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CONSIDERING REAL HYPOTHESIS IN DYNAMIC THERMAL SIMULATIONS OF SUMMER COMFORT IN LOW ENERGY SOCIAL HOUSING

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ABSTRACT

The object of this paper is to evaluate the impact of taking into account real behaviour on provisional Dynamic Thermal Simulations (DTS). The disparity that can occur between a model developed according to accepted hypothesis ordinarily used and a model deduced from real behaviour/ habits is significant. In order to take into account the hypotheses of real use, inhabitants are questioned about their practices in semi-directive interviews, based on a thematic grid. This allows the identification of genuine behaviour and its use as input in DTS software. The conclusions of the interviews permit the identification of non-thermal pressures the interviewees are subjected to. These pressures create illogical behavior from a thermal point of view which are not currently taken into account in predicted models.

INTRODUCTION

Buildings are adapting to energy rarefaction with low consumption goals (*BBC*) and now Thermal Law 2012 (*RT 2012*). The question of comfort in winter is technologically already resolved through good insulation and a reliable heating system, in both new and older buildings. Summer comfort is more difficult to model and therefore ensure. Indeed, it depends above all on the facilities that are available and how they are used by the inhabitants (windows, shutters). The increase in temperature in summer leads to discomfort. Buying an air-conditioning unit is a means of producing ones own constant indoor climate. The heat wave of the summer of 2003 contributed to the tripling of the number of air-conditioning units between 2001 and 2007. In effect heat within dwellings is considered a danger. The principal risk in massive air-conditioning equipment is creating new energy consumption while world context is increasingly moving towards energy moderation. The energy department has already observed peaks in the request for energy are increasing in the middle of summer days and it will get bigger in the future (*MEEDTL*, 2009).

Passive summer comfort in housing is an emerging stake.

Frames of reference about environmental quality have been created by contracting authorities (Rhône-*Alpes* region, *Grand-Lyon* metropolis and social backers). Their goal is to improve current and future accommodation but also to compare the operation of them.

For this reason these frames of reference impose a certain number of objectives in results and means of calculating. Dynamic thermal simulation is one of the tools to be put into place in order to prove that a certain quality of comfort can be attained in housing during summer without air-conditioning systems. It is a passive approach to summer comfort that is retained. For example, the frame of reference from the *Rhône-Alpes* region considers its objective of comfort to be not going over a temperature of 28°C inside the housing for more than 40 hours in one calendar year according to the climatic base of 2004.

Dynamic thermal simulation allows the consideration of complex hypotheses which can be divided into three classes: climate hypotheses, building hypotheses and users hypotheses. If the base climate file is imposed 2004 (*Meteo France* / French weather data) and the construction of the building defined, the hypotheses which depend on the inhabitants are not fixed for the calculation. For the same results behavior inputs can change, i.e. two models, with different hypotheses can reach the same objective but not in the same manner. This therefore compromises the comparison between the projects.

How can the proximity between retained hypotheses and actual behavior be confirmed?

Usually, there is not any connection between project management and building users. On an operational basis, the link between the different actors in a buildings life cannot be seen as a direct exchange. In effect the team that conceives the building does so according to the specifications of the management team, the norms and the suppositions they can make of the users. At this point, the building's response to users' demands is computed through the aid of different software, and therefore DTS software. Then, the project is built and delivered. The inhabitants occupy the building and manage it on their own. There are few studies about how people deal with indoor climate. Usually, this research is done by design offices that did not handle the conception (Enertech, 2012).

This study aims to develop a link between building design and occupation *by real inhabitants*.

