteristics.

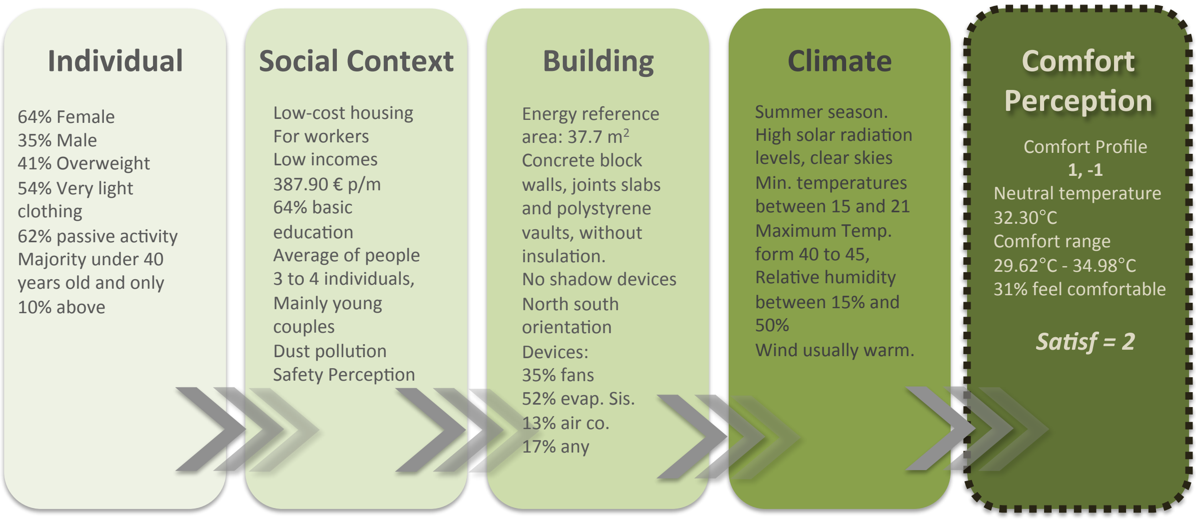


Figure 9 – Prior state to decision
Diagram by Author

The scale for the prior state to decision, that is described now by the satisfaction level, ($\boldsymbol{Staisf}$) goes from **0 to 3**, where three represents the highest level of satisfaction (**Table 20**). According to the value obtained in section V.1, which corresponds to 1, it will be necessary to invert the scale, since their values are opposite. Finally, according to data values, the uncomfortable condition corresponding to the current satisfaction level of the analyzed group is equal to two. $\boldsymbol{Staisf}$ **= 2.00.**

Table 20 - *Satisfaction level definition*

Element	Equation (1)	Description	Scale
Satisfaction	$Satisf$	Current satisfaction level, three is the higher satisfaction level.	0 to 3

VI.2. Behavioral adjustments

By searching optimal thermal conditions inside buildings, users might perform any available adjustment. So, these actions can offer the greatest opportunity for inhabitants to play an active role in the search of their own comfort. Ultimately, these actions might include the use of energy.

Behavioral adjustments are one of the three sub-groups crossing throughout the four main groups exposed in the final set of variables (see **Table 15**). This middle level contains all modifiable characteristics in the short-term that affect the system immediately and are performed only by behavior. Therefore, here is the location for human action and interaction with the environment. These modifiable characteristics are arranged according to two groups; one of them is personal adjustments such as clothing, activities and schedules, and it is referred to the available opportunities regarding individuals; and the other refers to technological adjustments related to all devices provided by building; these include windows blinds or curtains, and those that consume energy as fans, evaporative cooling system and air conditioning. In the following sections is explained what elements intervene and how to evaluate them.

VI.2.1. Evaluation of Adjustments

The evaluation of adjustments are given by three elements named by von Grabe [19] as *instrumentalities, expectancy and potential*.

VI.2.1.1. Instrumentalities $I_{\Delta Env \rightarrow \Delta Satisf}$

Through the cognitive process, the value of **instrumentality** (**Table 21**) involves the fact that the actor knows the environmental conditions that have to be changed in a given situation in order to reach desired thermal condition, including possible limitations given by the opportunities presented at the precise moment of decision. This value ideally exposes the user's intention to change the current uncomfortable conditions into comfortable ones. Thus, instrumentality is the opposite value of the $Satisf$ reflecting the intention to reach an ideal state equal to 0.00. Also, it has to be noticed that instrumentality values can be different to $Satisf$. This means that the change of environmental conditions is not at all instrumental (or at least not completely). According to this possibility, it might be necessary to consider other elements not included in this thesis. This opens an additional opportunity to improve this research in the future.

Table 21 - *Instrumentalities definition*

Element	Equation (2)	Description	Scale
Instrumentalities	$\boldsymbol{I_{\Delta Env \rightarrow \Delta Satisf}}$	Instrumentality of the change of current environmental conditions for the change of current satisfaction level. Zero means no change.	-3 to 3

Therefore, instrumentality value ($\boldsymbol{I}_{\Delta Env \rightarrow \Delta Satisf}$) is equal to -1.00 in order to change $Satisf$ to 0 by means of personal and/or technological adjustments. See **Table 29**.

VI.2.1.2. Expectancy over local environmental conditions $\boldsymbol{EX}_{adj \rightarrow \Delta locEnv}$

Later, regardless what it is desired, the particular given conditions may or may not help to achieve the desired satisfaction level. This appraisal is given by the individual expectancy (**Table 22**), which is defined as a mental set of beliefs about the immediate future that predisposes an individual to perceive and conceive environmental conditions and opportunities in particular ways [2]. Therefore, expectancy values describe in which degree the current opportunities change and lead to the achievement of change.

Table 22 - *Expectancy over local environmental conditions definition*

Element	Equation (3)	Description	Scale
Expectancy	$\boldsymbol{EX}_{adj \rightarrow \Delta locEnv} = \boldsymbol{A}_{locEnv \rightarrow \Delta locEnv} \times \boldsymbol{AD}$	To which degree available adjustments lead to the change of local environment conditions. One is the highest value	0 to 1

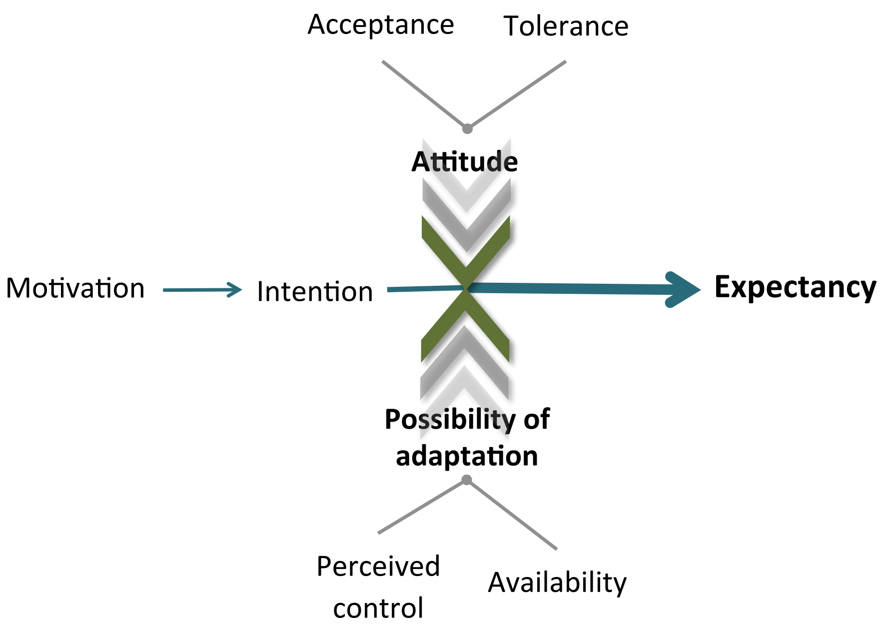


Figure 10 – Attitude and Possibility of adaptation to define Expectancy
Diagram by Author

Expectancy for the change of local environment conditions can vary due to many conditions, for instance, the type of building or type of activities, among many others. According to the Theory of Planned Behavior, Ajzen [65] mentions that the more favorable and greater the attitude concerning a behavior and the control perception are, the stronger should be an intention to perform the behavior under consideration. In this sense and according to the means and objectives of this thesis, we proposed an approach to evaluate Expectancy (Ex_{adj}) by appraisals of attitude (A) as a factor that is influencing the adjustment values (AD), where adjustments are composed by the perceived control (pc), and the availability (a).

In the next two sections the estimation for the **attitude** (A) and the **adjustment** (AD) values are explained.

VI.2.1.2.1. Attitude for a change $A_{locEnv\rightarrow\Delta locEnv}$

After understanding the **motivation** generated by comfort perception, the **intention** materializes. An intention is understood as a goal, a desire or impulse conceived as a conscious idea for a future state in order to fulfill those motivations [2, p. 260]. Yet, a mere motivation is not sufficient to declare an intention to act; it is necessary to include personal beliefs and evaluations describing the level of attitude for a change towards to the given situation. In this sense, attitude (**Table 23**) is defined as the degree to which a person has a subjective favorable or unfavorable evaluation based on experience and ongoing thoughts in a certain moment, influencing the appraisal by the strength of salient beliefs [2], [65], [66].

Table 23 - *Attitude for a change definition*

Element	Equation (3a)	Description	Scale
Attitude for a change	$\boldsymbol{A = A_{locEnv\rightarrow\Delta locEnv}}$	Attitude over the local environmental conditions to change current environmental conditions. One is the highest level.	0 to 1

In this case, we proposed to assess attitude according to two parameters: **tolerance** and **acceptance** of the current environment conditions. On the one hand, the subjective evaluation of a certain belief can be understood as tolerance. Tolerance means the capacity to endure differences from expectations with equanimity defining permissible deviations from "normality" [2, p. 547]. On the other hand, the strength of the salient belief is defined by the acceptance or acceptability that describes what is agreeable to the occupant or what he or she approves of [58]. The values of these two concepts are given by our field survey. The questions and the scale of judgment are expressed in **Table 24**.

Table 24 - *Attitude votes*

Vote	Acceptance	Tolerance
	How do you evaluate the environment inside your house?	How tolerable is the environment of your house in this moment?
1	Acceptable	Perfectly tolerable
2	Unacceptable	Tolerable
3		Lightly intolerable
4		Intolerable
5		Extremely intolerable

In this table are presented the attitude votes and questions regarding acceptance and tolerance; both parameters used in the field survey. Source [62]

The analysis procedure to define an attitude value is based on the same principles used with the definition of thermal comfort. In this case, attitude profiles are described in different levels of attitude by giving values to the distinct combinations of tolerance and acceptation. According to this: a combination of ten distinct profiles is obtained, see **Table 25**. In the best case, the code occurs (1, 1) when the environment is perfectly tolerable and acceptable. Therefore, the status is named as "favorable evaluation" and 0.00 is determined as the influencing value over behavioral tendencies (A), meaning null influence over behavior. The other extreme, that is the worst case, is the code (5, 2); where the appraisal is an "unfavorable evaluation" and 1.00 as attitude (A) numerical value. Between these two extreme evaluations are included a range of status from "slightly favorable", "moderately favorable" to "slightly unfavorable." Concerning tolerance and acceptation, this last one has the higher influence because even if there exists little tolerability, but the circumstance is accepted, then the situation might remain like it is. On the other hand, if there is an unacceptable condition, even if there exists some tolerance, the action has a higher probability to be performed. It has to be noticed that in the case of a code of (1, 1) meaning a favorable evaluation, the corresponding value of attitude (A) is zero, resulting in a product equal to 0 in the $\boldsymbol{EX_{adj \to \Delta locEnv}}$ equation. If this is the case, does it mean that actors do not implement any action or any expectative? Therefore, we identified the need of research concerning this aspect through field surveys and psychological evaluations in further studies.

Table 25 - *Attitude Profiles*

	Code		
(A)	**Tolerance**	**Acceptance**	**Status**
0.0000	1	1	Favorable evaluation
0.1111	2		Favorable evaluation
0.2222	3		Slightly favorable
0.3333	4		Slightly favorable
0.4444	5		Moderately favorable
0.5556	1	2	Moderately favorable
0.6667	2		Slightly unfavorable
0.7778	3		Slightly unfavorable
0.8889	4		Unfavorable evaluation
1.0000	5		Unfavorable evaluation

Proposed attitude profile

Finally, in **Figure 11** represents the attitude profile as a result of the collected data. On average, people consider the environment "Slightly favorable" within a tolerance evaluation equal to 3 (lightly intolerable) and yet acceptable rated with 1. Thus, according to the profile (3, 1) the corresponding value to the attitude for a change is 0. 2222.

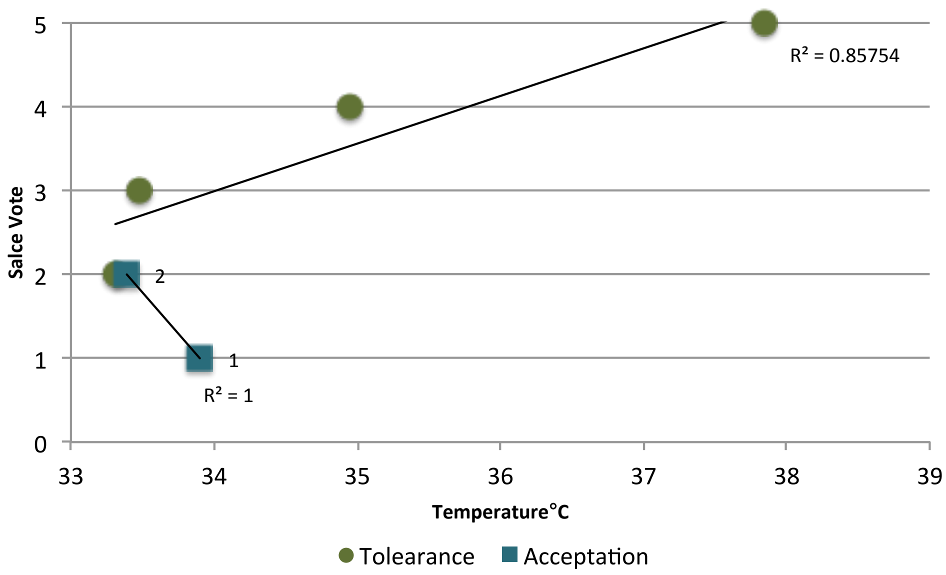
Tolerance	Acceptatance	
1		
2		
3	1	Slightly favorable
4		
5		
1		
2		
3	**2**	
4		
5		

Figure 11 - Final attitude profile

Image from the spreadsheet indicating the attitude profile for a change

Graph 5 corresponds to the whole real data showing a high dependency between answers and temperatures. Also, attitude and tolerance have opposite tendencies, and this result was not expected. Regarding tolerance the greater the temperature goes, the more intolerable the environment is considered. But regarding acceptance, 65.73% of the people find acceptable the given condition at 33.9°C (average). In contrast, the remaining 34.27% of the people consider the conditions unacceptable. This situation probably is due to the ambiguity of the questions. Also, it might be explained through the proximity of the temperatures. In other words, probably what matters here is only the answers and not the respective temperatures.

Graph 5 – Tolerance and Acceptation depending on temperatures



Values from all data

VI.2.1.2.2. Adjustments as a possibility of adaptation (AD)

Adaptation opportunities are contained in the sub-group of *behavioral adjustments* within the *personal, cultural, and technological adjustments* (see **Table 15**). These adjustments are the available possibilities to change current environmental conditions straightaway (**Table 26**). Thus, in order to evaluate these opportunities, it is necessary to consider the following two conditions.

