Energy Management in Residential Buildings: A System Dynamics Approach

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ABSTRACT

Due to a wide population growth context, unavailability of resources and climate changes, energy saving has become a great matter of interest especially during the last thirty years. One of the most evident human activities weighing on pollution and energy consumption is the construction of human residential buildings. However, the construction phase is just one of the stages in wasting resources. In fact, right after a residential settlement has been built, it is time for the dweller to use up resources. In our work, we propose an analysis of the socio-technical mechanisms which move people towards energy efficiency and technology innovation. We will then describe the model structure and the various leverages that the users are able to handle during the innovation process. A discussion of results and implications for future research will also finally be provided.

1. INTRODUCTION

1.1 Sustainability and Building trade

Sustainability is one of the great debates about global warming and about the big compromise humanity has to accept in order to continue having a healthy life on this planet..Worrying data unfortunately does exist. It is about the dimension of the change we should achieve in order to reach and introduce sustainability conditions. Von Weitzsaecker et al. (1998) talked about “four factors”: the necessity to augment the technologies eco-efficiency four times, doubling the comfort and halving the resources used. Considering the demographic growth and the increase in wellness demand throughout all the developing countries, some authors propose that we should rather talk about the “ten factors” (Manzini and Vezzoli 1998). In other words, the human kind should live with only the 10% of the resources which are actually used (Fregolent and Indovina 2002) which in turn means lowering the resources consumption of about 90%. After many international conferences and studies, this problem cannot be postponed anymore. Already during the 70s, the System Dynamics Group at the Massachusetts Institute of Technology (MIT) started a debate about humanity’s dilemmas on the threshold of the Technology Age. Its researchers started to think about possible Limits to the Human and Development Growth as well as about the eventual necessary changes to maintain a certain sustainability in the western socio-economical organisms. Now scientists and many politics all over the world agree that there is no more doubt about the connection between human activities and global warming.

There are two basic reasons that make sustainability strongly and full lengthy connected to the building trade. On one side, the construction sector has the main ambient impact if compared to other human activities: the 25-40% of all energy used in OECD countries goes to the building and construction sector, including production and transportation of the needed materials and the 40% of the world greenhouse emissions comes from the “built” environment. On the other side, the human beings dwelling in those buildings would tend to make their houses the most comfortable and healthy place possible. It is thus evident how the building sustainability issue is related to two kind of relations, that are between the building and the environment and between the building and the people living in it.

Also, sustainability runs down different scales: the territory, the urban scale, the building, and the single dwelling unit The resources’ exploitation, the territory use, the energy consumption in every life-cycle step of the building product and the wrecking garbage are activities that cannot stand apart from any environmental issue . This multi-scalar dimension makes it difficult to find a unique analysis criteria. Sustainable building and construction study has thus to be considered as a holistic, multidisciplinary approach.

In addition, the world population is still growing and in the next decades, the 98% of it will likely live in developing countries. It is expected that the 40% of people will live in urban areas as in the developed countries the three quarter of population lives in cities. As population and urbanization grow, the building and infrastructures demand increases. The most of the shelter demand will be satisfied with the so-called “informal houses”, which basically stands for self-built structures. Buildings’ construction industry has in general a certain economic, social and environmental impact. First, worldwide market volume amounts to over US$ 3 trillion and accounts for as much as 10% of world GDP (depending on how the sector is defined). Construction is the largest industrial sector in Europe (10-11% of GDP) and in the United States (12%). In the developing countries, it represents 2-3% of GDP. Construction also accounts for over 50% of the national capital investment in most countries. Second, it provides around 7% of world employment (28% of industrial employment) with a workforce of about 111 million, 74% of which reside in low-income countries (UNEP 2003). Also, renovation and maintenance account to 30% up to the 50% of construction activity in Europe. In fact, compared with other industrial products, buildings and infrastructure present as a quite unusual product since they are long lasting. Therefore, it is easy to renovate a building every 20 years considering a design life of 50 to 100 years. Just a part of waste and demolition products are used for recycling, and mostly in a rough way. After all, corruption is the value added effect in building sector. It allows substandard buildings and it leads to high-death tolls due to buildings collapse and natural disaster.