This approach is based on a case study done on a group of 6 semi-detached houses in urban area and 4 houses in rural area. They are all situated in the *Rhône-Alpes* region in France.
The cohesion of the information and the actors in this study is guaranteed by its being carried out by the architectural and thermal design offices which conceived the building. The design and construction work is completed through a veritable field investigation. Data collection took shape in the form of oral interviews in order to understand the behaviour and feelings towards comfort. This approach based on a narrow sample is qualitative rather than quantitative. No measurements were made because the goal is to understand how people react, and not the building's response which is calculated through the use of software. The behaviour considered is typical of a certain number of uses but cannot be considered exhaustive. This study cannot therefore be applied directly to other cases.
Nevertheless, it allows the estimation of the disparity between admitted hypothesis and those deduced from the interviews of the field investigation. This data is integrated into the Dynamic Thermal Simulations model representing the building where the inhabitants questioned live. The Comfort-behavior link can be viewed as a dialectic relationship between an accommodation and its inhabitants.
How taking into account the real behavior of occupants can allow the evaluation of the relevance of projected dynamic thermal simulations about summer comfort in housing?
How can a more accurate assessment of comfort conditions impacts the design of future accommodations?
We will attempt to identify non-thermal elements which come into play in the establishment of summer comfort. That is to say what can influence the psychological adaptation of people and which methods to develop while computing behavior models.
Firstly this paper explains the method developed for this work. Comfort notion is explained in order to place this study in the context of studies carried out on this subject. A software model is then described in order to transpose the real comfort process into a theoretical projected model. The real hypotheses deduced from the survey are integrated into the model, in which the inhabited building was computed, in the form of uses scenarios.
Secondly the results are exposed and interpreted to appreciate the gap that can exist between the two kinds of hypotheses those accepted and those based on fieldwork. The emergence of comfort conditions will be considered according to the adaptive comfort theory (Brager, 2001). The relevance of the hypotheses which come into play or not in the model will be discussed in relationship with the case studies. The impact of setting up less restrictive technologies in habitations with identical uses, will also be tackled.
Finally, and to conclude the influence of previous results on generally used methods for predicted studies will be assessed.

METHOD

From comfort notion to comfort process

Thermal comfort was first considered as physiological condition (Fanger, 1973) of a passive subject. Only physical exchanges between the subject and his environment are taken into account (radiation, convection, conduction, evaporation). This analytical approach towards comfort based on environmental test chambers, considers an abstract individual outside of his real physical context. Furthermore this approach is considered to be universally adaptable to all humans as it only takes into account the physical aspects.
The appearance of the adaptive approach (De Dear, Brager, 1998) based on a database built from real buildings and users shows an evolution because an individual is considered within his context and can act upon it. The particularity of behavioural adaptation is that the subject can affect the building itself by directly modifying the climatic conditions. (opening windows, closing shutters). Thermal adaptation could be divided in three categories: physiological, behavioral and psychological adaptation. Adaptive comfort theory defines simply that the occupant should be able to act directly on their environment so that the comfort zone proposed can be used. This statistical approach has been developed thanks to data collected in several offices and we are studying housing. The role of different adaptations could lightly vary from Brager's theory.
The purpose here is not to propose a new comfort theory but to transcribe it as a process dealing with the individual, building and indoor climate. Those parameters form a complex system. An indoor climate's effect on comfort sensations is object of the study on physiological comfort (Figure 1: white part).This is quantifiable and has already been widely studied.

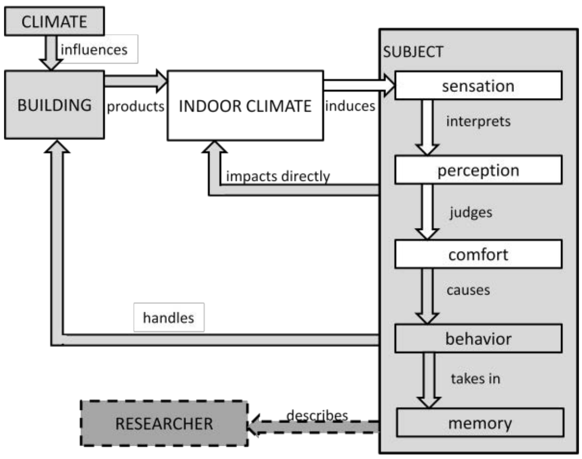


Figure 1 Process of adaptive comfort

Adaptive theory studies the relationship between indoor climate and an individual (Figure 1: light grey part). Although feelings are not quantifiable from an engineering point of view, behavior is a concrete element of which individual can communicate his own perceptions. So it is possible to collect information about his behaviour through discussion (Figure1: dotted grey part).
The chosen collect method is interviews based on a thematic grid tackling thermal issues (favorite temperatures, the experiences of discomfort, draft issues), control tools used (windows, doors, shutters) and comfort factors (thermal, acoustic, olfactory, visual…). The inquiry allows one to understand the way people produce their own comfort (Dard, 1986). Collect technique used is known in sociology as semi-directive interview. The data used here is constituted from what the individual says according to what he remembers. What people say from is memory founds database.

