Using a Climatic Chamber to Measure the Human Psychophysiological Response Under Different Combinations of Temperature and Humidity

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SUMMARY

Climatic chambers have been built and use for many proposes, including environmental psychophysiology research. The aim of this study is to determine the appropriateness of using the climatic chamber FITOCLIMA 25000 to measure human psychophysiological response under different settings of temperature and humidity. To evaluate its performance were done several tests. Results and chamber specifications were analysed according standards and scientific criteria. In spite of some disadvantages detected in short time settings, it was concluded that FITOCLIMA 25000 is able to reach the highest standards of regulation.

1. INTRODUCTION

1.1 Climatic Chambers in Occupational Health and Safety Research

There are a lot of activities exposed to different severe thermal environments in outdoor work, such as farming, fishing, open pit mining, constructing, police patrolling, street cleaning, and sweeping, wild land fire-fighting and so on. Indoor activities also have hard exposure conditions such in cooking, laundering, mining, foundry work etc. The hazards usually occur when the workers are exposed to extreme heat/cold for too long. In a situation of heat, exposure, hyperthermia can be worsened by the exercise/work that is being executed. Despite decades of research and technological development combined with sophisticated methods of risk assessment and preventive measures implementation, the accidents still happens.
Climatic chambers have been built and used with many purposes, such as: to assess thermal comfort for energy savers buildings (2), to test the treatments of respiratory diseases since 1955 (9, 10, 12) and for occupational health and safety, at least since 1968 (1, 5, 13, 14). Climatic chambers results have also been used to validate mathematical models of human thermoregulation applied in several knowledge areas (4).

1.2 Environmental Psychophysiology Experiments

Environmental physiology experiments related to psychophysiological response to thermal environment are usually done in controlled laboratory environments.
As it happens in other experimental devices it is necessary to control the parameters under study (in this case temperature and humidity) and ensure that the influence of other parameters that may interfere on the results is reduced or eliminated.
These thermal environmental studies comprise three levels of concern:

- Environmental Factors;
- Human Psychophysiological Response Factors;
- External Factors.

Environmental Factors can be divided into physical (including thermal environment parameters) chemical and biological parameters. Thermal environment can be characterized by temperature, humidity, radiation and air velocity. From these variables only temperature and humidity are regulated. The others have to keep their values over the time to assure environment stability. The noise is another concern. In spite of there is no relationship between noise level and human thermoregulation response noise clearly affects performance, so it must be reduced and kept as low as possible inside the chamber. During experiments one or more individuals are inside the chamber. Because of human occupancy, it is important to monitor the oxygen and carbon dioxide concentration. More people consume more oxygen and produce more carbon dioxide. The climatic chamber in test is the *Fitoclima 25000* that can be considered a closed room where the air exchange is performed with the inherent restrictions to the regulatory capacity and the accuracy of the camera itself. The problem here is that, in longer experimental exposures, high levels of carbon dioxide as well as low levels of oxygen can decrease physical and mental performance. High levels of occupancy and low rates of air flow may also increase environmental bio-burden. But air quality is not only influenced by human occupancy. The combination of temperature and humidity influences the individual consumption of oxygen, production of carbon dioxide and the increase and dissemination of microbiological organisms. High levels of temperature and humidity may also influence the releasing of volatile organic compounds (VOC's) from chamber's building materials (plastics, glues and paints).

Human psychophysiological responses are the most important factors. The state of knowledge gives us important information about the kind of factors that may influence psychophysiology performance; the human physiology provides clues about exposure limits where there is no influence; the human psychology gives advices about human behaviour and sensations of comfort/discomfort. For example, human thermoregulation responses, physical and cognitive performances are all influenced by the circadian rhythm. The performance after 1h of exposure to a specific environment is not the same as after 3h or 4h. The very own diversity of the human being makes difficult to define exactly what is or is not relevant to a specific analysis. When designing an environmental psychophysiological experiment, the collected data will always depend on several factors that must be taken into account but, by obvious reasons, cannot be completely eliminated.

This dimension helps in chamber's validations by quantifying the levels of environmental factors mentioned above, defining:

- The accuracy degree of the temperature and humidity regulation to assure a steady state environment;
- The admissible levels of radiant heat and air flow to assure steady state;
- Lighting quality within the chamber;
- Admissible levels of occupancy due to air quality changes;
- Cognitive ergonomic design to inhibit anxiety, fear and increase levels of confidence inside the equipment.

