A PRACTICAL EXAMPLE OF THE *CHAT_D* SOFTWARE APPLICATION FOR PREDICTING THE RISK OF THERMAL DISCOMFORT IN A HOUSE EQUIPPED WITH A COOLING FLOOR.

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ABSTRACT

The *CHAT-D* software environment was developed by the Electricity Applications in the Residential and Commercial Buildings Branch, of the research and development division of EDF (Electricité de France). Our main objective is to ensure the well-being and the comfort of the inhabitants.

Work carried out with the CNRS (Centre National de la Recherche Scientifique) of Strasbourg has enabled us to define the behavioural laws of a human being's metabolism, showing the advantages of a dynamic model.

In order to demonstrate the efficiency of *CHAT-D*, we will be studying an academic case which is a close simulation of a real situation and which initially qualifies the thermal environment experienced by a human being. The chosen example simulates various scenes of activity (reading, cooking, eating, working) of a human being in accommodation equipped with cooling floors during the summer.

According to the simulation conditions, we can continually monitor the comfort experienced, and also propose technical solutions capable of satisfying the inhabitant at any moment.

INTRODUCTION

In order to satisfy their consumers, EDF suggests various environmental control configurations. The capacity for predicting the quality of thermal comfort goes beyond economical considerations and it is for this reason that we have developed a computer model for risk prediction of thermal discomfort.

Depending upon climate, the building and the type of cooling and heating, the significance of thermodynamic influence can vary greatly, thus resulting in the occupants having a different perception of their quality of thermal comfort.

The variations in judgement are due to the differences between people (sex, age, culture, sensitivity to the seasons etc) and the inherently subjective nature of the perception of thermal comfort.

EDF and CNRS have begun to study and develop a dynamic model for thermal comfort, called CHAT-D (Human Behaviour in a Dynamic Thermal Environment) which is intended to qualify an environment with a given thermodynamic configuration.

Using this validated model we will study the effect of a cooling floor installed in a French house in mid-summer.

ANALYSIS

A human being, during his daily life, is subjected to large thermal variations. One's physiological system adjusts itself continually to the variation in one's physical activity, the changing weather and one's state of mind, not to mention the related subjectivity - happy or sad, tired or hungry, alone or in a group.

The human being is more capable of judging his thermal discomfort than his comfort. It is for this reason that we will only consider thermal discomfort in our work. For the same reason our work is limited to a French male and female population between the ages of 25 and 35 years old.

Thermal comfort is based on the thermosensory assessment of people exposed to steady state conditions. Comfort is predicted from the human heat balance equation which is quite easy to calculate when ambient parameters are stable.

The “ Stolwikj ” computer model[1] makes it possible to quantify the physiological responses to the ambient condition and deduce from it. We have elaborated a " psycho-physiological " model predicting the risk of discomfort originating from changes in local skin temperature distribution.

We have refined this model, taking into account the true reactions of a human being faced with the thermal changes close to those encountered in living conditions.

To check whether this model could also predict accurately the discomfort risk under thermal transients, we carried out experiments in which subjects were exposed to climates leading them progressively from a slightly cool sensation to a slightly warm sensation (and *vice-versa)* over periods of 30 minutes (equivalent to a convector or radiator panel) and 60 minutes (equivalent to a heating or cooling floor).

METHODOLOGY

In the model used here, the human body is divided into many segments. Each segment includes layers: core, fat, muscle and skin. In addition, blood is supplied to each layer, fat being the least irrigated. The large segments in our case are : head, trunk, arms, hands, legs and feet. Right and left limbs are considered separately.

Each body segment is divided into areas when assessing the radiant heat exchanges because of the angle factors involved in radiation with the environment. 45 sub-segments are identified, giving 180 sections, in addition to the blood. All body segments are cylinders, except the head, which is a sphere.

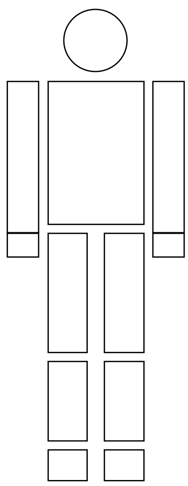

Fig 1: Main segments

This model may be clothed, in which case the heat exchanges are calculated after taking into account the outer temperature of clothing.

All local heat exchanges and metabolic heat production lead to section temperatures which are compared to the set point values.

Differences between actual and reference values induce physiological reactions : vasomotor adjustments, shivering heat production or sweating.

Due to these responses, the body temperatures will be adjusted, as will the heart rate which is the " heat convector " in the body. As a result of internal and external heat exchanges, local skin temperatures are generated, which provide the main inputs for comfort assessment.