Settlement of model

Although comfort works as a process, the model produces output based on input data, by intervention of a code. The *Mines de Paris* School developed a finite difference program simplified by modal analysis called *Comfie*. Input interface is *Pleiades* software developed by *Izuba energy*. This tool is currently used by design offices to realize projected comfort studies. *Pleiades+Comfie* are employed to settle reference models from ordinary use hypotheses. Building hypothesis are computed too, and fixed. It allows one to set a reference model for the building studied (Table 1). The second step is to collect real uses, convert them into behavior hypothesis and implement them in a model.

Table 1
Reference scenario hypothesis

HYPOTHESIS	BASE	SOURCE
Weather data	*Lyon Bron* 2004	*Météo France*
Order temperature	Day: 19 °C Night: 16 °C	French law: *RT2012*
Occupation	4 people	*Rhône-Alpes* region reference document
Presence	Evening and week-end	French law: *RT 2012*
Ventilation	190 m^3/h maxi, 20 m^3/h mini	Conception documents
Over-ventilation summer-night	1 vol/h from 9 a.m. to 6 a.m.	*Rhône-Alpes* region reference document
Occultation in summer	50% from 10 a.m to 6 p.m	Hypothesis
Heat emission	Similar among weeks and rooms	*Rhône-Alpes* region reference document

The output is compared to a reference model. It is possible to compare the two calculations as only use changes between models.

The last step consists in interpreting outputs in accordance with real hypotheses with the feelings collected during interviews taken into account. In other words numeric approach is related to verbalized life experience (Figure 2).

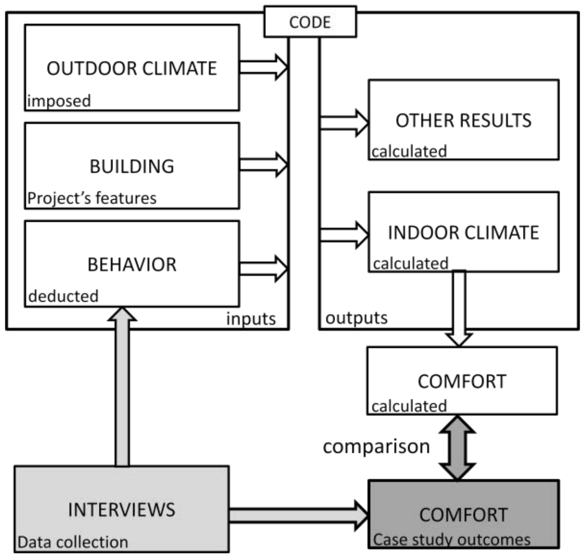


Figure 2 Parallel principle: projected calculation and case study

Data definition from case study

The case study is achieved through two real estate operations: four houses in a rural environment and six in urban areas. The researcher met with half of the families. This study presents urban case results (Table 2).

Table 2
Building features

BUILDING HYPOTHESIS	
Main orientation	South
Garden location	South of the house
Walls sandwich insulation	Outside : Styrofoam 11cm Inside : Styrofoam 8 cm
Roof insulation	Attic: 40 cm mineral wool
Isolation sol	Under slab: Styrofoam10 cm
Inertia	Average as to Thermal Law
Occultation	Roller shutter
Windows	1 leaf, inward opening
Heating system	Individual gas
Hot water	Solar, gas extra

The inhabitations studied are organized according to the same plan, duplex houses, with bedrooms upstairs. The design conception answers bioclimatic principles. Buildings are compact and the main rooms' windows face south. Only four small openings are made on the north side: one to naturally ventilate stairs, one to light up and ventilate the bathrooms, one with a non-opening window in the living room and one to set up cross ventilation in the kitchen. The constructive aspect of the buildings is recorded in the study and not modified to test the different use hypotheses. Semi directive interviews were done in spring 2012 with inhabitants in their homes.

