1. INTRODUCTION

Comfort comes from the interaction of physical, physiological, and psychological changes on human perception, depending on social and cultural aspects, such as architecture, clothing, eating habits and climate as defined by Kristian Fabbri [1]. In addition, Thermal Comfort is a state of mind where the subjects expresses satisfaction with the conditions they are exposed to [2]. Temperature, humidity, air velocity, and other parameters in a given environment, defines those thermal conditions.

The relation between Thermal Comfort and Productivity is show by the American Ventilation Commission (1916), which confirmed the influence of thermo-hygrometric conditions on physical labor income and special war situations [3]. For example, raising the ambient temperature from 20°C to 24°C decreases the working efficiency by 15%.

However, the definitions for this field are still limited since human behavior is quite complex and varies according to cultural, climatic, and other factors. Based on this thinking, the study field called Adaptive Thermal Comfort was developed in order to understand the influence on human perception and how to affect it in alternative ways.

With the same human-centered approach, there is the innovative KE (Kansei Engineering), developed in Japan by Mitsuo Nagamachi. A field focused on the research of human behavior in order to develop differentiated products that are more appealing to the five human senses: vision, hearing, smell, taste and touch [4]. Therefore, KE is able to translate the feelings into products’ design based on user’s needs [5] to propose projects that consider both physical and psychological limitations, acting as a unifying area since it covers human perception in all its senses.

In this paper, KE methodology and Mechanical Engineering were converged to propose a new model of AC (air-conditioner) based on students’ reactions to the use of air-conditioning system in a classroom. For that, the article is divided in five sections which are: Section 2 with the background history that unites the thermal comfort studies and Kansei Engineering development; Section 3, that explains the Methodology used to propose enhancements on a common AC model, passing through Kansei Engineering Methodology, questionnaires and how physical parameters should be measured; Section 4 with Results and the Discussion based on data from questionnaires and physical parameters analysis; and, finally, Section 5 concluding the improved parameters for the new AC model proposed. With this whole study the product is supposed to obtain better response or enhance productivity, since it should positively affect most of the human senses: visual, olfactory and auditory.

2. THEORETICAL BACKGROUND

In 1916, researchers (American Commission on Ventilation) aimed to determine the influence of the hygrometric conditions in labor productivity to seek enhancements to benefit economic interests [3].
studies arose with the World War and Industrial Revolution, mainly concluding that: (i) for the physical work, the increase in ambient temperature of 20°C to 24°C decreases the working productivity by 15%; and (ii) at 30°C ambient temperature, the relative humidity 80%, and working efficiency falls by 28%. Comments on the work performance in mines in England showed a low productivity for miners at 41% less when the Effective Temperature (ET) is 27°C, compared to the productivity level at 19°C [3]. Besides, they observed variations in production in industries, based on the changing of seasons of the year; and correlations between thermic uncomfortable environments with high rates of accidents at work [3]. Those studies confirm the Adaptive Comfort, which assumes there are other parameters that may affect the perception of thermal comfort in addition to temperature, as culture, climate and human behavior.

To determine the human thermal comfort and allow qualitative information to be obtained based on the thermal satisfaction with the environment, Fanger proposed in “Calculations for Thermal Comfort: Introduction to basic comfort equation” (1967) a rating scale for the perception of well-being, from which was developed some important indexes for the advancement of studies on thermal comfort zone: Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) [1], both related to the dissatisfaction of subjects about the thermal comfort.

Besides Thermal Comfort, the 21st century is marked by other studies in the area of ergonomics, comfort, and product’s quality, as in Kansei Engineering. Parsons [6] describes that the most important point is not to define why people report comfort or discomfort in an environment, but what conditions can produce thermal comfort or acceptable thermal environment. In addition to the physical parameters (temperature, humidity, air speed), which are usually considered on Thermal Comfort, should be considered other variables such as age, biotype, eating habits, and others such as cultural background and the influence of the environment through the five human senses.

The science of photobiology is based on the light energy of interaction with living beings, in other words, the influence of different light spectrums on biological processes [7]. Gerrard [8] used a number of studies to determine what lighting greatly influences blood circulation, by studying in red (620 nm) and blue (460 nm) light. The results determined that the red color tends to be more intellectually and emotionally stimulating, as well as promoting greater physiological arousal. The blue color is more likely to calm and reduce blood pressure.

The sounds emitted in controlled frequencies are studied by audio engineering, electronics and physics, and the noises classified in color, for example, white noise (White Noise), gray noise (Gray Noise), among others. The color is associated with the type of characteristic frequency, which is defined by the energy spectrum and noise signal [9]. In the auditory aspect, Pink noise (Pink Noise) sounds more natural than white noise (similar to the sound of running water or sea waves) and is quite relaxing [10], other colored noises may have different affections on users senses promoting from comfort to stress sensation.