As a matter of fact, it is stipulated that discomfort may originate from the rise and fall of skin temperature as well as from discrepancies between the actual temperatures and an ideal skin temperature distribution. This can be easily observed in the case of exposure to the thermoneutral homogeneous climate at low air velocity[2].

The formula used to predict the discomfort risk takes into consideration:

- The mean skin temperature, which is a major influence,
- In the case of no change in mean Tsk, body segments may be responsible for discomfort,
- Extremities and gradients between them are often at the origin of global discomfort.
- Asymmetries between right and left parts of the body are also accounted for in the prediction.

Discomfort may result from global or local cold or warm prediction but also from unpleasant thermal heterogeneity.

Discomfort risk : I.R.I

$$I.R.I. = [(\alpha.e^{\Delta Tsk} \times fct\ (\text{Gradients between extremities}) + \Sigma\ \text{Temp body segments}] \times \beta\ \Sigma\ \text{Temp extremities}.$$

ΔTsk : experimental variation of the mean skin temperature.

fct (Gradients between extremities) : experimental variation of a combined difference of temperature from the extremities.

Σ Temp body segments : experimental variation of the difference of temperature of the body segments.

Σ Temp extremities : experimental variation of the sum of the temperature of the extremities.

The predictions apply to a large population only since the inter and intra-individual variations are too great to be able to predict the dissatisfaction of a particular individual.

In order to use the results easily, CNRS and EDF developed together a computer program, called *CHAT-D* based on the human thermal-regulation model from " STOLWIJK ".

Normally, thermal comfort is based on the thermosensory assessments of people exposed to steady state conditions and comfort is predicted from the human heat balance equation which is quite easy to calculate when ambient parameters are stable.

The Stolwijk computer model makes it possible to quantify the physiological responses to the ambient condition and deduce from it. We have elaborated a psycho-physiological model[3] predicting the risk of discomfort originating from changes in the local skin temperature distribution[4].

EXPERIMENTS.

In order to check whether this model could also predict with good accuracy the discomfort risk under thermal transients, we carried out experiments in which subjects were exposed to climates leading them progressively from a slightly warm to a slightly cool sensation (and vice-versa) over a period of 30 or 60 minutes, such as is encountered in everyday living conditions.

We are now able to predict the discomfort due to the skin temperature for thermal condition variation periods of the order of 30 minutes, which is very reasonable for our building applications.

Subsequently, we wanted to validate the model in dynamic conditions and to show the advantages of a dynamic model. This was illustrated when it was found that *CHAT-D* informed us of the presence of the human being's memory concerning the appreciation of thermal comfort as well as a form of hysteresis which is not found in traditional models.

In figure 2, we observed a thermal step over a 30 minute period. In this example, thermal conditions evolved from PMV[5]=0,5 to a PMV=-1. This protocol will be used subsequently in the presentation.

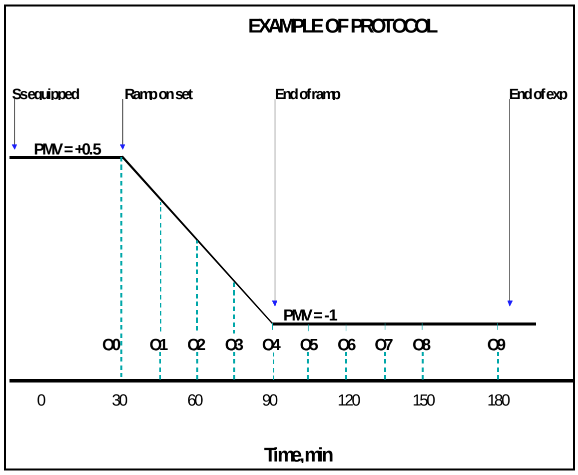

Fig 2 : Example of thermal step condition.

The response of calculated mean skin temperature is very close to the real one measured on people (fig 3). The same results were found for the other steps.

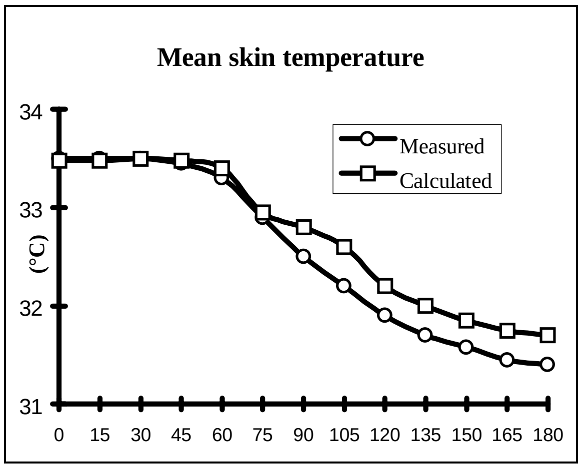

Fig 3 : Response of calculated and measured mean skin temperature to a step.