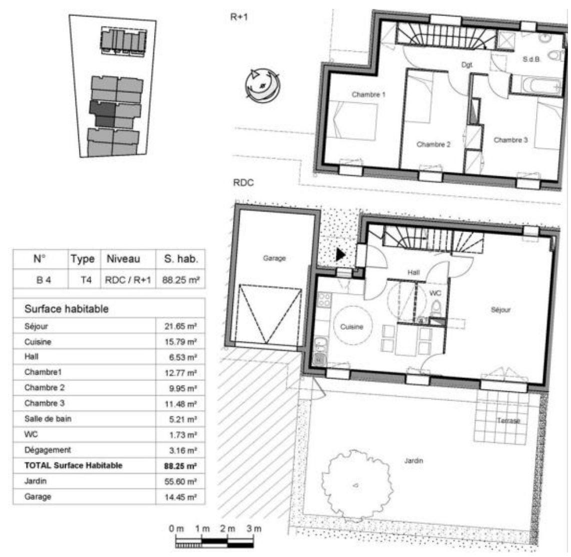


Figure 3 Building plan

Behavior indexes were created according to the records of the meetings and converted into behavior scenario, which can be entered into a model. The families were living varied situations. For example occupation, of four room accommodations, one of the families has a parent working at night, in another only one parent working, and the third one is a five people family.

Table 3
Deduced hypothesis in families scenarios, more common variant

FAMILIES	**1**	**2**	**3**
Occupation	4 people	4 people	5 people
Parent 1	Office hours	Do not work	Office hours
Parent 2	Three eight time	Three eight time	Morning or afternoon
Children	2 children	2 children, too young for school	3 children
Over-ventilation upstairs	Any	Any	1 vol/h from 6 to 10 a.m.
Over-ventilation downstairs	1 vol/h from 6 to 8 a.m., from 12 to 1 p.m. and from 7 to 9 p.m.	1 vol/h from 6 to 10 a.m. and from 5 to 10 p.m.	1 vol/h from 6 to 10 a.m. and from 5 to 11 p.m.
Summer occultation upstairs	100% from midday to 6 p.m.	100% from 1a.m. to 5p.m. and 8 p.m. to 8 a.m.	100% from midday to 6 p.m.
Summer occultation downstairs	100% from midday to 6 p.m. and from 9 p.m. to 6 p.m.	100% from 11 a.m. to 5 p.m. and from 8 p.m. to 8 a.m.	70% from 7 a.m.to 5 p.m., 100% from 11 p.m.to 5 a.m.
Heat emission	Weekly variation	Weekly variation	Weekly variation

This kind of situation is rarely taken into account in usual models. Indeed, usual scenario considers a four people family with two parents working at day.

Each interview leads to a concrete profile. Three typical profiles were considered according to the characteristics of each family meeting. They include: occupation, heat emission of electrical devices, occultation and ventilation (Table 3).

A weekly scenario of each kind has been programmed according to the information gathered and developed over the whole summer period. This shows a difference each day contrary to reference hypothesis where days are identical. Opening manipulations are matched with housing occupation time. In order to study outputs, a basis analysis period is chosen. This is the warmest week according to the weather file of 2004.

Data exactness

Setting up a model requires identifying the most pertinent zoning in order to evaluate the impact of the variation in the hypotheses. A zone by accommodation is specified in parametric test and a zone by room in coupled model. Additional, parametric tests have been done on a coupled model in order to confirm global zoning outcomes. The users met distinguished their behavior depending on the rooms of their house. Precise zoning emphasizes high heat emission rooms and low heat emission rooms (and rooms of passage). There is a concentration of electrical devices in high heat emission rooms (cookers, fridge in kitchen and television, computer in living room). Those zones are rather warmer in case study than in reference model where results are smoothed amongst the rooms.

RESULTS

Parametric observation

The reference model's sensitivity ("*base*") is studied in accordance with behavior hypothesis taken separately (Figure 4). For example: an inhabitant impacts on building and indoor temperatures (then his own comfort) by emitting heat. There are two sorts of heat: direct (metabolism) and indirect (electric devices).

- Occupation ("*occup A*"): while reference scenario plans no presence during the day, this hypothesis considers that there is at least one person in house all the time. The effect on temperatures is a curve shift rise. The difference is about half a degree Celsius.
- Internal heat emissions ("*apport réglementaire*"): heat emitted by electric devices varies during the day. Calculation done thanks to Thermal Law hypothesis is tested here. It impacts curve peaks but general temperature layout does not change.