According to Lyra [11], aromatherapy is the therapeutic application of essential oils, reaching various emotions, each influenced by a kind of fragrance. The influence is given by the following main points, as described Lyra [11]: (i) tonics effects (energizing); (ii) emotional effects of the essential oils in the limbic system; (iii) decrease in blood pressure, increasing the temperature of the skin. As stated by Andrei [12], the means of using scents are by spray and air diffusion, inhalation, compresses, baths and massages.

The authors [7-12] shows that if the product needs to bring positive emotions or even negative ones, the senses could be affected in different ways, with smell, sounds or lights.

By studying and searching ways to affect human senses, Thermal Comfort study can be further explored by using the Kansei Engineering Methodology, since it seeks to obtain, through the human behavior, appropriate features to design better products or new technologies on ergonomics and hygiene, design, architecture, promoting a better user experience. It is clear that the KE became a very broad field of study in the industry and product innovation, and it can be advantage using this methodology to develop more complete evaluation of the Thermal Comfort.

3. METHODOLOGY

This study combines two fields (Thermal Comfort and KE Methodology) to propose some features for a simple Split Hi-wall model of air-conditioning unit that could benefit the user in an affective way. The project methodology covers the following steps:

1. Design questionnaires with focus on Adaptive Thermal Comfort considering models of KE Methodology questionnaires (KE - Type I), including Emotional and Thermal perception.
2. Apply the questionnaires in a classroom at the University of Brasilia, for 53 students subjected to similar parameters of Environmental Comfort (including air speed, humidity, noise and thermal sensibility.).
3. Capture physical parameters (temperature, noise level, humidity and air speed) for further comparison with questionnaires’ results.

4. Analyze the data from questionnaires in the aspects of spatial analysis of the environment; thermal comfort analysis based on PMV and the PPD; analysis of adaptive point of view of the possibilities that the user can modify the environment; emotional and sensorial analysis based on Kansei Engineering Methodology.

5. Develop a new model of air-conditioning system based on previous analysis and scientific references, aiming to benefit most of the human senses (visual, auditory and olfactory) for a better efficiency in activities that require concentration.

3.1 Questionnaires

The questionnaires are divided on Thermal and Emotional response.

In the Thermal approach, students are asked about perceptions as (i) sense of comfort, (ii) warmth and cold, (iii) desired thermal sensation, (iv) perception of air currents and (v) local discomfort based on the temperature difference between their head and feet. Those points were evaluated in a 1 to 5 scale, from negative to positive meaning, as can be seen in Fig. 1.

For this project, the appropriate Kansei Words (KW) on the Thermal response questionnaire are: Refreshing, Relaxing, Good Air Quality, Humid, Warm, Good Air Distribution, Silent and Comfortable.

On the other hand, the Emotional response is assessed by a survey sent to 100 people online, asking them about the place where they usually get contact to air-conditioning and what is the model of the AC System; age, gender, feelings/emotions most felt when exposed to AC; and general comfort perceptions (air-flow intensity, temperature; humidity, general thermal comfort sensation and noise). The feelings shown on the questionnaire are happiness, anxiety, calmness, tiredness, energetic, enthusiasm, inspiration, irritation, pleasure, laziness, worry, rage, sleep, boredom, and sadness. The options for places are classrooms, offices, call-centers, rooms (TV-room, bedroom), cinemas, and others. Finally, the models of air-conditioning systems shown are: Split Hi-Wall, Built-in or Diffusers, Air-conditioning System with visible ducts, Split Cassette, “Invisible” AC Diffusers, or others.

<table>
<thead>
<tr>
<th>Not Refreshing</th>
<th>Refreshing</th>
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<tbody>
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<td>3</td>
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**Figure 1:** Scale for Kansei Words evaluation by users

3.2 Exposure conditions

The Thermal perception questionnaire was applied in a classroom, where 53 subjects were exposed to a Split Hi-Wall (BOSCH ACST WITH 22 FM), with a capacity of 22,000 BTU/h, in a room of 9 × 9 meters. The subjects were arranged in 7 rows, as illustrated in Fig. 2.

The AC was set to automatic in all settings and 21°C for temperature. The windows in this classroom were unable to open, and there is a small entrance next to the AC for air ventilation.

3.3 Physical parameters

The parameters measured are: (i) Dry Bulb Temperature (DBT), (ii) Absolute and Relative Humidity, (iii) Air speed, following the ISO 7726 [14] which must be followed for the measurement of parameters in a microclimate. The parameters were measured in order to create a mesh in the classroom with similar distances. On the questionnaire, the position from the air-conditioning was set with a scale of 1 to 5, dividing the room in a grid that corresponds to the responses, totalizing 20 areas in a 5 × 4 grid. Figure 3 illustrates this mesh, where the value in each cell represents the distance between the air conditioning and the location (sitting) point in meters, the colored-scale shows the scale of 1 to 5 related to the distance.