In order to compare the initial situations, we calculated from the responses of people, a " pseudo PMV " used for the dynamic steps and called it " Thermal sensation". In figure 4, we observed a reasonable prediction of thermal sensation in accordance with the theory, and we can deduce that in the same conditions, PMV is still a good parameter for measuring the effects of thermal transients

However, after 120 minutes, the thermal sensation value was less than the PMV value. In all the experiments, after a positive step followed by an equally negative step (for example : step for PMV=-

1 to PMV=+0,5 and then from PMV=+0,5 to PMV=-1), we observed at the end of the experiment a thermal sensation value which differed from the correct one. In our case, we should have had PMV=-1 but we found TS=-1,5.

This shows a type of " memory " of the human body, thus demonstrating the advantages of studies working with a dynamic model.

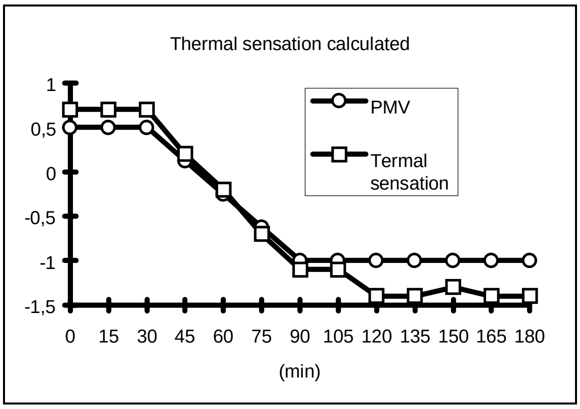

Fig 4 : Evolution of the thermal sensation according to the theory (PMV).

Considering a threshold of 30% as necessary for a pronounced discomfort this leads to the conclusion that the cool conditions were judged as uncomfortable while no discomfort was ever observed in the warm environment**.**. In our case, if we agreed this limit, we observed (fig 5) that after 60 minutes, people were dissatisfied until the end of the experiment.

The " **IRI** ", d**I**scomfort **Ri**sk indicates that for a value below 80, 80% of people judge the conditions to be without discomfort, above a value of 100, 80% of people judge conditions to be with discomfort. Between these values (80 and 100), the results are uncertain.

In our case, we observed (fig 5) that up to 65 minutes, predictions gave no discomfort, showing that there are differences between our predictions and the observations.

Depending, on whether the step is an increase or a decrease, and on the slope of the step, the " time constant " of the human body differs. When the slope is high (30 minutes) the time constant (60 minutes) is longer than for a slow slope (60minutes) where the time constant is close to 30 minutes.

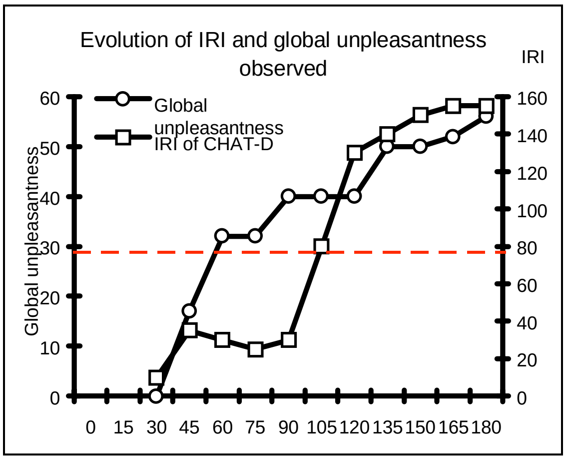

Fig 5 : Evolution of the global unpleasantness observed and IRI of CHAT-D calculated.

This shows a type of " hysteresis " of the human body, demonstrating once again the advantages of studies working with a dynamic model. Because we are in the domain of slow thermal transients, the proposed model gives satisfactory results.

But using this model for transients of under 30 minutes will give false results according to the real " human body memory and hysteresis ".

PMV is still a good parameter for use with low thermal transients. The *CHAT-D* model gives correct prediction of skin temperatures, but a better accuracy would be desirable. It is possible to predict (or simulate) the risk of human discomfort from the skin temperature changes.

CHAT-D gives satisfactory results for slow thermal transients, but It should , however, be validated for unsteady conditions (oscillating climates).

SIMULATION.

In order to demonstrate the efficiency of *CHAT-D*, we will be studying an academic case which closely imitates a real situation and which initially qualifies the thermal environment experienced by a human being.