Table 26 - *Adjustments for adaptation definition*

Element	Equation (3b)	Description	Scale
Adjustments for adaptation	$AD = \left(\frac{a}{f_1} + \frac{pc}{f_2}\right)$	Availability is the amount of existence of possible adjustments (features) Perceived control is capability to perform any adjustment	0 to 1

The first one is **availability** (a)**,** which refers to the existence of personal and technological adjustments. Availability is defined as the existence of features and devices such as windows, shades or HVAC and as the presence of personal adjustments (strategies) such as clothing or changing our activity. The reason to include this criterion is that, since the evaluation is concerning to a group of people who share similar characteristics; as it is a social condition, the proportion of availability of devices and strategies might influence the action tendency of the group. Availability values go from zero to one, meaning any existence or a full presence of personal and technological adjustments. For example, a hot day in an office where the dress code includes a suit, there is a possibility to change that condition by taking the suit coat off. Evidently, people are dressed most of the time, but this condition may change depending on the type of building or activity, as for instance in a sauna. Furthermore, in particular circumstances, some people could be dressed and some others not, like in a dressing room of a gym. In this sense, availability values could be less than one but more than 0. Regarding features and devices, availability means the proportions of its existence. Thus, availability is an objective answer representing the presence of any possible adjustment.

The second condition is the ***perceived control*** (pc). It can be interpreted as the confidence that an individual has over the capability to perform any adjustment. For instance, a weak perceived control could be when a person has relatively little information concerning unfamiliar elements that have entered into the situation. Another example is when only the maintenance department of an office building manages the control of environmental devices, and employees assume low or null ability to change those conditions. Also, this perceived control could be given via physical limitations, restrictions related to privacy, morality and so on. Hence, perceived control is a subjective evaluation regarding self-capability to change environmental conditions.

Moreover, the perceived control (pc), and the availability (a) are two values that complement each other in the assessment of adjustments (AD) with a total rate of 1. This value means that for example if one of them has a proportion of 0.7 $\left(\frac{pc}{0.7}\right)$, the other one must have a value of 0.3 $\left(\frac{a}{0.3}\right)$, and so on. Additionally, it was decided that if one adjustment were not available, consequently, the perception of control would be null. To define this proportion, the values must be related to a very particular contextual characteristic according to what it is evaluated. In the present analysis it has been decided to use a ratio of 0.5 (f_{21}) and 0.5 (f_1), since we did not found any reliable reference or suggestion to determine the weight of each counterpart. Thus, the proportion of perceived control (pc), and the availability (a) were considered as equal, since the evaluated object is a house and the availability of any adjustment and the user's capability over any adjustment is total.

In concordance to above and in relation to real data, values are presented in **Table 27**; regarding personal and technological adjustments selected from the behavioral adjustments (see **Table 15**).

Table 27 - *Adjustments Values*

Personal adjustments

Strategy	**Availability** $(\boldsymbol{a})$	**Perceived control** $(\boldsymbol{pc})$
Clothing	1.0000	1.0000
Activity	1.0000	1.0000
Schedules	1.0000	0.0390
Average	1.0000	0.6797

Technological adjustments

Device	**Availability** $(\boldsymbol{a})$	**Perceived control** $(\boldsymbol{pc})$
Windows	1.0000	1.0000
Curtains / blinds	1.0000	1.0000
Fans	0.3566	1.0000
Evaporative cooling	0.5245	1.0000
Air conditioning	0.1329	1.0000
Average	0.6690	1.0000

On the one hand, availability (a) values contained in the section of personal adjustments are esteemed with 1; since all of the surveyed people were dressed, performing an activity, and in some extend subject to schedules due to normal life activities, such as work. Here, schedules consideration is just an assumption trying to highlight external conditions that might influence the situation. On the other hand, technological adjustments values such as windows and curtains/blinds are defined only by supposing that all houses include these basic systems. Values regarding fans, evaporative cooling, and air conditioning are defined according to the factual existence determined by survey. The presence percentages of devices are also presented in **Graph 6**.

Concerning the real data of perceived control (pc), values in personal adjustments and technological adjustments are just assumptions and these are evaluated with 1. Since the type of building is a house, the opportunity to decide over these conditions could be perceived as total. Moreover, and as mentioned before in the description of data, all surveyed persons were healthy people without any particular condition that prevented them to decide over the adjustments. The only value rated differently was schedules, since it is supposed that individuals are involved in normal life activities where there is no possible modifications; the value was obtained in the data base of INEGI according to the percentage of people economically active or with some occupation [67]. The inverse of this number is represents the amount of people that could modify their schedules. To see values attend **Table 27**.

The set of questions and supposed answers were included and presented in section III.3, **Table 9**, and these will allow the assessment of the information in future projects. Regarding the spreadsheet, it has to be noticed that in case that when an adjustment is non-existent (zero availability), the value of the perceived control will be automatically registered as zero.

Equation 3 for personal adjustemnts

Expectancy over Personal Adjustments calculation:

$$EX_{adj^P} = 0.2222\times\left(\frac{1.000}{0.5}+\frac{0.6797}{0.5}\right) = 0.1866$$

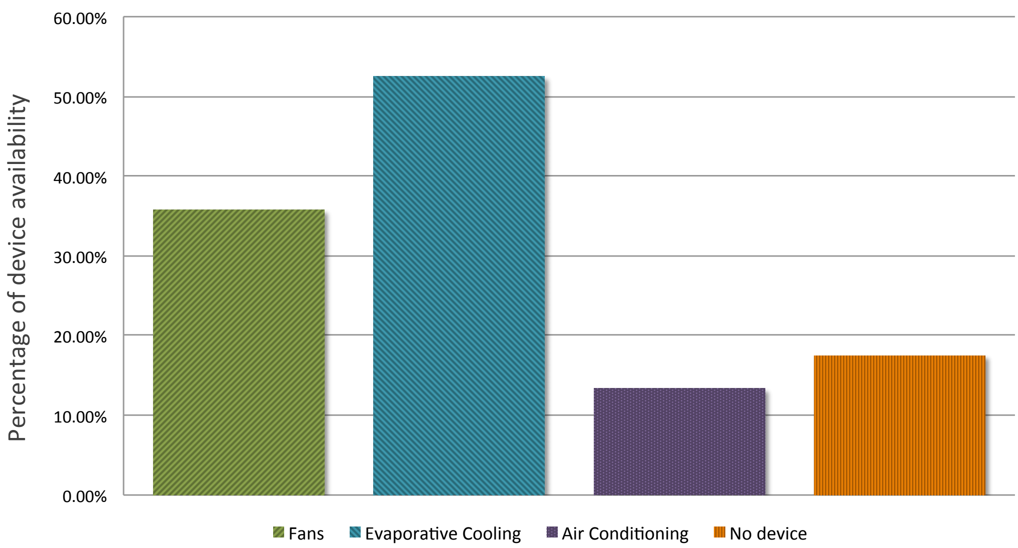
Equation 3 for technological adjustments

Expectancy over Technological Adjustments calculation:

$$EX_{adj^T} = 0.2222\times\left(\frac{0.6690}{0.5}+\frac{1.0000}{0.5}\right) = 0.1854$$

The value for expectancy concerning to personal adjustment is 0.1866 and technological adjustments is 0.1854. In both cases, according to the values of adjustments for adaptation, possibilities and beliefs are relative high (**Table 27**), although the value for attitude (**Table 23**, with a value of 0.2222) does not have great impact, since people considered their conditions "Slightly favorable."

Graph 6 - Availability of devices



Values from all data

VI.2.1.3. Potential over local environmental conditions - P_{locEnv}

According to von Grabe, the product of joining instrumentality ($\boldsymbol{I_{\Delta Env \to \Delta Satisf}}$) and expectancy ($\boldsymbol{EX_{adj \to \Delta locEnv}}$) would express potentials of the considered local environmental conditions to improve satisfaction. The scale of the local environmental potential goes from −3 to 3. See **Table 28**.

Table 28 - *Potential definition*

Element	Equation (4)	Description	Scale
Potential	$\boldsymbol{P_{locEnv}} = (\boldsymbol{I_{\Delta Env \to \Delta Satisf}})(\boldsymbol{EX_{adj \to \Delta locEnv}})$	Potential to improve satisfaction in the specific situation. Zero means no potential.	-3 to 3

Finally, in the **Table 29** is presented the values according to the evaluation of adjustments including the three elements analyzed (*instrumentalities, expectancy, and potential*) per each type of adjustment (personal or technological).

Table 29 - *Evaluation of Adjustments*

Personal adjustments		
Instrumentalities	**Expectancy**	**Potential**
$I_{\Delta Env \to \Delta Satisf}$	$EX_{adj \to \Delta locEnv} = A_{locEnv \to \Delta locEnv} \times AD$	$P_{locEnv} = (I_{\Delta Env \to \Delta Satisf})(EX_{adj \to \Delta locEnv})$
-2	0.1867	-0.3733
Technological adjustments		
Instrumentalities	**Expectancy**	**Potential**
$I_{\Delta Env \to \Delta Satisf}$	$EX_{adj \to \Delta locEnv} = A_{locEnv \to \Delta locEnv} \times AD$	$P_{locEnv} = (I_{\Delta Env \to \Delta Satisf})(EX_{adj \to \Delta locEnv})$
-2	0.1854	-0.3709

In addition, the above evaluation of the adjustments can lead to a general evaluation called by von Grabe as the *Expected Maximal Satisfaction* ($Satisf_{MAx}$) per each type of adjustment. This value means the maximal satisfaction that would be reached in a specific situation according to the specific resources available. This value is calculated by adding current satisfaction level ($Satisf$) and the local environmental potential (P_{locEnv}).

Table 30 - *Expected maximal satisfaction definition*

Element	Equation (5)	Description	Scale
Expected maximal satisfaction	$Satisf_{MAx} = Satisf + P_{locEnv}$	Maximal level of satisfaction expected from current conditions. Zero is the highest level	0 to 3

Values for personal and technological adjustments according to our data are $Satisf_{MAx} = 1.6267$ and $Satisf_{MAx} = 1.6291$ correspondingly, where personal adjustments have a slightly more satisfaction expectation as compared to technological adjustments. According to the evaluation, this group of people considers to have more influence over their personal adjustments, since they have a higher perceived control and availability. Nevertheless, according to the judgment of the analyzed group, any of these two adjustments would fulfill their expectations in order to reach a complete comfort state.

VI.2.2. Force to execute operation

After the evaluation of adjustments regarding the potential that an individual or a group possesses over the situation, it would be necessary at this moment to decide which of all available operations is the most efficient. This decision is evaluated by considering the *operational expectancy* (Eq. 6), *operational potentials* (Eq. 7) and finally *the forces* (Eq. 8).

VI.2.2.1. Operational expectancy $\boldsymbol{EX_{OP \to P_{locEnv}}}$

The first consideration is the operational expectancy $\left(\boldsymbol{E_{OP \to P_{locEnv}}}\right)$, and von Grabe defines it as the subjective expectancy on a particular operation leading to the possibility to change a current environmental condition (**Table 31**). Its values ranges go from 0 to 1, where 1 is the highest expectancy. This concept is related to the particular attributes of personal and technological adjustments. Therefore, decisions are chosen by the following considerations: one of them is about the available options provided by devices or personal adjustments, for instance, available features of windows such as the possibility to open it widely, partially vertically, or tilt it; the second one is about the current state of devices or personal adjustments, for example, the window is wide open, therefore, available opportunities are partially close it, completely close it or just as it is; and the third one, is concerning to the current environmental conditions such as indoor and outdoor temperature. Moreover, these considerations will change over time, the hour of the day or even season. According to the previews information, we proposed the following method to analyze operational expectancies.

Firstly, we included a set of possible operations for each group of adjustments. These operations are limited to a basic possibility, for instance turn-on or off some device, maintain or modify the activity or clothes, etc. Nevertheless, in a future research should be included a wider collection of possibilities based on field data to perform an accurate prediction in which would probably add more complexity.

Table 31 - *Operational expectancy definition*

Element	Formula (6)	Description	Scale
Operational Expectancy	$\boldsymbol{EX_{\mathrm{OP} \to P_{locEnv}}}$	The subjective expectancy over operation to the specific potential of local environment conditions. Zero is the highest value.	0 to 1

Regarding personal adjustments, there were added to each strategy two attributes or opportunities as available options to adjustment: maintain or change. For example, if a person feels uncomfortable with the thermal environment, she or he could decide to maintain or change its clothes to adapt to the existent conditions. In this sense, it is necessary to identify the current state of clothing, which can be represented by the average of answers regarding the level of clothes worn at the moment of the survey. The scales of clothes (**Table 5**), go from very light (1) to very sheltered (5). In this sense, the average value is equal to 1.4894 meaning that the interviewees dressed in very light clothes and light clothes. The following step was to define the operational expectancy. Therefore, we performed a basic calculation of proportions where the current condition (average of clothing) is divided by the corresponding number of scales (in this case, clothing presents five levels) obtaining a proportion for a possible modification. Regarding clothes, the obtained proportional value is 0.2979. Therefore, according to the low average level of clothes (1.4894); only a small fraction of possibilities is expressed in the operational expectancy to keep decreasing clothes, and conversely we see a higher opportunity to maintain the condition as it is (See **Table 32**). It has to be noticed that wearing fewer clothes during summer as an adaptation strategy is an assumption. The same procedures and considerations were made to define operational expectancy over activity and schedules. Operational expectancy values over personal adjustments are expressed in **Table 33**.

Table 32 - *Rating Operational Expectancy – example for clothing*

Level of clothes		Value	Opportunity
0	Naked	0.0000	Less opportunity to change regarding summer conditions
1	Very light	0.2000	
2	Light	0.4000	
3	Normal	0.6000	
4	Sheltered	0.8000	More opportunity to change regarding summer conditions
5	Very Sheltered	1.0000	

Table 33 – *Operational expectancies personal adjustments*

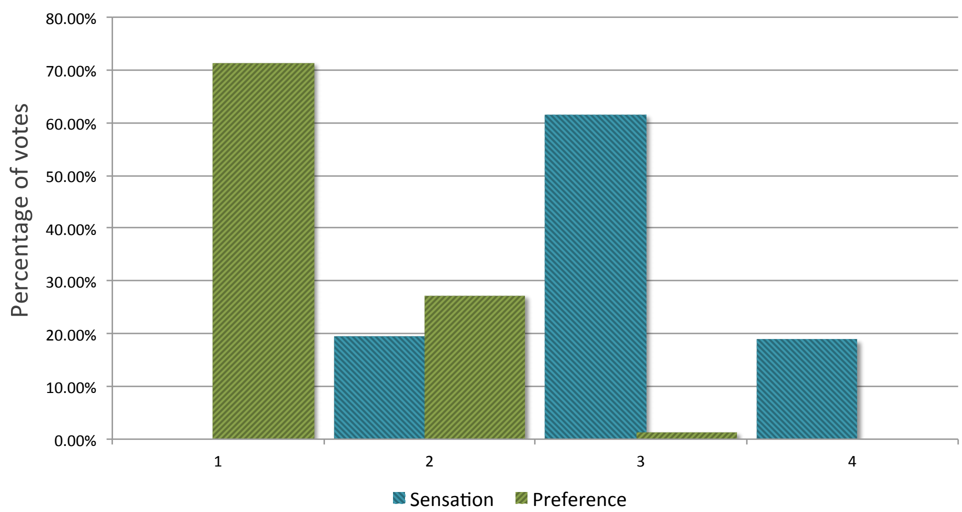
Strategy	Possibility	Current condition	Operational Expectancy $EX_{\mathrm{OP}\rightarrow P_{locEnv}}$
Clothing	Modify	1.4894	0.2979
	Maintain		0.7021
Activity	Modify	1.4406	0.4802
	Maintain		0.5198
Schedules	Modify	0.0000	0.0390
	Maintain		0.9610

Technological adjustment attributes for windows and blinds are either *open or closed*, and regarding fans, evaporative cooling system and air-conditioning attributes are *turn-on* or *off*. For these devices, the survey did not consider its current state. In this sense, we propose to evaluate operability defined by probabilities of use according to **environmental triggers**. Some of these values were selected from the literature review and some others from the field survey.