**Figure 2:** Classroom and positioning of desks, AC and other elements [13]

**Figure 3:** Classroom grid with distance (m) from the air-conditioner, adapted from [13]
The sitting positions distance from the Air-conditioner (AC) can be translated as: position 1 (White) from 0.0 to 2.0 meters; position 2 (blue) the surroundings from 2.1 to 4.0 meters; position 3 (green) from 4.1 to 5.7 meters; position 4 (yellow) from 5.5 to 7.5 meters; and, finally, position 5 (orange) from 7.9 to 8.9 meters around the AC.

For measuring Dry Bulb Temperature and Relative Humidity, Psychrometer HT-270 (thermo-hygrometer) Portable and Digital were used. For Sound level, a Thermo-Hygro-decibel meter-Luxmeter, THDL-400 model was used. For Air speed, a Digital Anemometer Hot Wire Term Portable TAFR-180 was used. The positions or distance from the AC was measured with a laser device, Digital Measurement Device - Disto D2.

4. RESULT AND DISCUSSION

4.1 Questionnaires and physical parameters analysis

The Emotional survey analysis shows that: (i) the AC most used by the subjects is the Split Hi-Wall (60%); (ii) the place where the subjects are more exposed to AC is the classroom (45%); (iii) the age of the people surveyed, mainly students, are from 18 to 25 years old (73%); (iv) the amount of male and female are balanced, which are 58% male and 42% female; and (v) the emotions mostly felt by the users are: calmness (65%), sleepiness (56.7%), pleasure (43.3%), and laziness (38.3%). Note that emotions do not sum up 100% since users can identify more than one emotion at the same time.

Also from the Emotional online survey, the general comfort sensation shows that more users feel discomfort from the drafts, air flow, over them. For the sensation of warmth-cold and the feeling of comfort-discomfort due to ambient temperature, people mostly feel the environment as cold, although they consider this aspect as being neutral or reasonably comfortable. The results from AC aspects analyzed indicates that the main critical point in an air-conditioning is the humidity, in most cases (48.3%) being described as ‘dry air’. While 34.4% of respondents declared the air breathed as neutral or pleasant.

Nonetheless, this result may vary according to the region where the questionnaire is made, since the cultural or regional aspect may affect the study. In this project, the region studied is Brasilia, Brazil Central-West, where half of the year is rainy and the other half is dry season.

Based on the measured data of the classroom, under which users were interviewed, the comfort zone was reached. The tool CBE Thermal Comfort Tool [15] was used to estimate, under ASHRAE-55 Psychrometric Chart shown in Fig. 4, the thermal comfort at the studied site.

With comfort conditions such that PMV estimated at 0.38 and PPD estimated at 8%, which can be considered reasonable for this study.

4.2 Kansei analysis

The data resulting from questionnaires were analyzed using Principal Component Analysis (PCA) by the software JUSE-StatWorks/V3.0 [16], which shows a correlation between the Emotional Kansei Words with characteristics of the air conditioning models. From the questionnaire, the PCA was developed for 8 different sensations to five positions in Thermal response questionnaire (Session 3.1). Three forms of PCA are calculated: PCL (PC Loading), PCS (PC Score) and PCV (PC Vector).

The PCA analysis is made using the data from the Table 1, the average rating of the 8 feelings/sensations from the Thermal response questionnaire. Crossing the positioning values with the feelings’ assessment it can be produced the Fig. 5, PCV Analysis, which unites PCL and PCS.

The chart shows that the position 5 (P5) presents better sensations: the strongest one was ‘humidity’ (4), followed by sensations of ‘good air distribution’ (6), ‘comfortable’ (8) and ‘relaxing’ (2). However, if the subject seeks a more ‘refreshing’ (1) sensation, position 3 (P3) is the most suitable. The position 4 (P4) is more favorable for a ‘quiet’ (7) environment. In addition, the position 1 (P1) is the best for a ‘better air quality’ (3). Finally, the position 2 (P2) is the least favorable and all sensations are expressed in a negative way, since in the chart they appear really far from P2.

Therefore, the position 5 (P5) would be more appropriate and would have a better emotional response. The positioning is the one with less interference from the
air-conditioning equipment, which has a reduced sound intensity, medium humidity, and very low air velocity, then a greater tendency to good sensations. While sitting at position 2, where the airflow intensity is greater and the noise of the air is felt by the user, does not meet the expectation of a cool and comfortable environment.

4.3 Analysis of the Senses

The analysis of this project, determined three main emotions that must be worked on: calmness, sleepiness and laziness. Then, the research focused on generating attributes for the most used air-conditioning model, Split Hi-Wall, which reduces these emotions, by applying physical modifications to affect: visual, olfactory and auditory senses.