The example retained simulates various scenes of activity of a human being in accommodation equipped with cooling floors during a summer in France.

We have on our site a laboratory called " ETNA ", comprising two twin cells built in accordance with the French thermal regulations. One cell was left unmodified while the second one was equipped with a cooling floor.

During summer 1997, we recorded all the thermal conditions (external and internal). The water in the floor cooling system was at 18°C, and the heat pump was turned off when the interior temperature was less than 21°C. Windows were closed all the time, and there were neither shutters nor curtains. Photo 1 illustrates the lab.

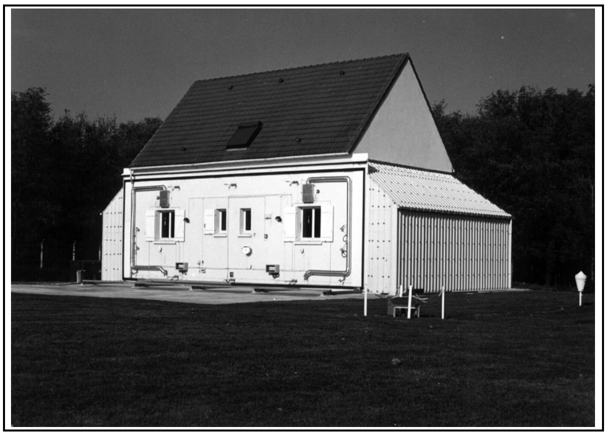

Photo 1 : The ETNA cells.

The external conditions were “ beautiful ” and figure 6 gives on a day (23/08) an idea of the sun global flux and the air temperature.

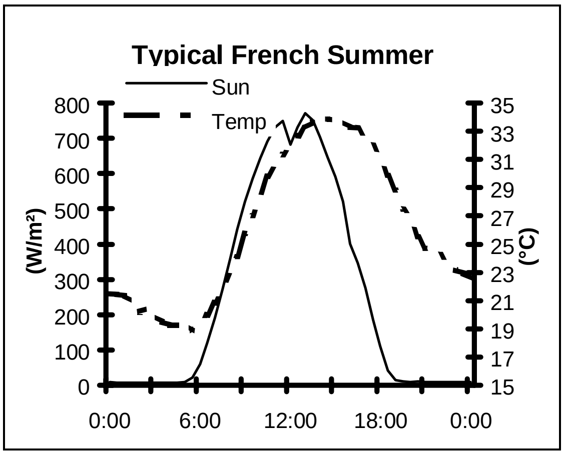

Fig 6 : Sun global flux and external air temperature for 1 day.

For these external conditions the temperatures (surfaces and air) within each of the cells were different. For example, we show in figure 7, the air temperature for the same day.

The difference in temperature had a mean value of 3°C, with a maximum of 4°C.

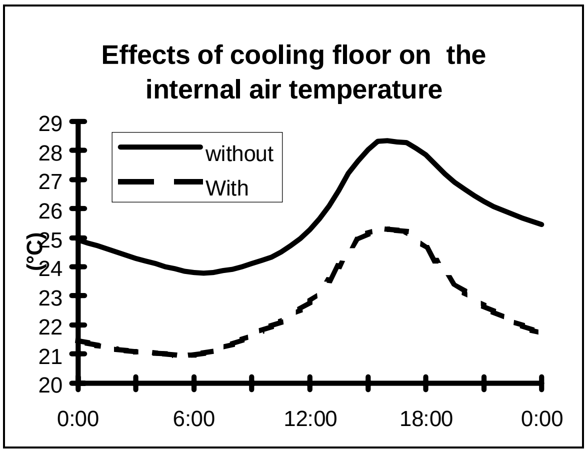

Fig7 : Effects of a cooling floor in a house.

Normally, International standards[6] define as comfortable an operative temperature of 24,5°C. In the unmodified room, the air temperature is up to 28°C. If we observed an air temperature 3°C lower in the cell equipped with a cooling floor, would it be right to consider someone living in this room as feeling better than if they were in the unequipped room ?

With the data base, we decided to test the benefit of a cooling floor in terms of comfort. We defined the conditions of someone in the “ house ” during a normal day, accounting for his position (standing, sitting, lying down) and clothing.

Figure 8 shows this configuration, representative of a French person during a typical working day in midsummer.