According to the paper, *A Stochastic Approach to Thermal Comfort—Occupant Behavior and Energy Use in Buildings* Nicol [14], surveys results regarding the use of controls in hot climate reveal some important tendencies. For instance, the indoor temperature when windows are opened was registered around 22°C. In this sense, current indoor temperature from our data was reported approximately 33.72°C average, more than 10°C above the trigger, this means that the probabilities to open a window (or remain opened) are high. Thus, it was given one as the weight of the possibility to "open." Also, Nicol indicates that the tendency for closing windows occurs when outdoor temperatures reach approximately 32°C. According to this data, the current outdoor temperature from our data was approximately 38.6°C average, more than 6°C above the trigger, this means that there also exists a probability of closing the window (or keep it closed) due to high temperatures. Consequently, there is a dual likelihood of opening or closing windows, since we did not find any explicit evidence that one environmental condition invalidates the other. In this sense, other variables gathered from the survey can be added as extra values to define a final operational expectancy. To see votes the references are in **Graph 7** and respective questions are seen on **Table 34**.

Information was collected in field surveys regarding the sensation and preference concerning ventilation, which provided parameters to evaluate expectancies over windows, fans and evaporative cooling system, since these devices comprise air velocity. Nevertheless, sensation value was excluded since it is just a description of what it is felt expressing direction and magnitude, but it does not express any motivation to modify the position of the window. Conversely, an insight of incentive could be ventilation preferences, which describes what would be ideal, so this has been chosen as the second trigger. According to the preference, the average value is 1.3007, meaning that people's preference is toward more ventilation (preference scale = 1).

Graph 7 - Ventilation and Sensation and Preference votes



Values from all data

Table 34- *Ventilation – sensation and preference*

Sensation		Preference	
How do you feel ventilation at this exact moment?		At this exact moment, how would you prefer to be?	
1	Too much ventilation	1	More ventilated
2	Moderate ventilation	2	No changes
3	Slightly ventilation	3	Less ventilated
4	No ventilation	-	-

For the purpose of this analysis, the ventilation preferences scale has been inverted, where 1 means preferring less ventilation and 3 more ventilation. Additionally, we attributed a weighting value to each scale and added the 0 as the option of "any ventilation" See **Table 35**. According to this, ventilation preference average in our data is about 2.6993 meaning a weighting of .8998 very near to the option of "open."

Table 35 - *Calculation of Operational Expectancy – example for windows*

Ventilation Preference		Weight	Opportunity
0	No ventilation	0.0000	Closed
1	Prefer less	0.3334	
2	No change	0.6667	
3	Prefer more	1.0000	Open

The option "open" has two values: 1.0000 obtained from **temperature trigger** plus 0.8998 obtained from **ventilation preference**. Nevertheless, the operational expectancy scale ranges from 0 to 1, where 1 is the higher value. Since there is no evidence of which characteristic could be stronger, it was decided to give equal influence to both parameters. It is possible to change this weighting in the spreadsheet, which leaves an open door to continue analyzing data in the future. Hence, total operational expectancy over the option "open" is .9499 meaning a high operational expectancy.

Regarding the "closed" option, the analysis procedure was the same, with the only difference that the amount concerning ventilation preference the amount will be one minus the "open" probability, resulting in a weight of 0.1002. Therefore, the expectancy to close the window (or maintaining it closed) is 0.5501. Calculations for the operational expectancy concerning the rest of the technological adjustments were done in the same way, to see results attend **Table 36**.

Table 36 - *Operational expectancies - Technological adjustments*

Device	Possibility	Trigger	Source	Current Condition	Ventilation Preference	Humidity Sensation	Op. Expectancy $EX_{\mathrm{OP} \rightarrow P_{locEnv}}$
Windows	Open	Indoor 22°C	[14]	33.72 °C Indoor	2.6993	-	0.9499
	Close	Outdoor 32°C		38.60°C Outdoor		-	0.5501
Curtains and Blinds	Open	No impact, small effect	[14]	-	-	-	0.1000
	Close			-	-	-	
Fans	Turn on	Outdoor Above 30°C	[14]	38.60 °C Outdoor	2.6993	-	0.9499
	Turn off	Outdoor Below 15°C				-	0.0501
Evaporative Cooling	Turn on	No data found	-	-	2.6993	4.9720	0.8050
	Turn off	No data found	-	-	-	-	0.1950
Air Conditioning	Turn on	Starts at 25°C	[14]	38.60 °C Outdoor	-	-	1.0000
	Turn off				-	-	0.0000

Calculations for the operational expectancy concerning to the rest of the technological adjustments are the same.

Regarding to curtains/blinds, these adjustments are more likely to be used in hotter climates and are commonly used to control glare from windows. They do have a small impact on indoor temperatures; yet, the control of luminance is probably a better explanatory variable for the use of blinds [14]. Based on this supposition, this adjustment was assigned a random value of 0.1000.

Concerning fans, their use has an important influence on the comfort of occupants since air movement improves the effect of the convective heat transfer. According to Nicol [14], the effect of higher air movement is equivalent to a temperature decrease and sensation goes up to 4°C. Moreover, in outdoor temperatures above 30°C the use of fans is almost universal; below 15°C, it is almost nonexistent. In this sense, the analysis is the same as the one made with windows including values for ventilation preference, only that in this case, all temperatures references come from the outdoor.

Concerning the evaporative cooling system we did not find evidence of its usage. Nevertheless, ventilation preferences and humidity sensation were used as parameters to define its operational expectancy.

Finally, according to Nicols, the use of air conditioning system, if it exists, starts at an outdoor temperature of 25°C as minimum and apparently no other variables intervene.

VI.2.2.2. Operational potentials (P_{OP})

According to von Grabe's definition, operational potential (P_{OP}) refers to the subjective expectancy over the operation of certain adjustments $(E_{OP \to P_{locEnv}})$ multiplied with the potential to improve satisfaction in the specific situation (P_{locEnv}). The scale goes from -3 to 3; -3 and 3 are the highest limits for potential and zero means no potential (see **Table 37**). To see the values corresponding our survey data see **Table 39**.

Table 37 - *Potential definition*

Element	Equation (7)	Description	Scale
Operational Potential	$\boldsymbol{P_{OP} = E_{OP \to P_{locEnv}} \times P_{locEnv}}$	Potential of an operation to achieve desired satisfaction.	-3 to 3

VI.2.2.3. Forces – (F_{OP})

Having evaluated the required opportunities and resources to perform the behavior, the inhabitants are closer to success in doing so [65]. According to von Grabe, forces indicate the stimulus to execute a specific operation considering all aspects of the evaluation of the adjustments as well as satisfaction and operational potential. In this sense, we propose to understand forces as the reinforcement of the initial motivation by the provision and evaluation of the means (**Table 38**). The scale rates go from 0 to 3; where zero represents the highest value. This value is calculated by adding current satisfaction $(Satisf)$ and the operational potential (P_{OP})

Table 38 - *Forces definition*

Element	Equation (8)	Description	Scale
Forces	$\boldsymbol{F_{OP} = Satisf + P_{OP}}$	Reinforcement of motivations. Zero is the highest value.	0 to 3

Values regarding to forces to execute an operation are expressed in **Table 39**. These values represent the reinforcement of motivation to use an adjustment involving the expectancy and the potential to change environmental current conditions. In this sense, the higher force is related to air conditioning, since its expectancy over its operation has the higher value.

Table 39 - *Force to execute operation*

Personal adjustments		Potential P_{locEnv} -3 to 3 0 means no potential	Operational Expectancy $EX_{OP \rightarrow P_{locEnv}}$ 0 to 1 1 is the highest expectancy	Operational potentials $P_{OP} = EX_{OP \rightarrow P_{locEnv}} \times P_{locEnv}$ -3 to 3 0 means no potential	Forces $F_{OP} = Satisf + P_{OP}$ 0 to 3 0 highest valence
Clothing	Modifying	-0.3733	0.2979	-0.1112	1.8888
	Maintaining	-0.3733	0.7021	-0.2621	1.7379
Activities	Modifying	-0.3733	0.4802	-0.1793	1.8207
	Maintaining	-0.3733	0.5198	-0.1941	1.8059
Schedules	Modifying	-0.3733	0.0400	-0.0149	1.9851
	Maintaining	-0.3733	0.9600	-0.3584	1.6416
Technological adjustments		**Potential** P_{locEnv} -3 to 3 0 means no potential	**Operational Expectancy** $EX_{OP \rightarrow P_{locEnv}}$ 0 to 1 1 is the highest expectancy	**Operational potentials** $P_{OP} = EX_{OP \rightarrow P_{locEnv}} \times P_{locEnv}$ -3 to 3 0 means no potential	**Forces** $F_{OP} = Satisf + P_{OP}$ 0 to 3 0 highest valence
Windows	Open	-0.3709	0.9499	-0.3523	1.6477
	Close	-0.3709	0.5501	-0.2040	1.7960
Curtains/ blinds	Open	-0.3709	0.1000	-0.0371	1.9629
	Close	-0.3709	0.1000	-0.0371	1.9629
Fans	On	-0.3709	0.9499	-0.3523	1.6477
	Off	-0.3709	0.0501	-0.0186	1.9814
Evaporative Cooling	On	-0.3709	0.8050	-0.2986	1.7014
	Off	-0.3709	0.1950	-0.0723	1.9277
Air conditioning	On	-0.3709	1.0000	-0.3709	1.6291
	Off	-0.3709	0.0000	0.0000	2.0000

VI.2.3. Costs, secondary costs, and benefits of action

Ajzen [65] associates normative beliefs or subjective norms with the likelihood of performing a behavior by approving or disapproving actions. According to von Grabe [19], these extra elements would influence individuals to select a specific operation by the significance attached to actions. Some of these additional considerations can be related to economic limitations, subjective rules, preference of use, and many other aspects influencing behavior besides the available adjustments by themselves. In the following paragraphs it is described how to approach to these influencing values, based mainly on von Grabe's methodology and some extra considerations.

It has to be noticed, that variables values regarding the followings sections, from the designation of costs and benefits to the data values, have been defined mainly by assumptions and based on available information from literature review, limiting the variety of effects and results. These limitations affect the outcome due to lack of information and the evaluation might be unequal affecting scale parameters, resulting in values that may be out of reality. Therefore, the influences over final results can be considered putting at risk the veracity of the information. Anyway, we tried to balance the values and to stay attached to literature information to affect as less as possible the final results. This is another opportunity to improve this research by collecting field data and generating values according to the specific context characteristics.

VI.2.3.1. Costs of operation - (C_{OP})

According to von Grabe this operation can include several types of costs and he exemplified them by proposing 3 types: one, the admissibility of the operation; two, the operability of the element in question; and three, the degree to which the current task implementation can be interrupted. However, the definitions of costs are related exclusively to the analyzed context characteristics that might be determined during the field research. In this sense, and under the corresponding assumptions, we decide to eliminate type two and three and propose one more. Thus, cost analysis was regarding the cost by the admissibility of operation, and two, the cost by unaffordable strategies. The scale to evaluate cost is from 0 to 1, where zero represents any costs, and 1 represents the highest cost (**Table 40**).

Table 40 - *Cost of operation definition*

Element	Equation (9)	Description	Scale
Cost of operation	$\boldsymbol{C_{OP} = C_{adm} + C_{uaf}}$	Significance attached to actions. Zero means no cost.	0 to 1

The first proposed cost refers to the admissibility of the operation (C_{amd}) in the given context. Since the analyzed object is a house, it is assumed that available personal adjustments are entirely admissible. Besides, some influence from subjective aspects as morality or privacy might occur, however, these data were not collected in the survey and no literature source was found to justify assumptions. So, it was decided to assign a zero as a value for personal adjustments (see **Table 44**). We hope to analyze this information in the future to add more reliability to findings.

Regarding technological adjustments, we assumed a complete admissibility related to those devices that consume energy. Mexico's energy system supports various sectors of the economy by energy subsidies. The Federal Energy Commission, (in Spanish: *Comisión Federal de Electricidad*, CFE) is a state enterprise and virtually the only one participating in the electricity supply market. The state fills the gap between 50% and 90% of the actual cost with financial backing depending on the zone and consumption level. According to CFE, subsidies classification is defined based on consumption levels divided into five main categories: industrial, farming, services, commercial and residential. Additionally, the residential category has subdivisions, which are established due to climate characteristics (Table 41). Thus, subsidies for housing in Hermosillo city corresponds to 1F level. Hence, this subsidy considers two main tariffs depending on season; one for summer, from May to

October and another for winter, from November to April (see **Table 42**). Field surveys were also performed during the period from August to September, within the summer tariff. We assumed that in this season people felt allowed to use electrical devices, giving zero as a value, meaning zero cost of operations.

Table 41 - *Residential subsidies in Mexico*

Subside Name	Characteristic
1	Basic
1A	Average minimum summer temperature up to 25° C
1B	Average minimum summer temperature up to 28° C
1C	Average minimum summer temperature up to 30° C
1D	Average minimum summer temperature up to 31° C
1E	Average minimum summer temperature up to 32° C
1F	Average minimum summer temperature up to 33° C
High consume	Residential high consume.

Source: [68]

Table 42 – *CFE Tariffs per season*

Regular Tariff - CFE From November to April	Price	Summer Tariff - CFE From May to October	Price
Basic consumption	0.0383 €	Basic consumption	0.0287 €
For each of the first 75 kWh		For each of the first 300 kWh	
Intermediate consumption	0.0462 €	Intermediate-low consumption	0.0358 €
For each of the following 125 kWh		For each of the following 900 kWh	
Exceeded consumption	0.1354 €	Intermediate-high consumption	0.0871 €
For each additional kWh to the previous ones		For each of the following 1300 kWh	
		Exceeded consumption	0.1381 €

Tariffs per kWh consumed according to season Source: Tariff expressed in euros in accordance with the exchange rate, August 2017. Source: [68]

The second cost is the unaffordable strategy ($\boldsymbol{C_{uaf}}$), since prices and income might influence energy demand. The high cost of energy compared to the low income can causes social and economic problems for inhabitants, as deficiencies in the functioning of the dwellings associated with thermal comfort [11].

Energy consumption per person in Sonora state is quite high, 3,866 kWh per person compared to the national average around 1,732.7 kWh per person [69]. According to The National Household Income and Expenditure Survey, (in Spanish: *Encuesta Nacional de Ingresos y Gastos de los Hogares*, ENIGH) household from low economical level (3-4 VSMM, see section 0) spent around 9.5% of its incomes concerning fuels; moreover, those households with air conditioning, 70% of their invoice electricity cost corresponds to its use [70].

Accordingly, we proposed the cost of energy as a limitation to use any electrical device to reach the desired comfort level. Unfortunately, we did not find any evidence from field survey nor suitable data from the literature regarding this restrictive parameter. Therefore, values are mere suppositions based on the factual existence of devices. The assumption process was first, to identify the current percentage of availability of each device, and then, we used the opposite value as the percentage of people who cannot afford the device itself or the cost related to its use. Values were adjusted to a scale from 0 to 1. See **Table 43**. As expected, air conditioning is the device that would be less used for its high cost of acquisition and operation.