External factors include variables such as lifestyle, diet, individual characteristics, global health condition, medications, sleep deprivation and many others. All these variables influence human tolerance to heat and cold, and also, the mental and physical performance. Nevertheless, they are not directly related to the features of the equipment or facilities, so they are out of the aim of this study.

1.3 Other Climatic Chamber Features

In some studies that analyse the thermal sensation is stated that the control of the accuracy is: ±0.12ºC around a set point temperature (Schellen et al. 2010); ±0.5ºC and ±5% of relative humidity and special discrepancy less than 0.2ºC (Chen et al. 2011); ±0.2ºC of temperature and ±1% to ±5% of relative humidity (0.25g/Kg), also ensure that *mean radiant temperature* and *air temperature* are the same over *steady* and thermal *transient* states (8).

For instance, based on the studies of Kjerulf-Jensen et al. (1975), Kolarik (8) describes a climatic chamber with 5m wide, 6m long, and 2.5m high. It was developed to accurately control the thermal environment. Temperature inside the climate chamber could be regulated between 5ºC and 50ºC, with the accuracy mentioned above. The control system of this climatic chamber was modified to provide steady changes of the temperature set point, necessary to establish the planned temperature ramps. The climate chamber walls consisted of vinyl sheets, which were separated from the solid outer chamber walls by an air space of approximately 16 mm. A fraction of the air supplied to the chamber flowed behind the vinyl sheets, ensuring that air and mean radiant temperatures were equal during both steady and thermal transients. Air and operative temperatures, air velocity, and air humidity are measured continuously at the center of the chamber at 0.6m above the floor (8).

2. MATERIALS AND METHODS

2.1 Methodology

The ability of climatic chamber to control temperature and humidity lead us to the concept of stability. The human thermal response is linked to the environment exposure, and is continually adapting to it. When the objective of an experiment is to see exactly how the cognitive and physical factors change according to a specific environment, it is fundamental to assure the stability of the system. Otherwise, instead of relating human response to a specific environment, it would be related to transient conditions (such as ramps, drifts or cycle variations), which are the opposite situations.

To define the system stability is not enough to ensure steady state conditions of temperature and humidity. It is also very important to assure that all environmental parameters that influence human cognitive, physical and physiological responses are under control.

The first thing to do is to define the purpose. Climatic chamber is a valid equipment if it is suitable to the experimental goals. Firstly, it is important to define what to measure, and in what circumstances.

Secondly it is fundamental to define evaluation criteria. Here the current state of knowledge gives information about what is or not admissible in relation to what may or may not influence the collected results.

Finally it is important to prove the suitability of the equipment. The evidence is based on data collected from the equipment and laboratory facilities, and these results must be compared with the established criteria.

2.2 Environmental Factors Evaluation Procedure

2.2.1 Temperature and Humidity

To test the ability of the *Fitoclima 25000* chamber in order to regulate temperature and humidity several tests were performed. Accuracy was tested in a

representative central combination of 25ºC and 60% RH for a 24h period. The trials were repeated 3 times to verify if the equipment' behavior was reproducible and stable for short, medium and long periods. All the tests were done through a period of 24h of data collection and 24h of resting time.
It was also tested how long the chamber takes to achieve steady state. Steady state is reached when the measured values are ranging up to ±0.5ºC and ±2.5% HR around the set points, according to the manufacturer's technical specifications. To collect these data, all trials started from the same environmental conditions (22ºC and 40% HR). The initial combination was chosen because it represents the most common temperature and humidity found indoors, inside the laboratorial room. Depending on humidity level, tests could be 6h to 8h long. At this point were evaluated: the time necessary to achieving a steady state, the upper and lower bounds of maximum and minimum values, and the higher amplitude at set point level. According to the manufacturer, the accuracy may depend on adjustment values, so these tests were done using different combinations of temperature and humidity in order to map the controlling behavior of *Fitoclima 25000*.

2.2.2 Concentration of CO_2 and O_2

The occupancy level, in the chamber, may change from 1 person to 3 people. In order to study the production of CO_2 and O_2 consumption, its concentrations were measured along a 2h period at 9 combinations of temperature and humidity and 3 levels of occupancy showed in table 1.
Tests were performed after both, temperature and humidity, set points were achieved and kept above ±0.5ºC and ±2.5% HR respectively. In all trials people were simulating sedentary pursuits. They were seated for the two hours, spending the least possible energy.
During the trials the door was only opened twice, at the beginning and at the end of the trial (two hours later) to allow the entry and exit of the people.