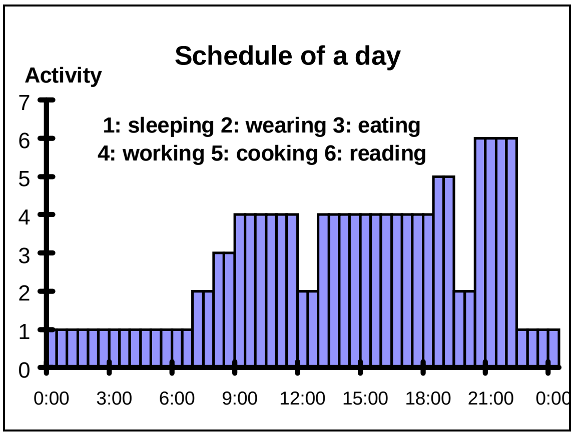

Fig 8 : typical working day.

In this schedule we have[5] :

- Phase 1 : sleeping, lying down in a bed, activity = 0,8 MET and clothing = 0,3 CLO (no top sheet, no blanket).
- Phase 2 : dressed, standing up or walking, activity = 1,6 MET and clothing = 0,5 CLO.

- Phase 3 : eating, sitting down at a table, activity = 1,0 MET and clothing = 0,5 CLO.
- Phase 4 : working, sitting down in the office, activity = 1,2 MET and clothing = 0,5 CLO.
- Phase 5 : cooking, standing up in the kitchen, activity = 2,0 MET and clothing = 0,5 CLO.
- Phase 6 : reading, sitting down in an armchair, activity = 1,0 MET and clothing = 0,6 CLO.

In all the situations, the person is in the centre of the room and looking at the south wall. When the person is asleep, he is lying down on the bed, without a top sheet or a blanket.

In figure 9, we observed the prediction calculated by *CHAT-D* for 30 minutes, for the room without the cooling floor.

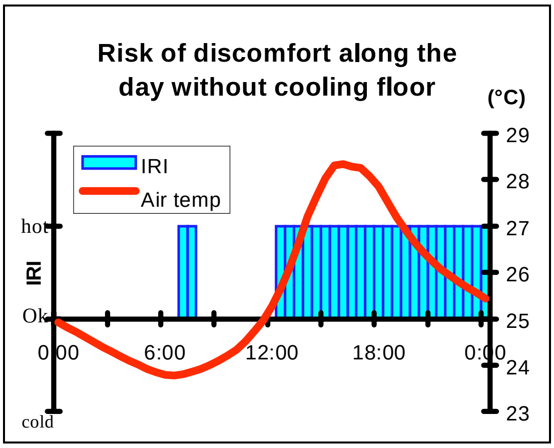

*Fig 9 : Risk of discomfort **without** the cooling floor.*

Someone living in this room will feel uncomfortable for more than 12 hours. For someone living out of a noisy urban centre, there is the possibility of opening a window but only during the night, when the external air temperature is less than the internal one. Without this possibility, people will tire quickly and could be " unsatisfied". Equally during the clothed phase, where air temperature is close to 24°C, IRI indicates discomfort.

In Figure 10, we observed the prediction for the room equipped with the cooling floor.

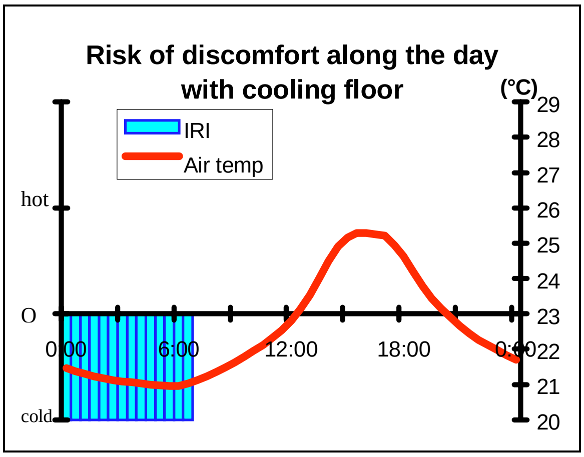

*Fig 10 : Risk of discomfort **with** a cooling floor*

Someone living in this room will feel pleasantness during more than 21 hours, without any change. But we can observed that the person was cold during the night (air temp : 21°C) and in this case, it's normal to put a blanket on the bed, increase by this way the clothing, and feel good. The quality of the " atmosphere " could be pleasant all along the day.

CONCLUSIONS

In this study, we have demonstrated that it is possible to predict the risk of human discomfort from the skin temperature changes, and our model *CHAT-D* gives satisfactory results where slow thermal transients are concerned.

On the very simple application of a cooling floor, we showed the usefulness of this tool (discomfort of the clothed and of the sleeping phase, and the advantages of a cooling floor). Obviously, we have to test and validate further the model, especially for faster thermal transients.

In our field (thermal building projects) the model can already answer many questions and we can suggest better air conditioning solutions taking into account human satisfaction.

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