Table 43- *Unaffordable strategy – estimation*

Device	Current Availability	Cost of operation (C_{uaf})
Fans	35.66%	0.6433
Evaporative cooling	52.45%	0.4756
Air conditioning	13.29%	0.8671

Finally, to calculate the total costs of operations (C_{op}), costs by admissibility (C_{adm}) and cost by affordance (C_{uaf}) are summed. To see results attend **Table 44**.

Table 44 - *Total cost of operation*

Technological adjustments		Admissibility of the operation C_{adm}	Unaffordable strategy C_{uaf}	Total cost of operation $C_{OP} = C_{adm} + C_{uaf}$
		0 to 1 0 means no cost	0 to 1 0 means no cost	0 to 1 0 means no cost
Fans	Turn-on	0.0000	0.6433	0.6433
	Turn-off	0.0000	0.0000	0.0000
Evaporative Cooling	Turn-on	0.0000	0.4756	0.4756
	Turn-off	0.0000	0.0000	0.0000
Air conditioning	Turn-on	0.0000	0.8671	0.8671
	Turn-off	0.0000	0.0000	0.0000

VI.2.3.2. Secondary costs and benefits - (S_{ac})

Table 45 - *Secondary Costs and Benefits definition*

Element	Equation (10)	Description	Scale
Secondary Costs and Benefits	$S_{AC} = \sum P_{OP}$	Total secondary effects of action. Positive numbers are costs and negatives are benefits.	-3 to 3

Secondary costs and benefits are identified as the probable consequences of a specific action, taking into consideration the satisfaction of other needs different from thermal comfort (**Table 45**). The consideration starts from a particular adjustment, for instance, to open the windows. Under the given the specific contextual characteristics and the individual's past experiences over the situation, inhabitants would anticipate the local environment change not related to thermal comfort, resulting from the action. When the windows are opened, this action would allow dust from outside to the inside, which might be an undesired effect that could affect indoors quality air. Thus, the consequence would be assumed as a cost (positive number). Conversely, opening windows would let in fresh air from the outdoor, replacing the existent air and improving its quality. Therefore, the consequence will be a benefit (negative number). To evaluate the available possibilities, it was necessary to assign a value that reflects the belief to which degree the current condition can be changed (Eq. 2, $\boldsymbol{I}_{\Delta Env \rightarrow \Delta Satisf}$). Additionally, the expectancy to change current environmental conditions (Eq. 3, $\boldsymbol{E}_{\mathbf{OP} \rightarrow P_{locEnv}}$) is multiplied for the potential to improve satisfaction (Eq. 4, $\boldsymbol{P}_{locEnv}$) to obtain the operational potentials (Eq7 ($\boldsymbol{P}_{OP}$). Finally, the total of secondary effects of actions (Eq. 10 $\boldsymbol{S}_{AC}$) are determined by summing up all the operational potentials for each expected change. To see results from data attend **Table 47**.

No secondary costs and benefits were considered regarding personal adjustments.

Concerning technological adjustment, **Table 47** presents the analysis for the secondary costs and benefits indicating the modified conditions. In order to define an insight of what terms would be affected by the envisaged adjustment, we searched reliable information from the literature review and data. For example, dust pollution levels in the city [48], [71] and according to security perceptions [72] might affect or benefit the usage of windows. Respective values are also acquired from the information source and adapted to the corresponding scale of judgment.

The report, *Environmental Pollution in Hermosillo II* (in Spanish: *Contaminación Ambiental en Hermosillo II*) presented by the Commission for Environmental Cooperation (in Spanish: *Comisión para la Cooperación Ambienta*l, CCA) [71], shows pollution levels according to AQI (Air Index Quality) offered by the Environmental Protection Agency (EPA) from The United States. This AQI index describes air quality regarding health effects due to pollution exposure. Index scale ranges from AQI 0-50, meaning good air quality conditions to AQI 301-500 meaning hazardous. Index scale ranges from AQI 0-50, meaning good air quality conditions to AQI 301-500 meaning hazardous. To see complete scale range attend **Table 46**.

According to the resume of values shown in the environmental pollution report, **Table 46** describes the percentage of days within the analyzed period, including each corresponding level of AQI. Therefore, 86.37% of the time, air quality conditions are good, and 12.21% of the time it is tolerable, and only less than one percent of the time it is unhealthy. To provide a value to each class, the percentage value was inverted by the assumption that the opposite value can represent the occurrence of certain condition. For example, the corresponding percentage of days with a level AQI 0-50 of air quality is 86.37%, this means that this condition was 86.37% of the time during the monitoring analysis. Thus, this number was subtracted, representing the occurrence from the unit to obtain a final value (1 - 0.8637 = 0.1363). The result was 0.1363, representing the dust potential to change current conditions. According to **Table 46**, the potential selected was regarding to the highest percentage of occurrence, this means that most of the time, air quality conditions are good and the environment potential to change air conditions to a bad conditions is low, with 0.1363 as potential.

Table 46 - *Air Quality Index - Resume of values*

Air Quality	Air quality conditions	Percentage of days	Potential to change conditions
AQI 0-50	Good	86.37%	0.1363
AQI 51-100	Moderate	12.21%	0.8779
AQI 101-150	Unhealthy fir Sensitive Groups	1.24%	0.9876
AQI 151-200	Unhealthy	0.18%	0.9982
AQI 201-300	Very Unhealthy	0.00%	1.0000
Above AQI 300	Hazardous	0.00%	1.0000

Therefore, regarding windows: if the windows were open; it would affect the indoor air quality by the outside dust. Moreover, current satisfaction level is zero because, before opening the window, the indoor space was clean from any damaging pollution from dust. In this sense and according to values from the literature review, the potential assigned was 0.1363 based on pollution levels in the city [71]. Also, the operational expectancy was assigned with one; this means that if the windows were completely open, it would certainly affect conditions due to the air movement between indoor and outdoor environment. Finally, the **operational potential** is the resulting number from a multiplication between **potential** and **expectancy values**.

Regarding security cost and benefits affecting the use of windows, values were obtained according to the National Survey of Public Urban Security (in Spanish: *Encuesta Nacional de Seguridad Pública Urbana*, ENSPU) [72]. The value for potential was determined according to the incidence rate of robbery in households, and value for operational expectancy was defined according to the security perception of households regarding their homes. These values were converted to percentages and adapted to a scale from 0 to 1. To see values, attend **Table 47**.

Concerning technical adjustments, we took into consideration values for fans and for the evaporative cooling system based on preference ventilation data, which indicates that the group of people analyzed prefers more ventilation. Thus, this can add extra costs and benefits to the use of these devices. Also, we considered the humidity sensation to extra costs and benefits regarding the evaporative cooling system.

Table 47 - *Secondary costs and benefits*

Technological adjustments		Condition modified	Source	Current satisfaction $Satisf$ 0 to 1 0 highest level	Potential $\boldsymbol{P_{locEnv}}$ -1 to 1 0 no potential	Operational Expectancy $EX_{OP\rightarrow P_{locEnv}}$ 0 to 1 0 no expectancy	Operational potentials $P_{OP} = EX_{OP\rightarrow P_{locEnv}} \times P_{locEnv}$ -1 to 1 - = Benefits + = Cost
Window	Open	1. Dust pollution	[48] [71]	0	0.1362	1	0.1362
		2. Security perceptions	[72]	0	0.3566	0.2700	0.0962
						$\boldsymbol{SAC}$	**0.2325**
Curtains/Blinds	Close	1. Privacy	[73]	0	-0.2000	1	-0.2000
						$\boldsymbol{SAC}$	**-0.2000**
Fans	Turn-on	1. Air velocity	Data	0.8	-1.0000	1	-1
						$\boldsymbol{SAC}$	**-1.0000**
Evaporative Cooling	Turn-on	1. Air velocity	Data	0.8000	-1.0000	1.0000	-1.0000
		2. Humidity	Data	0.5000	-0.5000	0.3000	-0.1500
						$\boldsymbol{SAC}$	**-1.1500**

According to predictions, SAC value, in reference to opening windows is 0.2325 meaning a cost. In other words, the consideration of these consequences would reduce the probability to action tendency of opening a window. Contrasting, SAC value for closing blinds or curtains is -0.2000, this means that it might be about privacy needs that curtains or blinds are used. Regarding fans, the opportunity to change ventilation conditions by turning-on the fans and the evaporative cooling system represents a benefit with a value of -1.0000 and additionally humidity for the evaporative cooling system with -0.1500 as benefit value.

VI.3. Action tendency – $(\boldsymbol{T_{AC}})$

Table 48 - *Action tendency definition*

Element	Equation (12)	Description	Scale
Action Tendency	$\boldsymbol{T_{AC} = F_{op} + C_{OP} + S_{AC}}$	Probability to perform an action. Zero is the highest value to perform an action.	0 to 3

The action tendency (Eq. 12, $\boldsymbol{T_{AC}}$) is the prediction towards which adjustment people could select. This tendency is calculated based on the addition of forces (Eq. 8, $\boldsymbol{F_{OP}}$); operation attached costs (Eq. 9, C_{OP}); and the secondary costs and benefits of the action (Eq. 10, $\boldsymbol{S_{AC}}$) (**Table 48**). The scale for this tendency goes from 0 to 3; the **closer the value to 0.00 is, the higher the tendency to perform an action goes.** Results of the action tendency are expressed in **Table 49**.

Table 49 - *Action Tendency (Eq. 12)*

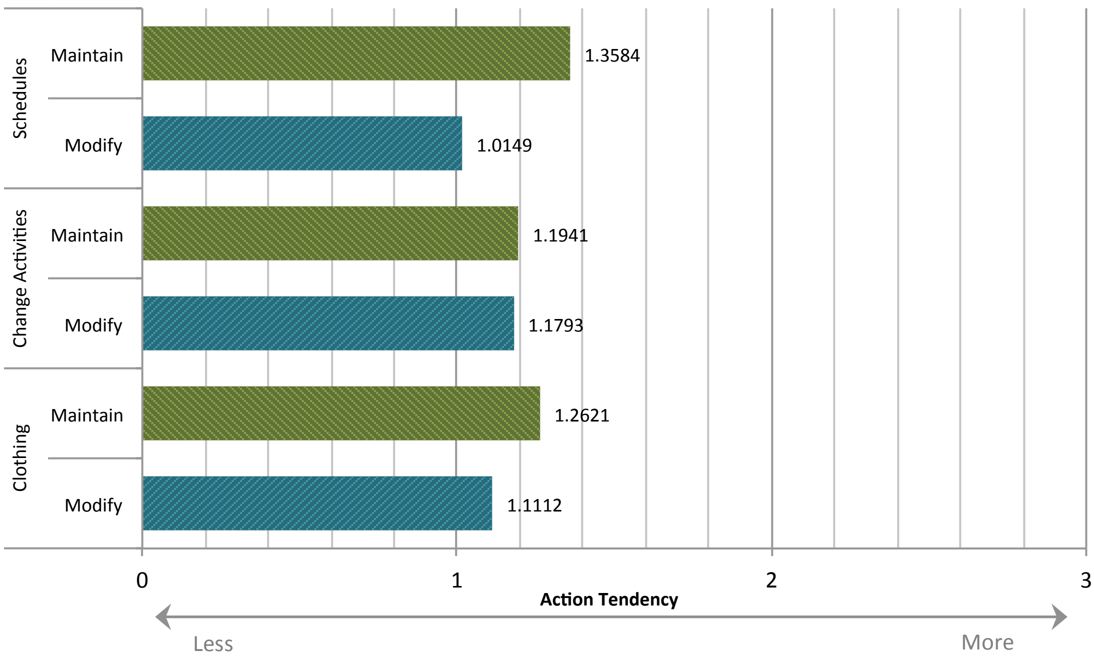
Personal Adjustments		**Forces** $F_{OP} = Satisf + P_{OP}$ 0 to 3 0 highest valence	**Cost of Operation** $C_{OP} = C_{adm} + C_{uaf}$ 0 to 3 0 no cost	**Secondary cost of operation** $S_{AC} = \sum P_{OP}$ -1 to 1 - = Benefits + = Cost	**Action tendency** $T_{AC} = F_{op} + C_{OP} + S_{AC}$ 0 to 3 0 higher tendency to perform
Clothing	Modify	1.8888	0.0000	0.0000	1.8888
	Maintain	1.7379	0.0000	0.0000	1.7379
Change Activities	Modify	1.8207	0.0000	0.0000	1.8207
	Maintain	1.8059	0.0000	0.0000	1.8059
Schedules	Modify	1.9851	0.0000	0.0000	1.9851
	Maintain	1.6416	0.0000	0.0000	1.6416
Technological Adjustments		**Forces** $F_{OP} = Satisf + P_{OP}$ 0 to 3 0 highest valence	**Cost of Operation** $C_{OP} = C_{adm} + C_{uaf}$ 0 to 3 0 no cost	**Secondary cost of operation** $S_{AC} = \sum P_{OP}$ -1 to 1 - = Benefits + = Cost	**Action tendency** $T_{AC} = F_{op} + C_{OP} + S_{AC}$ 0 to 3 0 higher tendency to perform
Windows	Open	1.6477	0.0000	0.2326	1.8803
	Closed	1.7960	0.0000	0.0000	1.7960
Curtains/Blinds	Open	1.9629	0.0000	0.0000	1.9629
	Closed	1.9629	0.0000	-0.2000	1.7629
Fans	Turn-on	1.6477	0.6433	-1.0000	1.2910
	Turn-off	1.9814	0.0000	0.0000	1.9814
Evaporative Cooling	Turn-on	1.7014	0.4756	-1.1500	1.0270
	Turn-off	1.9277	0.0000	0.0000	1.9277
Air conditioning	Turn-on	1.6291	0.8671	-0.6000	1.8962
	Turn-off	2.0000	0.0000	0.0000	2.0000

According to the values for action tendency presented in **Table 49**, the highest possibility regarding the clothing level is to maintain this as it is with a value $\boldsymbol{T_{AC}} = 1.7379$; the chance to modify the activity level is less than maintaining it with a value of $\boldsymbol{T_{AC}} = 1.8059$, and finally, schedules also have a higher tendency to remain as they are $\boldsymbol{T_{AC}} = 1.6416$. In the **Graph 8** is exposed each adjustment with its respective values.

Regarding technological adjustments, the highest tendency is to use the evaporative cooling system $\boldsymbol{T_{AC}} = 1.0270$, followed by the use of fans $\boldsymbol{T_{AC}} = 1.2910$, and, only after closing windows and curtains, it is the action tendency to use air conditioning system with a value of $\boldsymbol{T_{AC}} = 1.8962$.

To continue with consumption estimations, the scale of action tendency (T_{AC}) was inverted. Therefore, zero represents null action and three represents the highest action tendency. **Graph 8** (personal adjustments) and **Graph 9** (technological adjustments) show each adjustment with its respective inverted values.