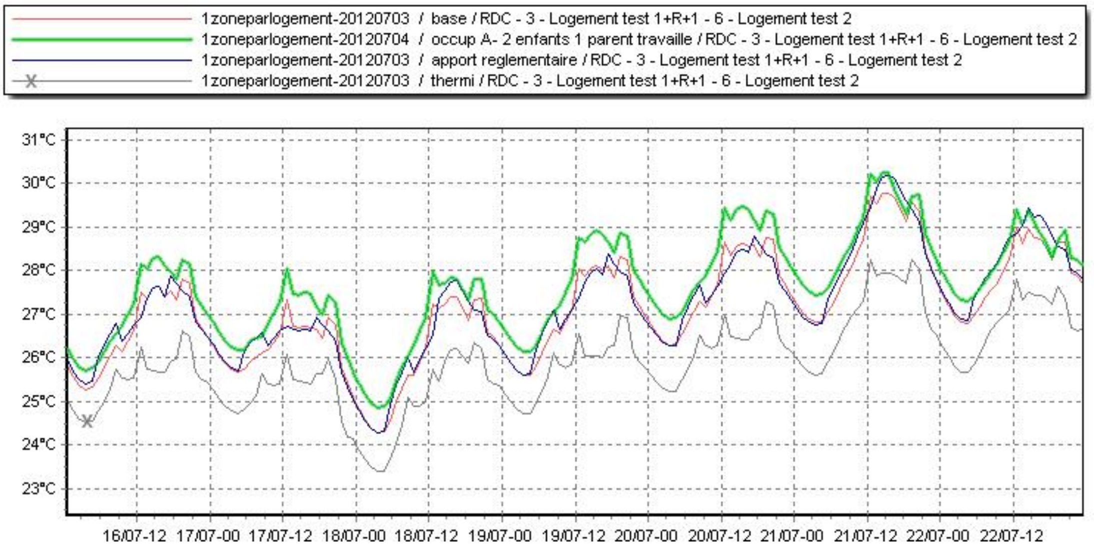


Figure 4 Temperatures curves, warmer week (July 16 to 23), parametric observation

The second way inhabitants affect temperature is to modify indoor/outdoor relationship. That is to say to act on openings by handling windows and shutters (ventilation and occultation). Action on these control devices is simultaneous.

- Opening ("*thermi*"): a maximized use scenario has been inputted. Solar protections (shutters) are totally closed at day and opened by night. A draft is set up at night too as to thermal principles. The effect is a curve shift at the low point of around a degree Celsius.

Coupled hypothesis

The next stage is to input the whole scenario. The accommodation is cut up into one zone per room in order to analyze more precisely outcomes. Temperatures differ between rooms, for instance between ground and second floor.

Temperature is lower downstairs. Case study scenario works on all factors at once: occupation, heat emission, ventilation, and occultation. The effect of coupled scenarios on building is greater than the addition of all effects taken separately in a parametric model. We can notice a large difference between temperature outcome from case study and from reference hypothesis (Figure 5). The three families studied have varied behaviour but the outcomes show similar inside climate. The gap in comparison with a reference model spreads between a three degree Celsius difference at day and six by night. When it comes to comfort, the situation is tough, as indoor living room temperature is higher or equal to outside temperature.