Table 1. Temperature, humidity and occupancy level

*Occupancy Level**	*Temperature (ºC)*	*Relative Humidity (%)*
1 2 3	20/25/30	30/60/90

* Number of people inside the chamber.

3. RESULTS

3.1 Fitoclima 25000 description

The entire camera design was thought to be used by human subjects so the design of the chamber transmits comfort and confidence when being in use. It was built by "ARALAB" which strictly follow all the international rules of safety engineering and cognitive ergonomics.
Fitoclima 25000 has one door, three windows, the walls are all white, have very good artificial lighting levels, the floor is grey, the indoor lock is green, (in order to be easily seen), and the door can always be open from inside. That is an important feature, because it allows the research subjects to end the trial whenever they want and, still more important, it assures that no one can be locked inside. Windows are very important because they allow subjects to see what is exactly happening outside the chamber all through the period of the trials (in the entire laboratory facilities), reducing anxiety and increasing confidence (fig. 1).

Fig. 1 - Climatic chamber seen from the inside.

The climatic chamber also has safety mechanisms that shut it down automatically when overheated. Given the following conditions or inadmissible anomalies, safety devices turn off the apparatus in order to avoid its destruction:
• High temperature inside the chamber;
• Low temperature within the chamber;
• Excess temperature in the condenser;
• Lack of water in an ultrasonic generator;
• High pressure in the cooling system;
• Low pressure in the cooling system;
• High temperature compressor discharge;
• Low temperature at compressor suction;
• Internal failure of the compressor;
• Excessive consumption of the compressor;
• Excessive consumption of the fan;
• Failure of the internal fan;
• Abnormal conditions in the supply voltage.

Installed sensors continuously monitor the levels of CO_2 and O_2 inside of the chamber and an alarm sounds when limit values are exceeded.

As recommended (7), the laboratory facilities have changing room, with shower, as well as areas for subjects to change clothes, to be prepared in privacy and, if necessary, to rest and recover after going through an experiment. The entrance of the climatic chamber has a large free area to assist people who may feel sick during the trial. The space is large enough to lie down a person and provide medical aid considering all the emergency equipment that may be necessary. The area also has natural direct ventilation trough two windows to facilitate the cooling down of the air.

3.2 Technical Specifications

The climatic chamber *Fitoclima 25000* was built to regulate temperature and humidity within a specific range (-20ºC to 50ºC and 30% to 98% RH), being able to control relative humidity (<±2.5%) between 10ºC and 40ºC (see fig. 2).

Carbon dioxide and oxygen cannot be adjusted but are controlled all along. Carbon dioxide monitor presents a measuring range from 0 to 5000 ppm, an accuracy of less than ±50ppm plus 3% of measuring value, at 25ºC, with an increase of 2ppm/ºC around it. The sensor supports temperatures and conditions ranging from -20 to 60ºC and from 0 to 100% RH. Oxygen sensor is also a sturdy apparatus. It works in environmental conditions ranging from -25ºC to 70ºC and from 0 to 95% RH. The accuracy assured is 3% in the range of measurement.

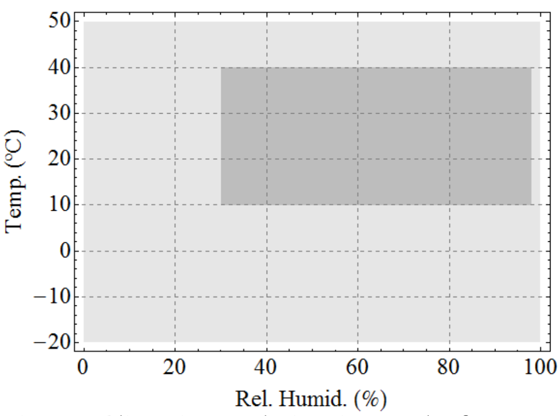

Fig. 2 - Climatic regulation interval of temperature and humidity.

3.3 Temperature and Humidity Adjustment

According climatic chamber specifications, *Fitoclima 25000* is only able to ensure relative humidity regulation between 10ºC to 40ºC and that is why it were tested combinations within this temperature limits.