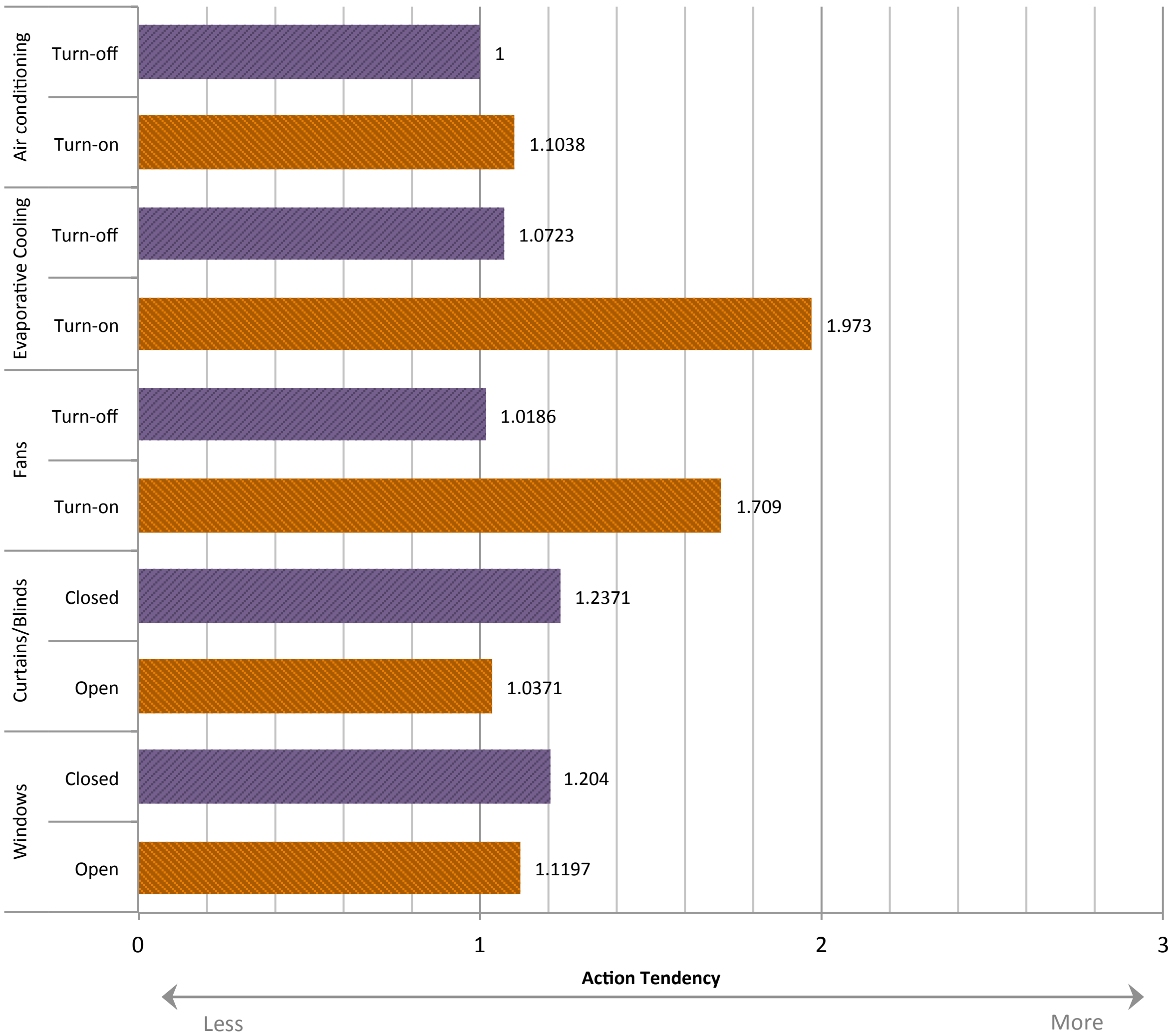
Graph 8 - Action tendency per Personal Adjustment



Values from all data

Since the objective of this thesis is the estimation of the user's influence on energy consumption, we will not take these personal adjustment values beyond this point.

Graph 9 – Action Tendency per Technological Adjustment



Values from all data

From this point, and according to the third specific objective of this thesis, we will use only electrical devices; therefore, curtains and windows are now excluded.

VII. Energy consumption

At this point, it has been analyzed the structure that describes how variables from several dimensions influence inhabitant's decisions regarding thermal comfort based on its perception to influence then energy consumption.

The final energy use is an important parameter to explain and understand the energy consumption patterns and how they are used as a key to strategic planning for future energy consumption leading to efficiency improvements [74]. In this section, and after obtaining values for an action tendency per each electrical device, we will explain the calculation of energy consumption.

To calculate energy ($\boldsymbol{E}$) values it is necessary to include some characteristics as the device power ($\boldsymbol{P}$), the amount of time that certain device will be used ($\boldsymbol{t}$), number of devices ($\boldsymbol{d}$), the total number of square meters of the housing prototype ($\boldsymbol{A}$) and the action tendency factor ($\boldsymbol{Fact}$).

Equation 13

$$\boldsymbol{E} = \frac{\boldsymbol{P} \cdot (\boldsymbol{t} \cdot \boldsymbol{Fact}) \cdot \boldsymbol{d}}{\boldsymbol{A}}$$

To obtain the tendency factor ($\boldsymbol{Fact}$), the scale of action tendency ($\boldsymbol{T_{AC}}$) was inverted, thus zero represents the null action and three the highest tendency to perform an action (as explained in the section above, VI.3). Finally, each value was divided by three, obtaining a factor between zero and 1, in which 1 means the highest value for the factor of an action tendency ($\boldsymbol{Fact}$).

To describe the process of calculating energy consumption, we used fans as an example. Firstly, it was necessary to define the amount of time of usage to determine how many hours the fans could function during the year. To this, it was considered the total amount of hours regarding the season analyzed (summer): and between May and October, there was a total of 4,416 hours. But from this total, how many hours the fans could be turned on? To answer this, we used the outdoor temperatures as the most influential trigger since the relationship between the use of controls and the outdoor temperature is highly related; moreover, outdoor temperatures are a part of the input of any simulation, whereas the indoor temperature is an output. Finally, temperatures to turn-on fans reach 30°C [14]. According to Hermosillo's climate data, within May to October 4,229.00 hours correspond to temperatures above 30°C. This amount of hours was multiplied by the tendency factor to the probability of using fans ($\boldsymbol{Fact_{fan}} = \boldsymbol{0.5697}$). Then, the total hours obtained was multiplied by the device power (W), which typical value used in the analyzed social housing is 100 W [75]. Thus, the number of existing fans or the average of the existing fans multiplies the already calculated amount of energy. Finally, the total number of square meters (energy reference area: 37.7 m^2 = useful indoor area) divided the obtained energy amount resulting in the total of energy that can be invested by the use of fans in one square meter during a year. The unit of measurement is **kWh/m^2 per year**, which is very useful to compare different type of housing, regardless specific characteristics and providing quantified information concerning energy consumption or energy efficiency of a building.

$$E_{fans} = \frac{0.100\ kW\ (4{,}229h \times 0.5697) \cdot 1}{37.7m^2} = 6.39\ kWh/m^2\ year$$

It has to be noticed that regarding winter season, the same analysis to determine an action tendency was performed. Nevertheless, according to data, any evaporative cooling system or air conditioning was used, due to energy subsidies restrictions. Moreover, during winter only fans were available with a very small occurrence, only 6.29%; thus, the probability of using fans during winter was very low ($\boldsymbol{Fact_{fanW} = 0.0233}$). The same energy calculation was performed obtaining $\boldsymbol{E_{fans} = 0.10\ kWh/m^2\ year}$ for winter and the result was added to summer value.

Regarding the use of the evaporative cooling, it is important to highlight that this system is not widespread in Mexico; it is commonly used only in the northern region where climate conditions are is very hot and dry. Concerning time usage, it was selected the same amount of hours as we did with fans, because we did not found a reliable source with evidence of outdoor thermal temperature in which this device would be turned on. Finally, according to the action tendency factor ($\boldsymbol{Fact_{ecooling} = 0.6577}$), the total amount by the evaporative cooling system is $\boldsymbol{E_{ecooling} = 18.44\ kWh/m^2\ year}$.

Concerning air conditioning, the average power used was 4,363 W [76] and the trigger to define hours of usage was outdoor temperature above 25°C [14], with a total amount of 4,409 hours multiplied by the action tendency ($\boldsymbol{Fact_{ac} = 0.3346}$) obtaining the amount of energy for the greatest consumer device with a total of 170.73 kWh/m^2 per year.

In **Table 50** are presented all values and final energy consumption by each device.

Table 50 - *Energy Consumption*

Energy reference area: 37.7m^2

Fans							
Summer				Winter			
Trigger to turn-on Temp > 30°C Hours	Factor Tendency $Fact$	Power W	Number devices	Trigger to turn-on Temp > 30 degrees Hours	Tendency $Fact$	Power W	Number devices
4,229	0.5697	100	1	1,566.00	0.0233	100	1.00
Energy	**6.39**	**KWh/m² year**		**Energy**	**0.10**	**KWh/m² year**	

Evaporative Cooling						
Summer				Winter		
Trigger to turn-on Temp > 30°C Hours	Factor Tendency $Fact$	Power W	Number devices	No consumption		
4,229	0.6577	250	1			
Energy	**18.44**	**KWh/m² year**		**Energy**	**0.00**	**KWh/m² year**

Air-conditioning system						
Summer				Winter		
Trigger to turn-on Overheating >25°C	Factor Tendency $Fact$	Power W	Number devices	No consumption		
4409	0.3346	4,363	1			
Energy	**170.73**	**KWh/m² year**		**Energy**	**0.00**	**KWh/m² year**

In order to evaluate the reliability of the results, the first option was to resort the simulators. In this sense, the selected simulator was DEEVi [76], which is the official simulator in Mexico and it is used to evaluate energy efficiency in housing. This simulator performs a thermal evaluation of a house including various aspects such as architectural design, construction systems, materials and embedded technologies. The calculation method is based on the physical phenomenon of heat transfer through the thermal envelope and the calculation of the energy demand in order to reach a thermal comfort between temperatures of 20°C – 25°C. The results provided by the simulator are in respect to the amount of energy necessary to maintain the mentioned temperatures. The simulated building's characteristics are the same as the specified in section III.2.3. Therefore, the specific cooling demand resulted in 471 kWh/m^2 per year. This result does not consider the influence of summer tariffs; this means that the calculated amount implies the fact that at any month of the year air conditioning could be turned on. This simulator only considers characteristics concerning the architectural project, and it does not include any user variable such as sensation, preference or attitude, neither expectancies nor potentials. In conclusion, the energy demand calculated by us represents only the 36.24% of the predictions calculated by the Mexican official simulator, which does not include any contextual characteristics but only building features.

Continuing with the objective of comparing results, the average monthly energy consumption during the summer period in a low-income dwelling in a hot-dry climate is 730.67 kWh [77]. Moreover, the same type of household can reach up to 70% concerning the invoice electricity cost, corresponding to energy consumption by the acclimatization devices. Therefore, according to the existing devices and combination of devices according to our data, the monthly average consumption about acclimatization is approximately 513.91 kWh, very close to the reference consumption 511.469 kWh. To see calculations and results attend **Table 51**.

Table 51 – *Consumption comparison between real consumptions and calculated consumptions*

Reference consumption

Monthly Average (Summer period)		% Corresponding to the use of Air-conditioning
730.67	kWh	70% = 511.469 kWh

Monthly Average from analyzed data (Summer period)

Devices	kWh/m^2 per year	m^2	kWh per year	Summer period kWh
Fans and E. Cooler	31.22	37	1,155.14	192.52
Fans and Air-conditioning	183.51	37	6,789.87	1,131.65
Air-conditioning	170.73	37	6,317.01	1,052.84
Evaporative Cooler	18.44	37	682.28	113.71
Fans (two devices)	12.78	37	472.86	78.81
			Average	**513.91**

VIII. Integration of the system

All the analysis regarding comfort and behavior was programmed in a spreadsheet with the aim of systematizing the procedure. This analysis tool is available to predict action tendency automatically by introducing required value data. Moreover, the spreadsheet can analyze all data according to a specific characteristic as body mass index, age, clothing level, acclimatization time, and so on.

The first part of the system includes general data regarding the analyzed population, definition, and description of the type of building, type of available devices, season analyzed and as well as the evaluation of the thermal comfort profile and the attitude profile. The second section examines environmental characteristics such as temperature, humidity, and air velocity.

The third part concerns the analysis of the context, including expectancies, potentials, and costs regarding personal and technological adjustments to finally determined a factor of action tendency.

The last part is in view of the calculation of energy consumption according to existing devices, and the possibility of using them. Finally, this spreadsheet calculates CO_2 emissions according to amounts of energy consumption.

Therefore, by using the mentioned spreadsheet, data was analyzed according several variables classified by the four groups of the ***behavioral actions: Physiological acclimatization*** variables, ***Behavioral adjustment*** variables and ***Psychological expectations*** *variables* (see **Table 15**). The results of general data, comparisons among the different analyzed variables, discussion and limitations of this proposal are exposed in the next chapter.

IX. Results, discussion and limitations

Regarding general evaluation of data, occupants of the surveyed houses were workers with low income. Families were young couples with one or two children. The majority of these individuals are habituated to the local climate with very hot temperatures in summer between 15°C and 21°C as minimum and 40°C to 45°C as maximum.

According to thermal sensation in the precise moment of the survey, 31% of the population felt comfortable between 29.62°C and 34.98°C. The remaining 69% could have greater possibilities to perform an action to change those current conditions.

The general attitude for a change of the analyzed group of people is slightly favorable. Approximately 72% of them, considered the situation slightly tolerable and 66% found the conditions acceptable. In this sense, the attitude regarding acting is somewhat low.

The device with a higher tendency to be used is the evaporative cooling system. This device presented more advantages than fans since, besides the air velocity rises, it includes the use of water, which modifies relative humidity and therefore changes thermal sensation that in a dry, hot climate represents a positive influence. Additionally, this device has another advantage compared to air conditioning that its cost of acquisition and energy consumption is significantly high. **Table 52** summarizes analyses results.