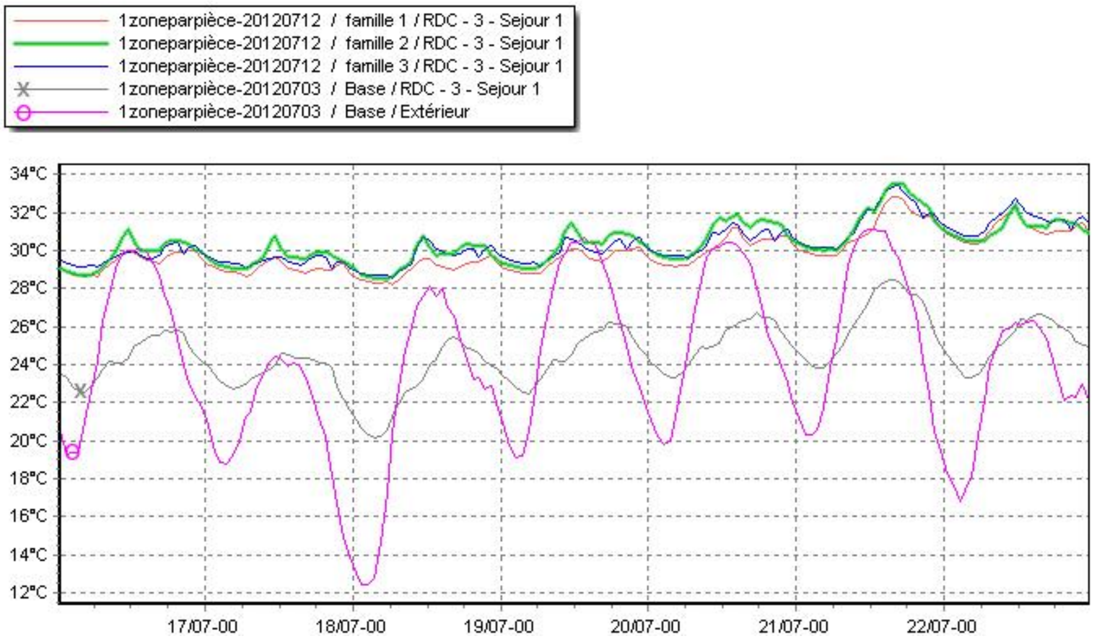


Figure 5 Temperatures curves, living room, warmer week (July 16 to 23), case study hypothesis

Brager comfort zone study comfirms this observation (Figure 6). Considering reference ("*base*") hypothesis the house is comfortable but with case study hypothesis comfort is unreachable.

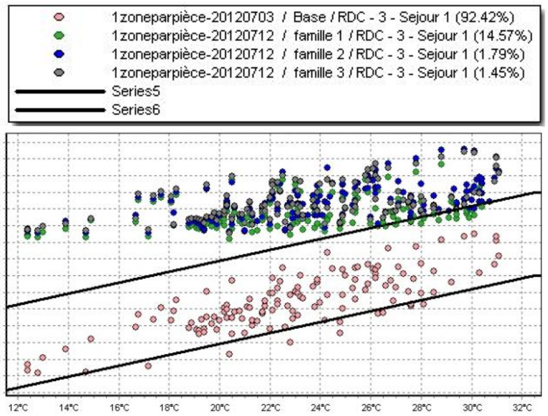


Figure 6 Brager's comfort zone (outdoor temperatures on the abscissa, indoor temperature on other axis)

We can identify the different causes of discomfort that exist between the fieldwork hypotheses and the office study. First, real occupation is widely under-estimated in a reference model. Secondly, occupants do not necessarily know heat science theory. They can encourage overheating without being aware of their action. Their behaviour could be efficient in one domain (occultation) but not in another (heat emission). The accumulation of faults in the uses of the building has a high impact on over- heating.

Calculated comfort versus narrated comfort

The outcome is that this house cannot be comfortable in real tested conditions. During the interviews families corroborated this observation. Two of them had already bought an air conditioning unit the previous year and the third family had just bought one in anticipation of the coming summer. This is neither an automatic purchase nor a luxury but due to previous summers being too warm inside the house. If we look at heat emissions from inside the house, we realize that there is often somebody in the house during the day. This is due to parents schedules which are not office timetables and imply a greater occupation. For example one father achieves a three-eight times.

Moreover; bioclimatic design promotes south orientation. As a result the garden is unusable on summer days. There are no shadows and it is too warm. People stay into the house to avoid the warmth outside during this period which heats up rooms even more. Given that the accommodation is well insulated according to low winter consumption targets; each heat emission is retained inside unless ventilation drains it off. Electrical devices heat emissions increase according to presence inside: television is turned on, computer is working… Heat created by cooking is extremely high and punctual. The cultural angle has to be considered. Certain families chose to cook outside to avoid temperature peaks inside. Others cook inside even in summer.

Inside/outside relation thanks to openings is impacted because of non thermal stresses. It cannot be taken into account by a heat transfer design office which realizes a projected model. Solar protection by roller shades is in competition with natural room lighting. In fact one has to choose between solar protection and natural light because if roller shades are closed the room is dark (Table 4).

Opening windows at night to freshen-up is limited because of the intrusion from insects. Security is also a parameter which can restrict opening, because of the fear of intrusion, through ground floor windows. Houses are located close to a factory. It restricts openings too because of smells. Discomfort due to cross drafts is mentioned by families too because it implies doors and windows slamming. The neighbourhood is not noisy, so this difficulty had not been mentioned by families.