It was proved the reproducibility of the tests. Although the environmental conditions within the laboratory facilities being different for all experiments, the behaviour of the chamber was exactly the same in the three experiments performed for each one of regulation combinations (fig. 3).

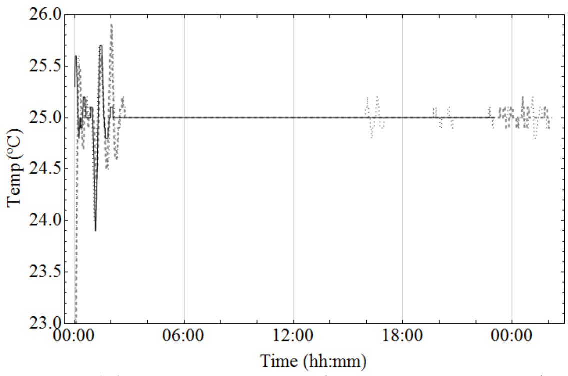

Fig. 3 - Temperature regulation at 25ºC with 30%RH. (Legend: Day 1 – Gray Dashed Line; Day 2 – Black Dotted Line; Day 3 – Black Thin Line).

This test also shows a slight instability after a work period that exceeds 16h of consecutive work. But the amplitude of this change does not exceed 0.2ºC. Temperature set point is reached faster than humidity set point. With this first trial we got 1:2 period. The lowest amplitude value (zero variation), was achieved after 2h for the temperature test. For the humidity, the time increased to 6h. A completely stable environment inside the chamber was always assured in less than 10h. After the 10h period the temperature and humidity amplitude ranged within 0.1 to 0.2ºC and 1 to 2% respectively.

The stabilization times were measured considering the criteria defined in section 2.2.1. It was chosen points that represent the boundaries of the climatic regulation range.

According to *Fitoclima 25000* specifications, its admitted stability is reached when amplitude ranging 2ºC and 5% RH around set point values. Data confirm that temperature get always set first than humidity, that is because relative humidity depends on temperature values and a precise regulation can only be done after temperature is set. Results also showed that is easier to regulate humidity at moderate temperatures. At 40ºC, the *Fitoclima 25000* does not reach the target of 98% relative humidity in the first 8h of trial. From the intermediate values we can see that in these boundary limits chamber's behaviour is more unpredictable, more instable, maybe because as in nature, these environments are difficult or impossible to get. Very high temperatures are not compatible with extreme levels of humidity, and the same happens with low temperatures.

The values in table 2 are examples of boundary conditions. Under these conditions have been found the largest amplitudes and stabilization times

For all the other combinations the results are, at least, equal to ones listed on Table 2. For long trials, such as 24hrs, the *Fitoclima 25000* proved to be able to ensure high stability throughout the test.

Table 2. Maximum/Minimum and Amplitude Values after steady state and steady state achievement time.

a) Temperatures				
T(ºC)_HR(%)	Max	Min	Amp	Time
10_30	10,4	9,7	0,7	03:14:10
10_98	10,4	9,8	0,6	01:43:10
25_30	25,1	24,9	0,2	00:45:50
25_98	25,1	24,7	0,4	00:52:10
40_30	40,3	39,7	0,6	02:22:10
40_98	40,2	39,7	0,5	01:31:30

b) Humidity				
T(ºC)_HR(%)	Max	Min	Amp	Time
10_30	30,8	27,8	3,0	02:13:10
10_98	98,0	96,3	1,7	07:30:50
25_30	30,8	29,1	1,7	01:45:10
25_98	97,7	96,0	1,7	03:27:50
40_30	30,9	38,5	2,4	00:49:50
40_98	Not achieved in 8h trial.			

3.4 Concentration of CO_2 and O_2 Monitoring

Fitoclima 25000 presents an excellent behaviour in the air renewal. Carbon dioxide concentration along the time was studied by linear regression models, and Person's correlations indices were calculated to assure the best levels of correlation. Linear regression models represent, with high accuracy, the collected data (fig. 4). The concentration increase per hour was calculated and the values for 1 person and 3 people are showed in Table 3.

The Figure 5 shows the drift of the data along a 2hrs trial period for the Oxygen. More tests were done and the maximum variation found was of 0.1-0,2% in the whole period. This proves that insufflated air is enough to assure a good level of oxygen. Oxygen level is always maintained around 21% of volume.