Table 52 – *Thermal comfort perception and its influence on Energy Consumption*

Description	Comfort analysis		Attitude	Action Tendency	Energy Consumption $kWh/m^2\ year$	Co_2 emissions [75] CO_2kg/kW
Workers with low incomes. Families made up of young couples with one or two children. The majority habituated to the local climate	Comfort range	29.62°C to 34.98°C	Slightly favorable	$\boldsymbol{Fact_{fan} = 0.5993}$	6.72	3.4709
	People in Comfort	31%		$\boldsymbol{Fact_{ecooling} = 0.6577}$	18.44	9.5261
	People in Discomfort	69%		$\boldsymbol{Fact_{ac} = 0.3346}$	170.73	88.18
	Sensation	1				
	Preference	-1				

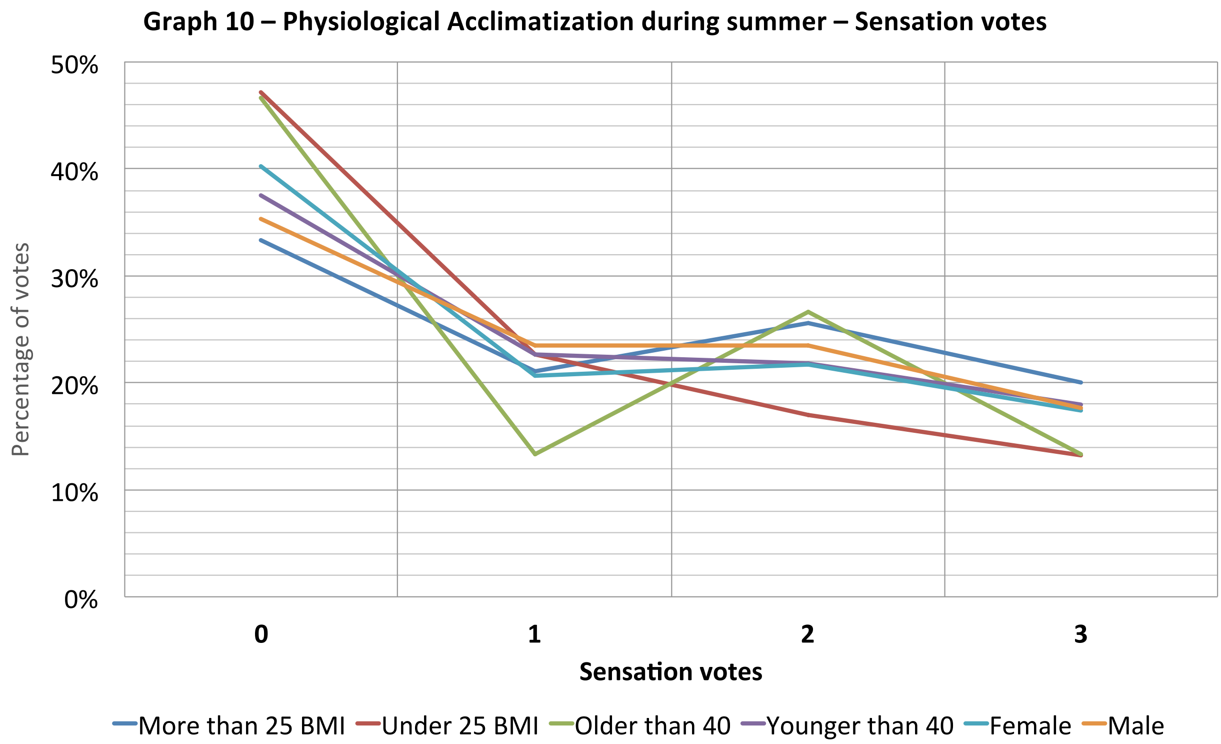
The following sections are organized according to the *Physiological acclimatization* variables, *Behavioral adjustment* variables and variables from *Psychological expectations* in order to define which of these characteristics have a higher influence over comfort perception and, therefore, to determine the impact over energy consumption.

Influencing energy by Physiological Acclimatization

As a general description of thermal comfort perception, on the one hand, we have that sensation votes, according to physiological acclimatization variables, present a consistent tendency. Most of the people despite the high temperatures felted neutral (sensation = 0) with an average of 32.3°C, see **Graph 10**. The same variables describing preference votes are a bit messier, either way, the tendency is also evident and most of the people would prefer to be cooler (preference = -2) compared to their current conditions, see **Graph 11**. In Table 53 is presented the average temperature per each vote.

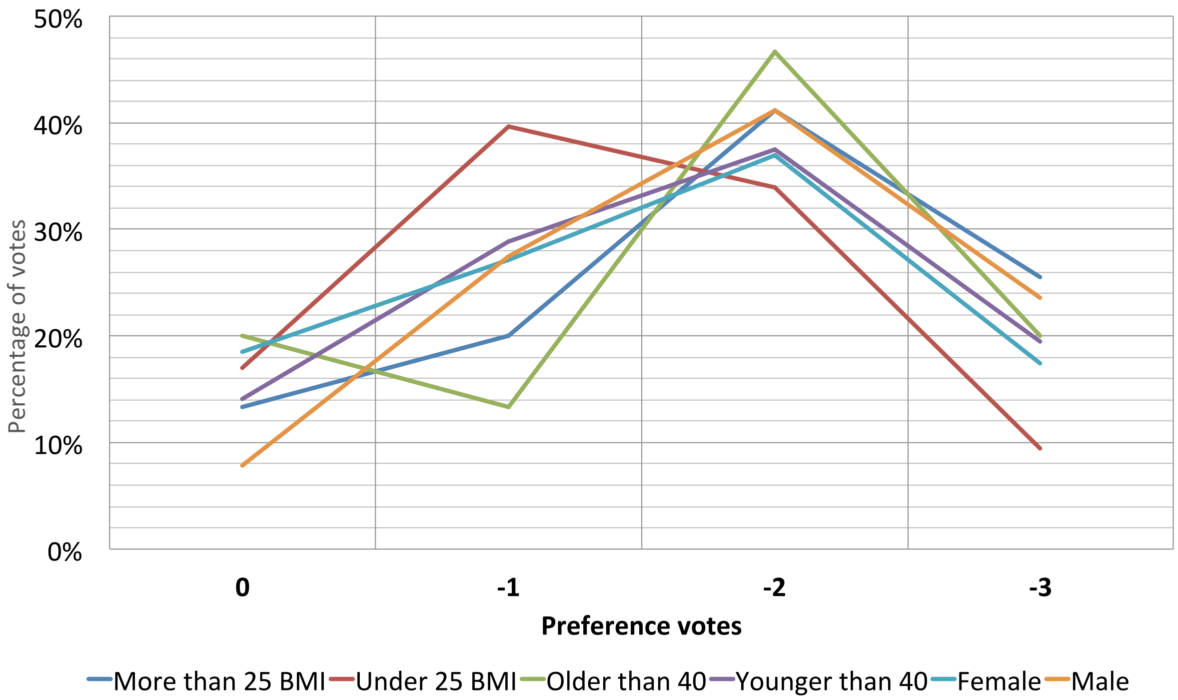
Table 53 – *Temperature according sensation and preference vote*

Sensation and Preference concerning indoor temperatures			
Sensation	**Temperature C**		**Preference**
0	32.3	32.7	0
1	33.6	33.6	-1
2	34.3	33.8	-2
3	36.1	34.6	-3



Values *analyzed by physiological acclimatization variables – sensation votes*

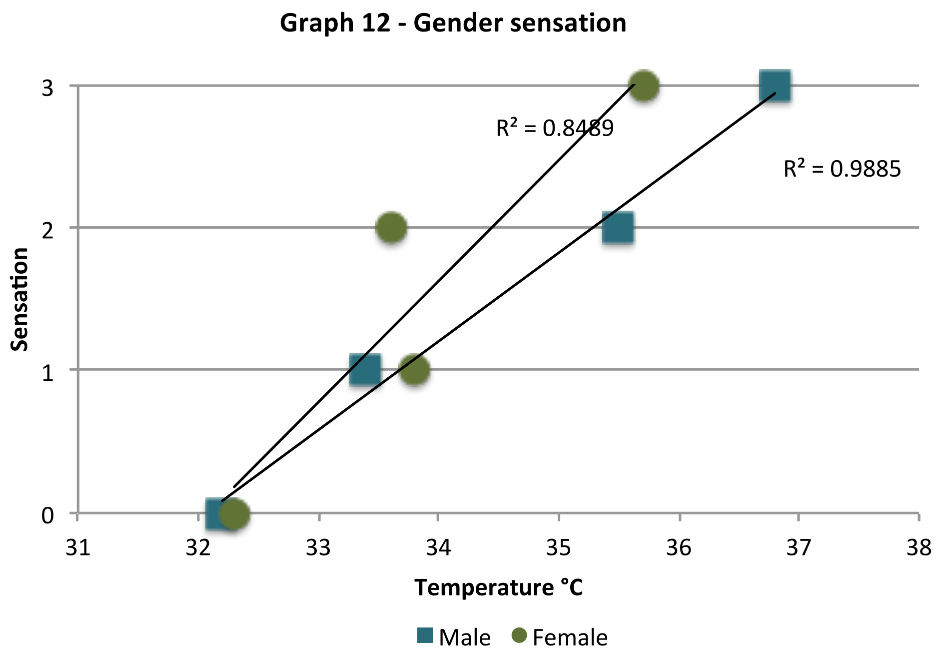
Graph 11 - Psychological Acclimatization during summer – Preference votes



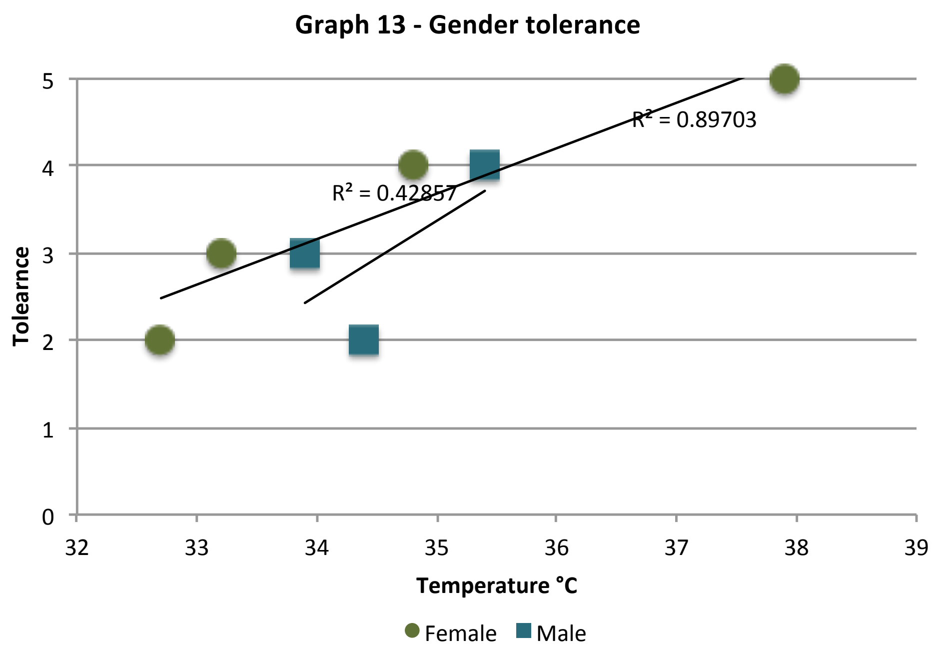
Values *analyzed by physiological acclimatization variables – preference votes*

Gender

Differences between female and male group presented only a small variation; women are slightly more sensitive to thermal changes than men (see **Graph 12**). Yet, women register a higher tolerance (See **Graph 13**). Almost the same percentage of women and men voted in the comfort band (sensation -1 to +1), 60.87% and 58.82% respectively, either way, more women felted neutral (sensation = 0) with 40.22% compared to man with 35.29%. In addition, women registered a slightly wider comfort range than men, from 29.67 to 35.08 compared to 29.54 to 34.80 respectively, suggesting that women would have greater tolerance to the variations of temperature. In other similar analysis, it has been registered that in most of the cases women present more dissatisfaction but they adapt better or more frequently to the given conditions [25], [51], [78]. Indraganti [79] argues that this situation, beyond physiological differences, might be caused by different perception of their residential environments given by gender's role, adding that women spent more time at home and possess a higher sense of belonging, promoting better control on the environment. The difference between gender perceptions presented in this research is too small to provide significant results. Nevertheless, we should take into account that Mexico is a country with gender disparity where 78.5% of men in working age have a job compared with women that only 44.8% have one [80]. This presents an open opportunity to continue analyzing energy consumption patters regarding thermal comfort perception defined by cultural characteristics.



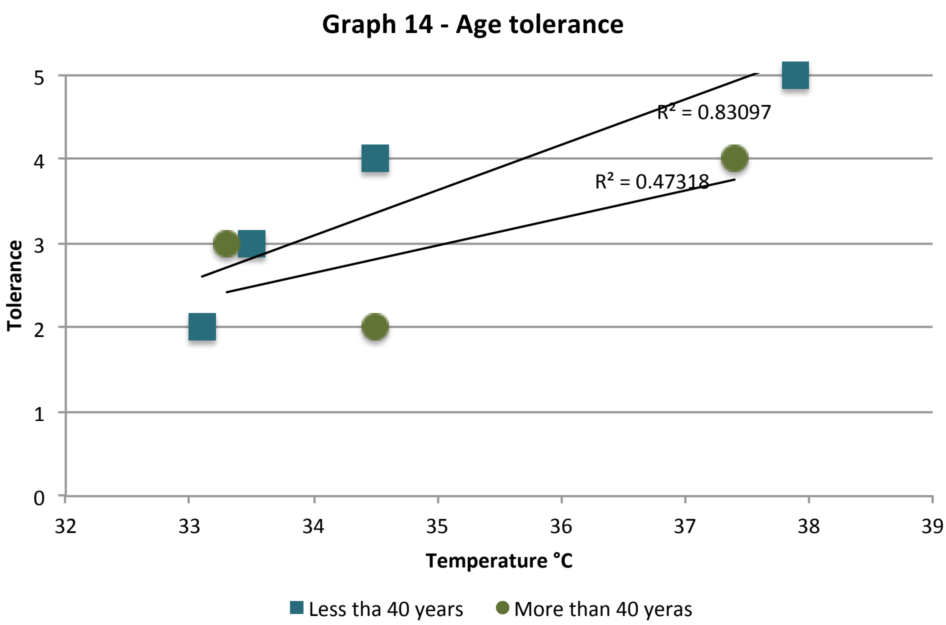
Values analyzed by gender variable - sensation



Values analyzed by gender variable - tolerance

Age

As gender, age differences neither presents high impact over comfort perception, younger people registered comfortable conditions between 29.45°C to 34.98°C and older 30.78°C to 35.10°C. In other words, the younger people felt in discomfort first than the old ones, but the group with old people has a smaller comfort range, which means less tolerance to changes (see **Graph 14**). From the point of view of physiological variables, older people were the group who felted comfortable at higher temperatures, they registered an average of neutral temperature at 32.94 °C, although they also exposed prefer to be cooler (preference = -2). Older people were less tolerant to changes, but accepted better the given conditions. Similar results ascribe this effect due to low metabolic rates and sedentary life style, probably, in some cases, less mobility due to health conditions limiting the access to controls affecting they thermal comfort perception, even from a psychologically influence [25], [78], [79].

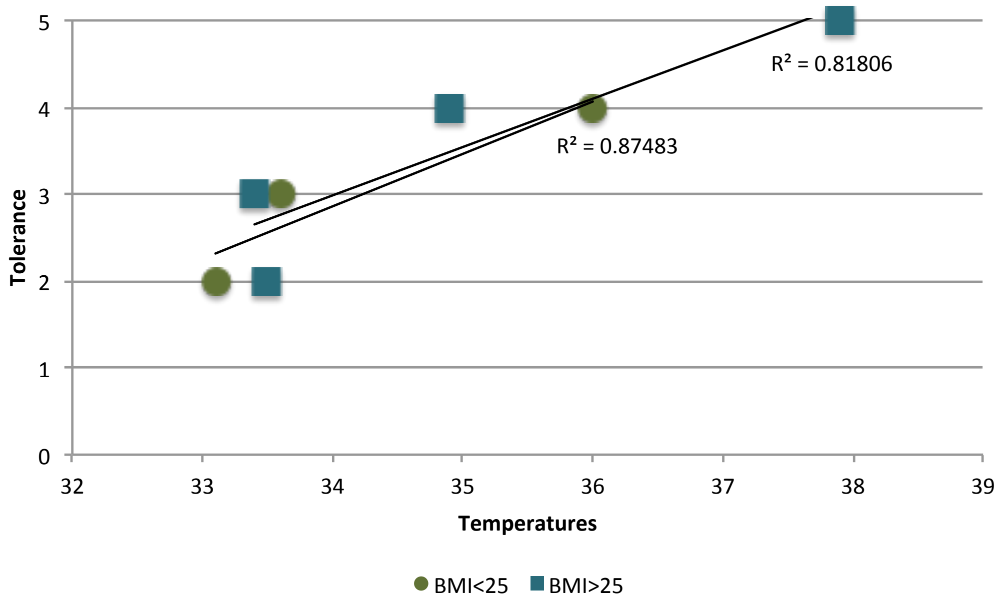


Values analyzed by age variable - tolerance

Body Mass Index (BMI)

The variable found with higher differences was the body mass index, which describes the relationship between weight and height. People with underweight and normal weight corresponds to an BMI less than 25 and they presented the higher amount of people felling neutral (sensation = 0) with 75.51%, in contrast with people with BMI that have more than 25; in this sense, they registered 54.44% felling neutral. Regarding to comfort range, BMI less than 25 registered to be comfortable between 30.13°C and 34.26°C, obtaining the smaller variation between temperatures with only 4.13 degrees. Moreover, this is the only group with the majority preferring to be slightly cooler (preference = -1) which represents a preference of a smaller change compared to the rest of people, but still preferring a change. Throughout these values, it can be appreciated that thinner people have less tolerance to thermal changes, see **Graph 15**. In the other hand, group with BMI more than 25 exposed to be comfortable between 29.32°C to 35.43°C varying 6.09 degrees, which is the highest variation compared to the rest of all physiological acclimatization variables represented in **Graph 10** with the line that has the softest slope. We did not find evidence in the literature review regarding the impact of the relation between height and weight in comfort according to field surveys in housing in hot dry climates. Nevertheless, Auliciems [78] argues that the heat dissipation depends on the body surface, and a thin person would have a greater surface-to-volume ratio than someone with a bigger body shape. Therefore, a thin person has proportionately greater heat exchange with the environment, consequently, less tolerance to temperatures fluctuations, additionally, subcutaneous fat is a good insulator; therefore fat people would prefer lower temperatures.