Table 4
Non-thermal pressures effect

NOTICED BEHAVIORS	NON-THERMAL STRESSES
Inside withdrawal	Garden privacy Garden solar over-exposure
Windows closing	Nasty smells Door slamming Noise Insecurity feeling Insects
Shutters closing	Home privacy Natural lighting

The last point underlined by families during interviews, is the lack of privacy. The withdrawal inside the house is also due to the proximity of neighbours. South facing window location promotes free heat in winter thanks to the sun. However a major pressure comes up here as to the opening of shutters. The entrance to the neighbours is at the back of the garden which gives them an easy view on the inside of the house. Roller shutters stay closed in order to protect family from external gaze. A person said that in summer shutters are closed because of the sun, and in winter because of people looking in. This is a case study but it shows that human factor, which seems only to be linked with uses, can impact thermal behavior. Those specific uses are affected by the space design of the considered houses.

Comfort processes presented before (Figure 1) have to evolve in accordance with what we find (Figure 7). Indoor climate is not the only stress impacting people's behavior. Models are ignoring an important part of external confines on individuals. Dynamic thermal simulation can take into account precise thermal inputs but it could be pointless if a major pressure is forgotten. The issue is to know if non-thermal stresses are important enough to be considered. Moreover a designer cannot foresee what will happen in future building.

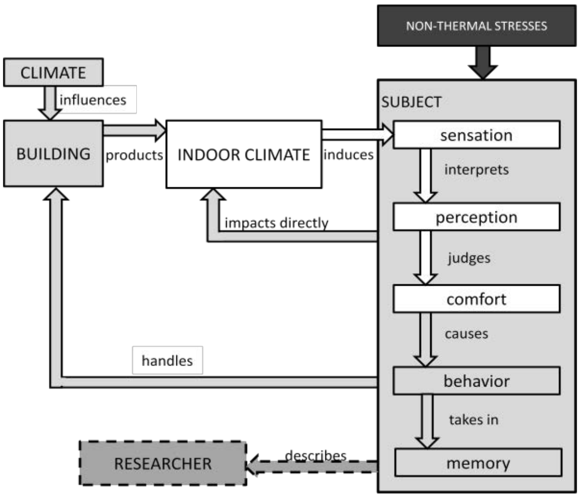


Figure 7 Effect of non-thermal stresses on comfort process

Model robustness

Three different behaviors give the same outcome. Inhabitants discomfort is due to their own actions on the building. They are acting according to thermal and non-thermal stresses. An additional model is calculated. Building hypothesis is changed to turn from binary technologies to less restrictive devices, which helps to deal with non-thermal pressures.

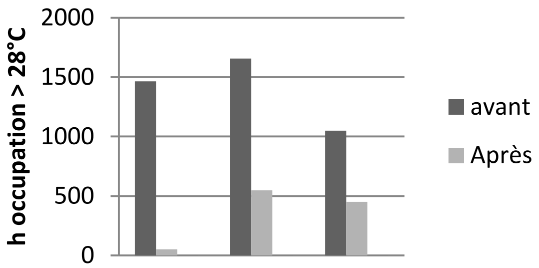
For example, roller shutters can be opened but there is not any solar protection or closed but there is not any light in the room. External louvered mobiles replace them, protect sun glaze and let diffuse light come into the house (Table 5). Tilt and turn windows allow ventilation without draft and opening without the danger of intrusion. Those less restrictive technologies called soft-tech can be easily understood and handled by the user himself. Soft-tech has as the special feature of being able to vary the uses of openings.

Table 5
Soft-techs

NON-THERMAL STRESSES	INVOLVED BEHAVIOR	MATCHING SOFT-TECH
Garden privacy	Inside withdrawal	Shrub hedge
Garden solar over-exposure	Inside withdrawal	Threes shading
Nasty smells	Windows closing	∅
Door slamming	Windows closing	Door wedge
Noise	Windows closing	∅
Insecurity feeling	Windows closing	Tilt and turn window
Insects	Windows closing	Mosquitoes net
Home privacy	Shutters closing	Louvered shutter

An additional model is done with same occupation and heat emission taking into consideration better ventilation by night and better solar protection by day. In other words non-thermal pressures are not in conflict with thermal stresses anymore.

They can be managed together. Thanks to a soft-tech scenario overheating time is reduced (Figure 8).



FAMILIES	1	2	3
Overheat before	1465	1656	1050
Overheat after	51	547	450
Gain	97%	67%	57%

Figure 8 Over-heat duration gain

In the three cases comfort improvement is meaningful with a half of overheat time gain at least. This outcome has the particularity of distinguishing families from one another even though their outputs were closer in a case study model. A family who already used roller shutters by day even if it meant living in a dark room had fewer benefits than a family who preferred natural light. As occupation and heat emission parameters are unchanged, overheat due to those parameters continues. One family is even in a comfortable situation according to Brager theory during the warmest week of the year (Figure 9: "possible"). Outcomes from additional models are prospective and the subjects' behaviour if their house was equipped with soft-techs could be extrapolated from the case study.