For classrooms and concentration demanding places, the indication is red, orange and yellow. On the other hand, when it is desired to feel calm and relaxed, the indication is to use blue-green colors as lighting. In all the cases, the light intensity should not draw much attention, so the aim of color therapy treatment, to reduce the feeling of sleepiness and laziness, would not be achieved. However, when it comes to influencing emotions more intensely, an adaptation to the air-conditioned model may be the implementation of LED lighting on its back. Figure 6 shows illustration of the proposed air-conditioning model with red, yellow, and blue LED to influence positive emotion.

In the auditory aspect, an air-conditioning equipment can be changed as to their natural sound. Pink noise (Pink Noise) sounds more natural than white noise (similar to the sound of running water or sea waves) and is quite relaxing [12].

The proposed improvement in air-conditioned model is to add a sound output, which controls the noise emission of air conditioning in a pink noise frequency. The user will be immersed in an environment with greater influence to their concentration in class or study. The intensity of the noise cannot be higher than that considered as natural by the users, 54.4 dB.

As stated by Andrei [15], the means of using scents are by spray and air diffusion, inhalation, compresses, baths and massages. The adaptation of an AC model that emphasizes a better olfactory sensory perception can be given off by aromatic diffusers which are responsible for sprayings a jet of a mixture with essential oil between periods of 10 to 20 minutes. For classrooms, the chosen

<table>
<thead>
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<th>Position</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>Refreshing</td>
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<td>3.00</td>
<td>3.46</td>
<td>2.86</td>
<td>3.13</td>
</tr>
<tr>
<td>Relaxing</td>
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<td>2.71</td>
<td>3.31</td>
<td>3.14</td>
<td>3.38</td>
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<tr>
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<td>3.43</td>
<td>3.31</td>
<td>3.29</td>
<td>3.50</td>
</tr>
<tr>
<td>Humidity</td>
<td>2.24</td>
<td>2.14</td>
<td>2.46</td>
<td>2.43</td>
<td>3.25</td>
</tr>
<tr>
<td>Warm</td>
<td>2.59</td>
<td>2.71</td>
<td>2.38</td>
<td>3.29</td>
<td>2.75</td>
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<tr>
<td>Good distr.</td>
<td>2.35</td>
<td>2.14</td>
<td>2.62</td>
<td>2.43</td>
<td>3.13</td>
</tr>
<tr>
<td>Silent</td>
<td>4.12</td>
<td>4.29</td>
<td>4.15</td>
<td>4.43</td>
<td>4.38</td>
</tr>
<tr>
<td>Comfortable</td>
<td>3.41</td>
<td>2.71</td>
<td>3.46</td>
<td>3.29</td>
<td>3.38</td>
</tr>
</tbody>
</table>

Figure 5: PCV chart (PCL + PCS) relating positions and feelings from user’s Thermal response.

Figure 6: Proposed air-conditioning model with red, yellow, and blue LED backlight [13].
aroma must not induce sleepiness or laziness. Thus, the use of rosemary and lemon flavors may be indicated. Sedatives flavorings are contraindicated. Figure 7 shows illustration of proposed sound output and aroma diffuser.

5. CONCLUSION

The paper based on Kansei Engineering Methodology to analyze an air conditioning model in an academic environment in Brazil has led to some conclusions. ASHRAE-55 [2] explains that the sense of neutrality stands to size an air conditioning system. However, for the sensations and emotions caused by thermal conditions, neutrality is not the best at influencing these sensations. Neutrality considered by ASHRAE-55 [2] is associated only to the body temperature control, leaving the desired emotional and sensory aspect, which should be better studied to understand its real influence on further psychological scale.

Among the feelings measured by the emotional perception questionnaire, the most expressed emotions among all AC models are: calmness, sleepiness and laziness. Which can be worked on by KE to produce products that cause less sleepiness and laziness, especially in a work environment. Emotions ‘joy’ and ‘pleasure’ were the other major response of air conditioners users. In an environment where the user is not bothered by noise distractions, visual distractions or foul smell, in other words, a conducive environment, the tendency to feel happy and motivated, contributes to increased productivity.

In the studied environment (classroom), they found that students who were positioned farther from the comfort of air-conditioning reported a better sense of relaxation. In the situation where the interviewee was subjected to constant air currents, greater discomfort was reported. Therefore, air currents at higher intensity are unwanted by most respondents. Visual, auditory and olfactory were proposed to the model of Split Hi-Wall air-conditioners, which are: (i) LED light installation with colors that can affect people’s emotion in the appropriate way for each environment; (ii) sound output installation with emission of white noise, pink noise or no output. (iii) flavor spray installation to affect users positively through smell.

For greater reliability in the research, further study is proposed on the real influences of LED lighting, aroma and sound on users of air-conditioner, and also application through different environments and regions around the world.

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