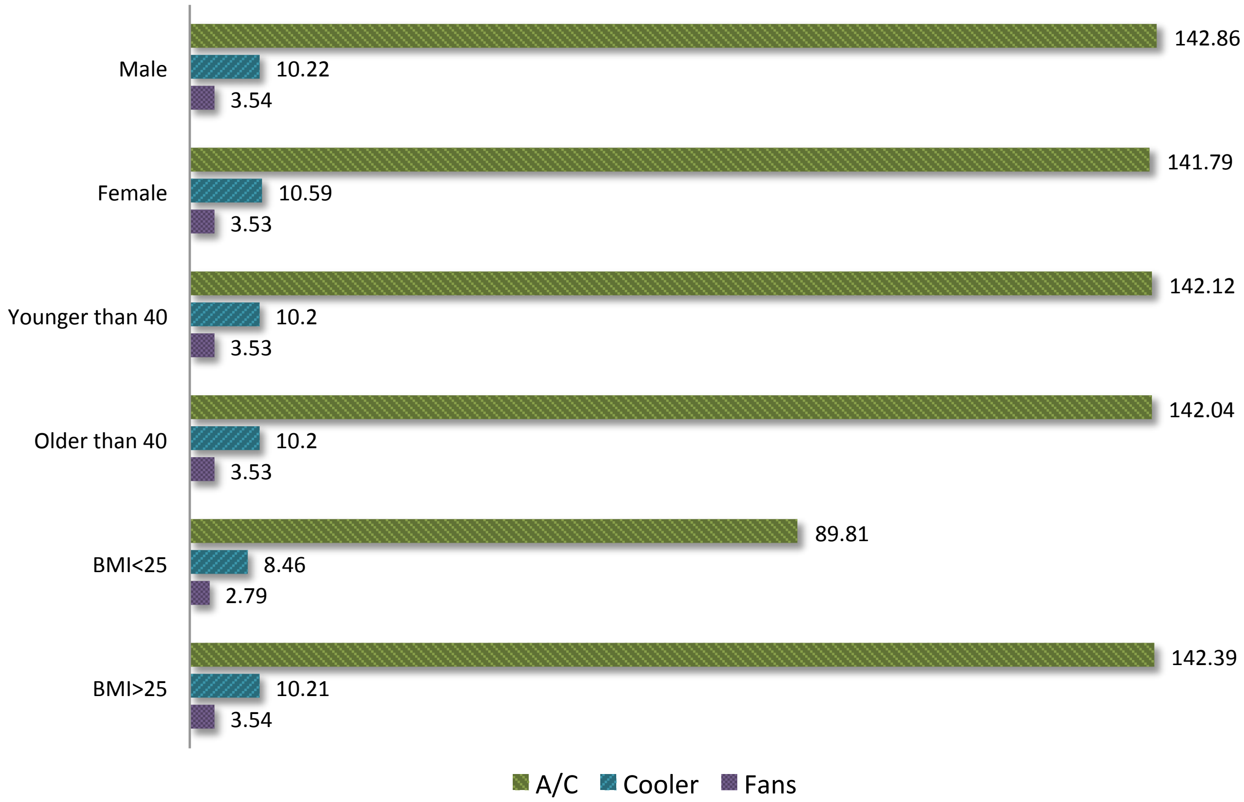
Graph 15 – Tolerance BMI less than 25



Values analyzed by BMI variable - tolerance

Graph 16 presents the estimation of energy regarding the influence of each of the mentioned variables. In this sense, all physiological acclimatization variables impact almost the same, however, the impact of the group of people with BMI less than 25, presents a smaller influence, approximately 37% less than the rest of the group. This result might be explained by physiological reasons although only partially, the explanation for this might be the attitude from individuals towards situations [81]. It might be assumed the fact that what is really impacting energy consumption is not specifically a body characteristic but instead a perception of the environmental conditions. As Indraganti [79] argues in his field study research in a hot dry climate, the increased and the tolerance thermal acceptability might resulted in a higher overall comfort vote.

Graph 16 – Influencing energy by Physiological Acclimatization (kWh/m² per year)



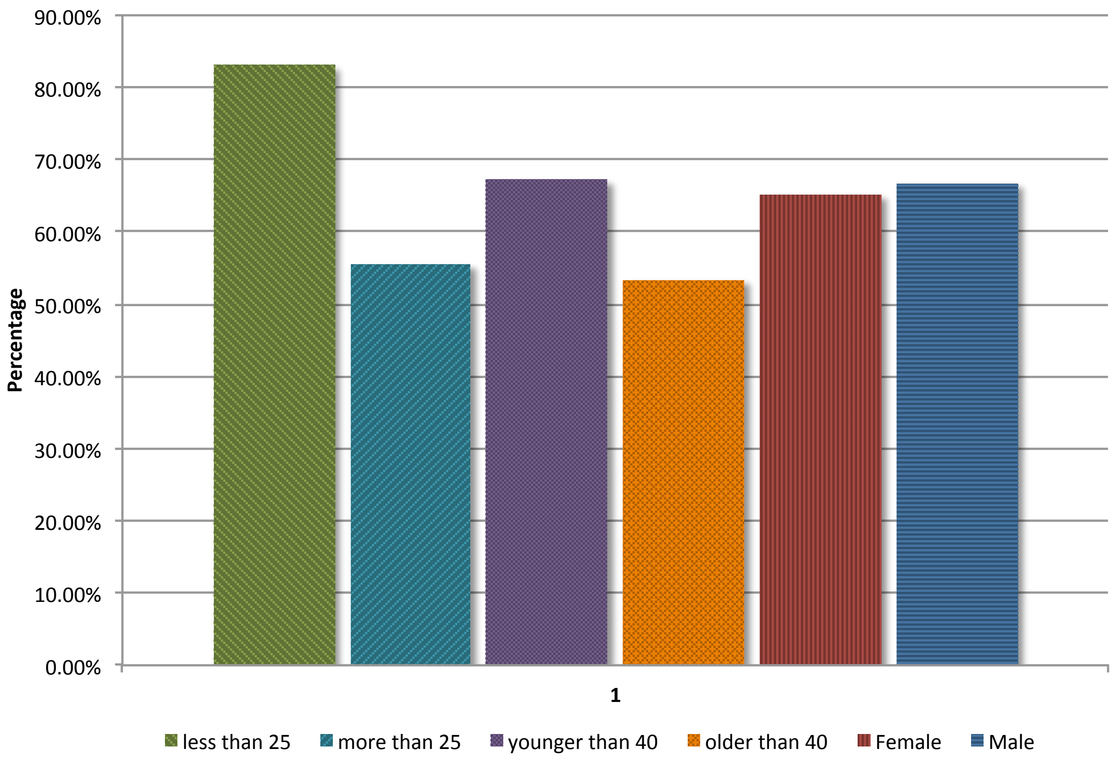
Values analyzed per each physiological acclimatization variable – energy consumption

According to this, in the next graphs (**Graph 17** and **Graph 18**) is presented values of acceptation and tolerance respecting each physiological variable.

Graph 17 presents acceptation percentages, and the higher value corresponds to the group of people with BMI less than 25.

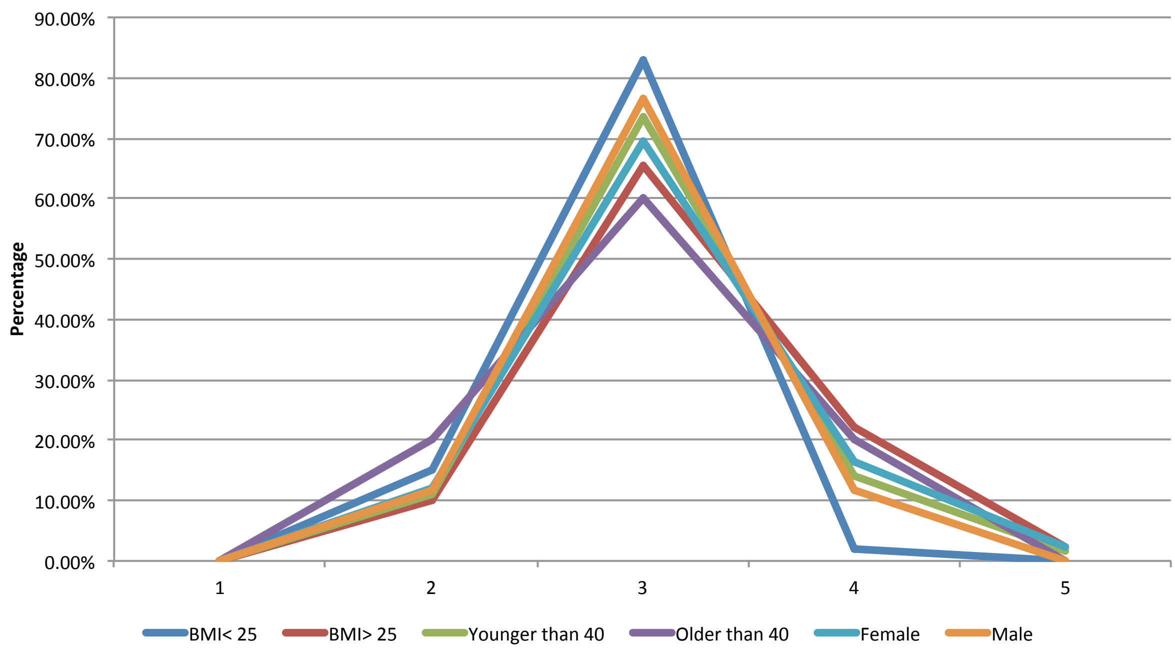
Regarding tolerance, the **Graph 18** presents all variables maintaining the same tendency towards a "slightly intolerable" (tolerance = 3); nevertheless, people within the group of BMI less than 25 registered the higher rate of answer with 83.2% in level 3, meaning a stronger tendency.

Graph 17- Acceptation per Physiological variable



Values analyzed per each physiological acclimatization variable – percentage of acceptation

Graph 18 - Tolerance per Physiological variable



Values analyzed per each physiological acclimatization variable – percentage of tolerance

Influencing energy by Behavioral Adjustments

This is related to variables in the group of Personal Adjustments. These are strategies by themselves, this means that just changing a personal adjustment, such as an activity or clothes, thermal perception could change. Therefore, these adjustments also would influence the use of energy. In this analysis seems that behavioral adjustments have small or null impact, since the conditions are provided by the type of building. In other words, since individuals were at home at the moment of the survey, they had already taken a personal adjustment, as wearing adequate clothing and most of them with a low rate of activity.

Clothing

Any evidence was found regarding to the different levels of clothing influencing energy consumption; moreover, data values for acceptation and tolerance presented almost the same percentage, thus all calculations performed resulted with almost the same values. From other study cases, most of them in building offices, clothing registers a significant impact over thermal comfort [29]. Therefore, it was considered that the type of building influences the significance of clothing as a strategy to adapt. Thus, since the present analysis is concerning houses, people could wear whatever fits better to their preferences and consequently the impact of the variable is less.

Activity

Regarding the activity performed just before survey, most of the people reported to perform passive activities; therefore, the influence of this variable is very low. In general, individuals who registered low activities presented the lower temperatures in the upper limit of the comfort range, meaning that beyond of 33.72°C people could be in a stage of discomfort by heat.

Acclimatization time

The parameter was the time that the individual has been at home, les than 30 minutes or more than 30 minutes. According to inhabitants' answers, people with less than 30 minutes registered the lower neutral thermal temperature and the lower temperature in the inferior limit of the comfort range compared to all other variables, 31.59°C and 28.82°C respectively.

Influencing energy by Psychological expectations

According to all the data presented above, subjective variables as the relations between sensations, preference, tolerances, and acceptation have an impact over energy consumption. In this sense, we arranged data according to these subjective parameters to prove their influence.

Next tables present estimated consumption per type of device and per psychological parameter. The values were arranged according to the scale of each variable, this means that blank spaces do not correspond to any value. As explained in earlier chapters, the smaller values mean positive appraisals. Thus, the consumption per each device increased according to the increasing of the scale.

What is noticeable is that in each device the smaller amount of energy and the highest are located in the preference variable (as shown in **Table 54**, **Table 55**, and **Table 56**) probably indicating that this is the variable whit a higher influence over consumption.

Table 54 - *Energy consumption per psychological variables - Air conditioning*

Scale	Sensation	Preference	Tolerance	Acceptation
	kWh/m2 per year			
0	108.15	60.00		
1	139.14	170.48		139.18
2	198.53	281.50	138.40	328.57
3	337.25	420.12	143.26	
4	-	-	325.20	
5			362.14	

Table 55 - *Energy consumption per psychological variables - Evaporative cooling*

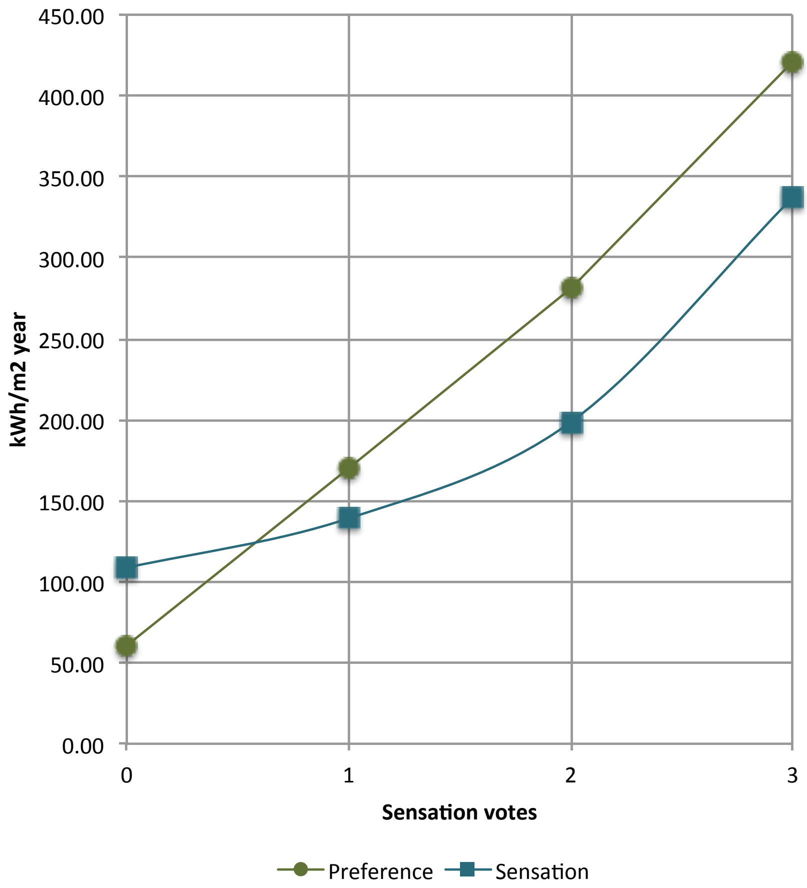
Scale	Sensation	Preference	Tolerance	Acceptation
	kWh/m2 per year			
0	15.31	8.37	-	-
1	17.05	18.43	-	17.05
2	20.04	24.82	17.01	25.43
3	28.00	32.76	16.86	-
4	-	-	27.10	-
5	-	-	29.10	-

Table 56 - *Energy consumption per psychological variables - Fans*

Scale	Sensation	Preference	Tolerance	Acceptation
	kWh/m2 per year			
0	5.05	2.31	-	-
1	5.73	6.38	-	5.73
2	7.01	8.86	5.72	9.69
3	10.09	11.94	5.78	-
4	-	-	9.80	-
5	-	-	10.61	-

Graph 19 presents the comparison between energy consumption with preferences and sensations regarding to air-conditioning, and their respective temperatures, exposing preferences as the higher force over consumption compared to sensation.