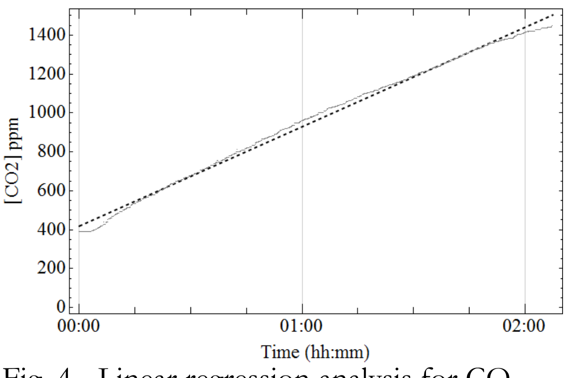

Fig. 4 - Linear regression analysis for CO_2 concentration over a 2h trial at 30ºC/90%HR with 2 people inside. (Legend: *Linear regression curve*: black dashed line; *Original data*: grey dots)

Pearson's coefficient values vary around 0.9. So, all the models were considered to be representative of the experimental data. Calculated results prove an increase in CO_2 levels with the occupancy and with the set point of temperature and humidity. The production of CO_2 increases more rapidly to higher values of temperature and humidity than for lower temperatures.

3.5 Other environmental conditions

In order to prove complete suitability of climatic chamber *Fitoclima 25000* there are other aspects that must be tested as mentioned above (lightning, noise levels, COV's release, bio-burden concentration, etc.). The diversity and extension of the theme, thus, demands that these aspects be subject of a further analysis.

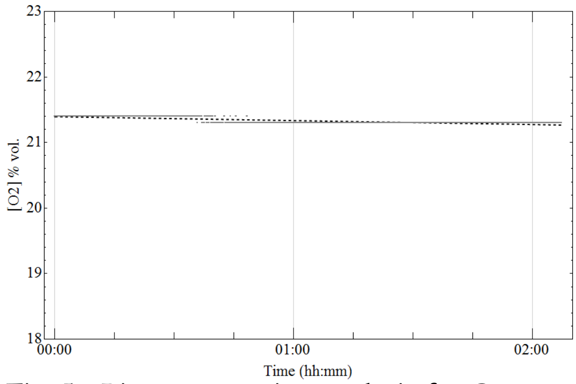

Fig. 5 - Linear regression analysis for O_2 concentration over a 2h trial at 30ºC/90%HR with 2 people inside. (Legend: *Linear regression curve*: black dashed line; *Original data*: grey dots)

Table 3. Variation of CO_2 concentration according temperature, humidity and number of people.

Temp.(ºC)/Humid.(%)/_Nº. People	[CO2] $ppm.h^{-1}$
20_30_1P	329
20_30_3P	493
30_30_1P	174
30_30_3P	579
20_90_1P	209
20_90_3P	838
30_90_1P	425
30_90_3P	94

4. CONCLUSIONS

According international standards drifts should not vary over 2ºC/h and cycle temperature should be less than 1ºC peak-to-peak (6). The 2ºC in space can warrantee no variation in thermal sensation (2) between acceptable limits. Literature values are more demanding than international standards.

Technical specifications of *Fitoclima 25000* perfectly assure the interval considered admissible to experiments.

Some scientific studies said that for drifts, with 0.5clo, are suggested 0.5-0.6ºC/h to assure non-

sensible variation within a period of at least 3-4h (2, 8).
In their study, Schellen et al. (11) refer an accuracy of ±0.12ºC around the set point. Kolarik et al. (8), in turn, present an accuracy of ±0.2ºC, ±1 to 5% RH (0.25g/Kg) and also ensure that mean radiant temperature and air temperature are equal during steady and thermal transient states.
For less accurate settings *Fitoclima 25000* is able to do several trials in one day, depending on the exact values of temperature and humidity set point needed. For high accurate adjustments, *Fitoclima 25000* is able to do a trial per day or one in two days. This happens because it needs to include a rest period from one set point to another. However, when properly rested and settled, *Fitoclima 25000* is also able to reach the highest demanding criteria of stability.
Finally, according the presented facts, we can state that the chamber *Fitoclima 25000* and laboratory facilities, considering the presented analysed data, are adequate to the purpose of evaluating psychophysiological responses of the human body at different combinations of temperature and humidity.

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