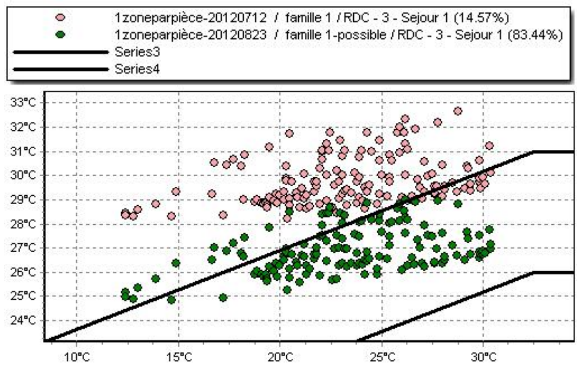


Figure 9 Brager's comfort-zone, warmer week (outdoor temperatures on the abscissa, indoor temperature on other axis)

The interest of this model comes from the fact that soft-tech implementation in building leads to a more important variation between families than a case study model with binary techs (actual). The instability of results expands at the same time the users' power to manage their own comfort grows. Finally the fewer freedoms the users have, the more precise the model is.

Giving an important role to the user is giving him the possibility of acting in an illogical way according to a heat engineer point of view. Designing soft-tech buildings demands the acceptance of a greater vagueness in the outcome of models and to sensitize people to summer indoor climate management.

CONCLUSION

Dynamic thermal simulation can take into account scenarios which change every week. In this study, concrete scenarios are developed on a whole year (non heating period). The most precise variation comes from climate data. Software can consider uses but not feedback from comfort level to behaviour.

The difficulty in making a model of comfort even with software that meshes accurately time and space is due to transposition of a process on a linear calculation. This topic is currently studied and work has been done through describing a motivation loop which leads to a different use of ordinary hypothesis (Moujalled, 2007).

This study is a step to estimate concretely, comfort conditions in housing. The original purpose is to check the relevance of projected DTS currently done. The weakness of knowledge about behaviours allows us to ensure that it is impossible to foresee comfort conditions in an accommodation. Therefore, model outcomes have to be closer to real indoor climate conditions experienced.

Two progressions are possible. The first one consists in adding a security margin to results i.e. any precise guarantee of comfort level is given based on uses which never happen in truth but a range of results surrounding comfort possibility. It can be managed, during the design time of each project, by the estimation of trouble due to non-thermal pressures. It implies the consideration of the effect of outer stresses on thermal issues. For this, one has to be able to take into account the different external conditions and so be able to benefit from a database created from research done in the field.

The principal of margin assumption does not work if binary technologies are left for soft-techs because results are vary more according to behavior. Temperature results obtained by efficient users are much more different from users with unreliable uses when soft-tech are implemented in building.

The second approach consists in reacting to hypothesis more than on the results of calculation. In the facts, only the automation of control technologies assures reaching maximum exactitude of the program and applying standard hypothesis. For example, we can consider that ventilation goes off automatically if it is colder outside than inside. The limits of a mathematical model are due to the unpredictability of human behaviour, contrary to automatism.

The calculations based on a return of fieldwork have shown the gap that can exist between accepted hypotheses and reality. In order to better estimate user impact on the building and so on the comfort, it is possible to develop typical scenarios. For example a set of three hypotheses can be established: first one with efficient uses, second one with unreliable uses (high level of non-thermal stresses) and a median one. In this case, projected models will not be based on one scenario changing for each simulation but on three fixed scenarios. This study points out that it is possible to come close to real uses. Therefore, typical hypothesis can be defined, based on case studies. It implies deploying studies on a bigger scale. Then a frame of reference, with different behavior deduced on real outcomes, can be established.

Besides qualitative approach, it can be useful to know the frequency with which each profile occurs. That is to say, being able to determine a great number of use scenarios, close to reality. Each one has to be computed in a projected comfort model to obtain temperature results. Moreover, it requires a statistical approach to behavior in order to know the occurrence of each profile. Finally one has to weigh results by appearance frequency. In other words, it is an analysis of the risks applied to comfort issue in housing. The manpower that must be deployed is then extremely unwieldy.

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