Graph 19 –Preference Energy Consumption depending on Sensation and



Air conditioning consumption according to sensation and preference votes as analyzed variable

It has to be noticed that plotted data has a few points, however, it was used the correlation coefficients to prove the linear relationships between variables and consumption, to see values attend **Table 57**.

Table 57 - *Correlational Coefficient per variable per device*

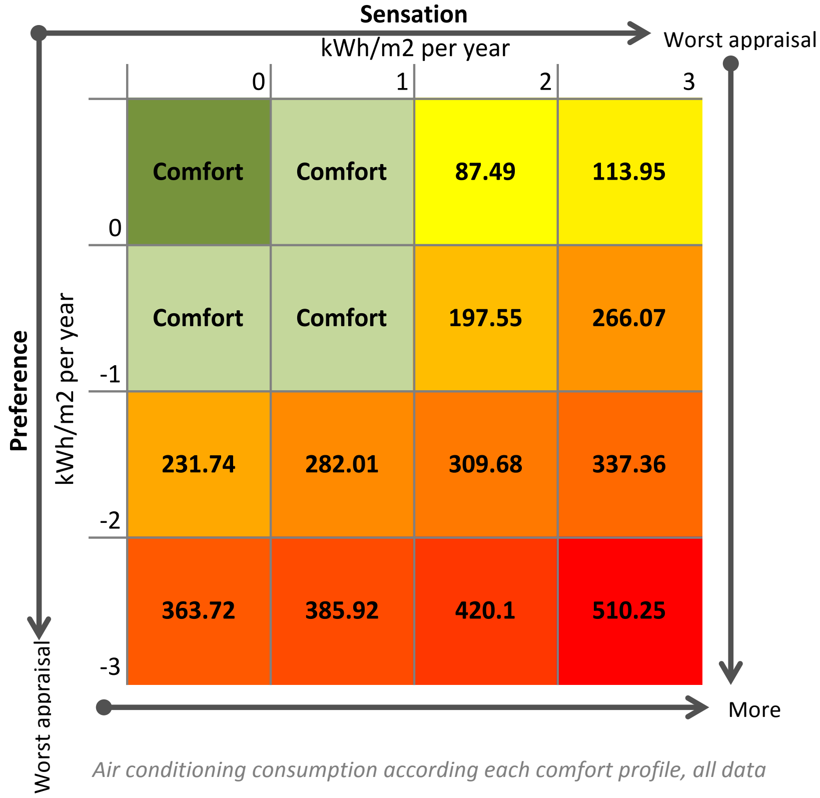
Device	Preference	Sensation
Air-conditioning	0.9984	0.9497
Evaporative Cooling	0.9961	0.9437
Fans	0.9951	0.9481

In all devices, preference presents a higher correlation with consumption. Nevertheless, according to Matias [17] thermal comfort cannot be explained only by sensation nor by preference, since both meanings complement comfort perception (as explained in chapter V). This effect can be understood as, meanwhile the sensation describes magnitude and direction of what is felling, preference better describes a motivation to perform an action.

Graph 20 presents energy consumption concerning air-conditioning in kWh/m^2 per year according to the thermal comfort perception, based on each combination of sensation and preference (Profiles of thermal comfort) from all data.

By the increase of the thermal sensation vote, the energy consumption raises; moreover, the increasing by the preference shows even a higher amount of energy consumption. Profiles within comfort area (0,0; 1,0; 0,-1 and 1,-1) can also imply a certain amount of energy, yet showing lower rates. In the case of the worst profiles (2,-3; 3, -2 and 3,-3), the amount is very similar to DEEVi results (see chapter VII), which estimations are approximately 471 kWh/m^2 per year.

Graph 20 – Influencing energy by Thermal comfort



Air conditioning consumption according each comfort profile, all data

Concerning tolerance and acceptance, these two variables represent the attitude regarding the situation. Less tolerance and less acceptance means a "bad" attitude (since it is based on a negative appraisal), and therefore more tendencies to use a device in order to change the current environmental conditions. In this sense **Graph 21** shows how acceptance and tolerance affect energy consumption. Each coordinate in the table represents a comfort profile and spaces with "NV," means no values, since information of the data was not available (not sufficient). Therefore, in tolerance 3 and acceptation 1, the comfort profile of sensation 2 and preference -2 registers a 198.36 kWh/m2 per year; compared with the same profile (sensation=2 and preference= -2) in tolerance 4 and acceptation 1, consumption is equal to 324.98 kWh/m2 per year; moreover, sensation 2 and preference -2 in tolerance 4 and acceptation 2 is equal to 399.52 kWh/m2 per year.

Graph 21 – Four variables affecting energy consumption

Less Tolerance

		TOLERANCE 1 Sensation kWh/m2 per year				TOLERANCE 2 Sensation kWh/m2 per year				TOLERANCE 3 Sensation kWh/m2 per year				TOLERANCE 4 Sensation kWh/m2 per year				TOLERANCE 5 Sensation kWh/m2 per year			
		0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
Acceptance 1 Preference kWh/m2 per year	0	NV	NV	NV	NV	NV	NV	NV	NV	30.34	NV	87.49	NV	93.47	NV	NV	NV	NV	NV	NV	NV
	-1	NV	NV	NV	NV	108.28	NV	NV	NV	141.92	171.43	198.36	NV	NV	NV	NV	NV	NV	NV	NV	276.47
	-2	NV	NV	NV	NV	231.74	262.61	NV	NV	255.68	282.35	309.75	336.94	NV	NV	324.98	NV	NV	NV	NV	NV
	-3	NV	NV	NV	NV	NV	NV	NV	NV	363.72	391.96	420.1	NV	NV	NV	NV	NV	NV	NV	NV	NV
Acceptance 2 Preference kWh/m2 per year	0	NV	NV	NV	NV	NV	NV	NV	NV	268.28	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
	-1	NV	NV	NV	NV	NV	NV	NV	NV	324.24	NV	340.09	369.7	NV	359.62	NV	377.26	NV	NV	NV	NV
	-2	NV	NV	NV	NV	NV	NV	NV	NV	360.94	382.61	393.48	NV	NV	394.9	399.52	422.62	NV	NV	NV	NV
	-3	NV	NV	NV	NV	NV	NV	432.69	NV	NV	NV	435.84	NV	NV	NV	438.99	NV	NV	NV	NV	NV

Less Energy

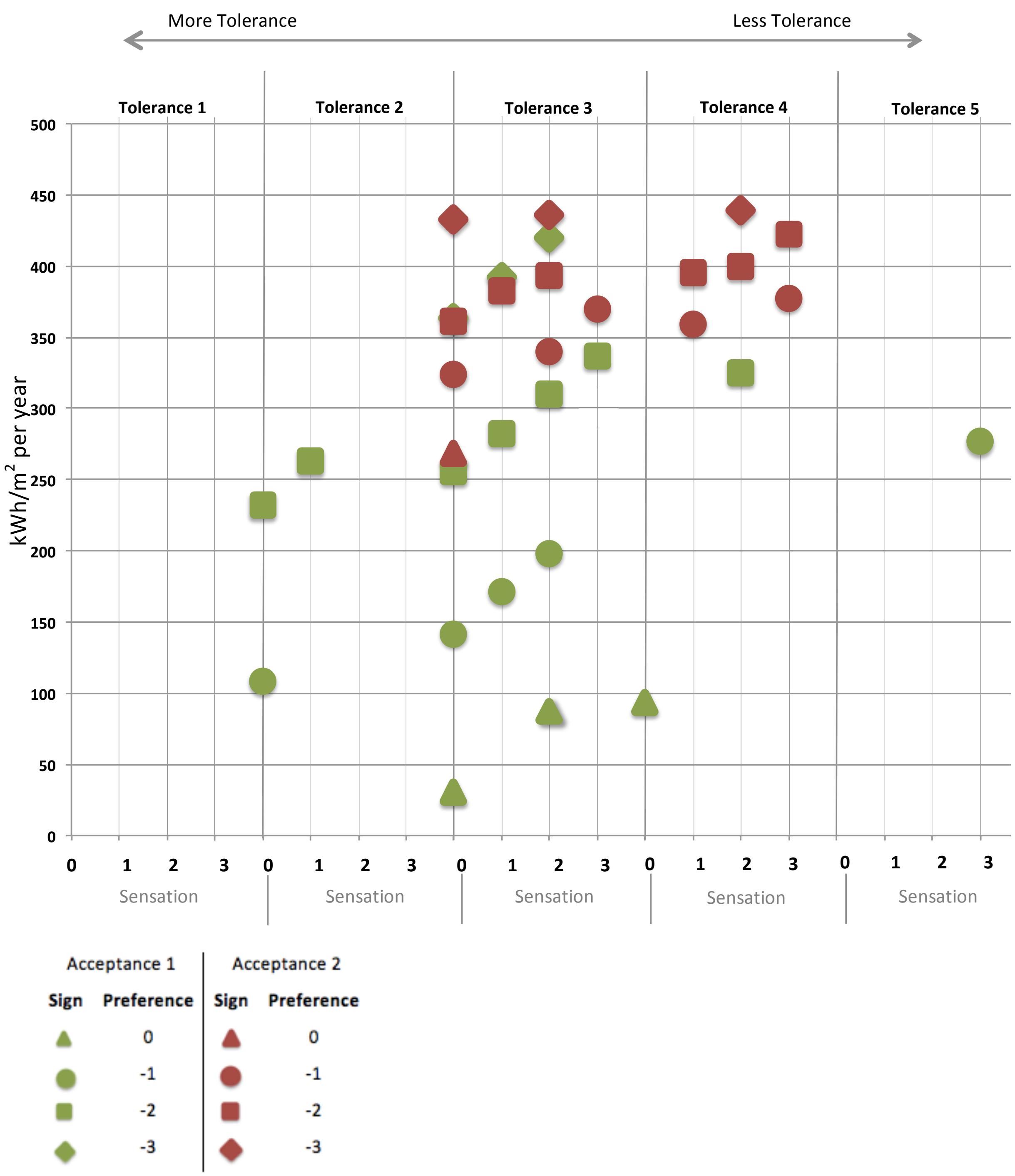
More energy

Less acceptance

Air conditioning consumption according to each comfort profile and the influence of attitude (tolerance and acceptance), all data

Graph 22 also describes the interaction of the four variables and the impact on energy consumption of all data regarding to air-conditioning. This time can be noticed that preference (identified by geometric figures) impact on different levels even if the sensation vote is the same, thus, all triangles are in the bottom (preference = 0) and all rhombuses are located at the top (preference = -3). Meaning that preference has a higher influence over energy than sensation. Moreover, all geometrical figures in red represent acceptation 2, and all those are located in the highest part of the graph.

Graph 22 - The influence of attitude in energy consumption



Limitations

The proposal presented in this thesis is clearly provisional. However, it is based on a real framework, highlighting relevant information concerning comfort perception, which provides insights of how energy is consumed in real life. Moreover, thermal comfort perception and behavioral analysis integration, including the evaluation of attitude by tolerance and acceptation, are speculations only based on literature and not complete confirmed by empirical data.

Also, it must be highlighted the key role of context analysis as essential in the understanding of the variable's dynamic (inputs) and behavioral responses (outputs). Additionally, this proposal needs adjustments concerning the scales; since we measured variables form very different dimensions the system presents significant limitations. Therefore, the accuracy of the results highly depends on the reliability of information of proper gathered throughout field studies, moreover an accurate evaluation of scales impact. During the process of this analysis it was noticed and mentioned some gaps of information that must be fill up with future research in order to finally propose a stronger analysis system.

X. Conclusions

Far from pretending to develop a human behavior predictor, what provides this exercise is a closer holistic approach of what elements are involved, how they interact between themselves and which of them impact the most in the energy consumption. This gave us valuable information to understand behavioral patterns concerning energy consumption. Thus, it is necessary to propose better strategies on how to ensure thermal comfort throughout energy efficiency as a key to the strategic planning for accurately energy policies to the low-cost dwelling's inhabitants, and consequently, improve their well-being.

Overall, all respondents, even if their physical characteristics vary, maintain a tendency towards thermal comfort perception. This group of people has been living in extreme climate conditions and apparently they are used to it, since its comfort profile and attitude towards the situation shows that they do not completely perceive the thermal comfort as proposed by traditional models.

Physiological acclimatization partially defines comfort perception throughout the body heat transfer and metabolism defined by features as age, gender, body fat and so on. These characteristics can be analyzed, according to geographic regions or phenotypes, but also, defined by groups of population concerning to specific activities as for instance, a kinder garden or a nursing home, among others. Besides, the particular type of building will also determine the available behavioral adjustments (personal, cultural and technological). For instance, the impact of clothing in a building that it cannot be modified, influence the comfort appraisal. But the higher impact has been found in the bottom level of variables (**Figure 5**). The psychological expectations play a crucial role in the construction of the perception of what means comfortable to some one, or to some group of people.

The analyzed group presents a variety of physical characteristics, however, they showed a central tendency towards thermal comfort perception. Their appraisal was uncomfortable, yet their attitude was slightly favorable. The final responses towards a stage of discomfort belong mainly to the given contextual characteristics rather than purely body effects or building conditions.

The variables related to behavioral adjustments as clothing and activities did no impact as expected. Results might be linked to the type of building, since a house provides high flexibility regarding adaptation, thus, at the moment of survey people already had selected the strategy of their preference or choice.

All surveyed individuals belonged to a particular social group; therefore they were within the same structure (see **Figure 5**). These people had a common background fed by similar past experiences regarding climate, experiences with buildings and context possibilities. The influence on energy consumption mainly depends on the appraisal of the given circumstances and past experiences as well as future aspirations. Moreover, they might share similar expectations on the short term of thermal conditions. This might be the main reason why psychological variables impact the most in energy consumption instead of physical acclimatization or personal adjustments variables. In this sense, the most important variables are preferences and attitudes.

Finally, this level is not modifiable during a short-term period; it is part of a stable structure, which has been built throughout life experiences and constantly evolving, resulting energy consumption in a matter of life style.

XI. References

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