Steps through sustainability in construction and building thus include the reduction of material waste or increasing the use of recycled waste, any kind of, as construction materials, as well as improving the energy efficiency of the building, particularly regarding water and electricity use. By using a wide approach, it could be useful to rethink construction policies and financial incentives, improving social responsibility through the promotion of corporate, augment investments and research in innovating materials and technologies. The whole sector has a big potential to contribute to the achievement of a global sustainable development process.

As said, applying the concept of sustainability to specific buildings or other construction works, necessarily needs a holistic approach, bringing together the global concerns and goals of sustainable development and the demand and requirements in terms of product functionality, efficiency, and economy.

1.2 The European directives on buildings' energy efficiency

Energy efficiency issues at a European level go back to the SAVE 93/76/CEE. Such a directive was created with the objective of limiting carbon emissions by improving energy efficiency. To have some directives on buildings efficiency, the UE had to wait for the Energy Performance of Buildings 2002/91/CE. This shed light on the need to introduce, by 2006, a certification system for the energy performance of new buildings as well as for retrofit activities on existing ones, in order to succeed achieving the Kyoto Protocol objective to reduce European emissions by the 8% by 2010.

The UNI EN ISO standards in buildings energy efficiency provide a simplified calculation method for the assessment of the building system, in every part of it, frame insulation, plant efficiency (in other words the primary energy demand), the ventilation level, the infiltrations, etc. Some of these constitute specific arguments like materials and building component, their thermal resistance and transmittance, heating and cooling system necessities, losses, efficiency characteristics calculating the annual energy use for space heating, the heat losses and gains of the building, the annual heat required to maintain the specified set-point temperatures in the building, and lighting,. Finally they has to give a method to test and monitor energy efficiency for maintenance and during inspections.

To formalize some differences, it has been introduced the Degree Day unit, basically summarizing the differences in external mean temperatures, and consequently heating periods, so that the heating system will work just in that period in which the external temperature and Internal reference Temperature, commonly fixed at 19°C, will be different. In Europe, there are three different climate zones, Cold, Moderate and Warm and, consequently, different transmittance values are indicated for walls, closings, glasses. This shows the importance given to the building frame insulation as the basis for energy savings: no plant efficiency or distribution losses containement can be useful without a good barrier to the external environment. To take into consideration the energy efficiency in heat use, also the gain-losses ratio and the utilization factor, always linked to the internal heat capacity of the building, was introduced.

Moreover, carbon emissions levels in relation to different kinds of energy used are indicated. Many standards were added in recent years in order to face the summer temperature problems. In this work we will quite often refer to some of the UNI norms and European directives, especially concerning heating and cooling systems, leaving out other more physical aspects and concentrating on a qualitative analysis.

We cannot ignore that the user behavior at home, and in general that of every actor of the building environment, is not necessarily and always moved by rationality. Therefore, it is not possible to understand the building, the technologies and the private consumptions as a matter of economy, technology existence or adequate information alone (Bourdieu 1979, During 1993). A socio-cultural analysis and explanation of the human-technology interaction at home is necessary.

1.3 End-use relevance on the consumer

Leaving water flowing away, opening a window for too long, putting some heating element just close to an opening, turning on lights when it is not necessary, leaving the computer on all day long without using it: these are wrong, automatic habits. Thinking over about those expenses linked to an unconscious attitude has not been common, as until some time ago resources appeared unlimited. Energy sources are able to get into debt importer nations, burdening families' bill through their end-use energy. Nevertheless, why should we consider saving energy in our house? Is it just an economic question or does it include a comfort aspect?

Energy saving in residential buildings could be led by the correct use and choice of heating system, electrical household appliances, lighting and renewable resources technology application.

Housing comfort is an individual parameter. Using gumption, we can cope with having a sure and warm house and healthy ambience maintaining low energy consumption and an acceptable bill for electricity and gas. Being aware on normative is the next step. Not everybody questions himself about what he can do individually to save energy, and about the big impact that a different attitude can have.

Here we want to analyze the small though still very important changes that every user can easily make. If we really want to understand ”which kind of consumers we are”, we should approach residential energy use from the user's everyday life routine point of view and from the meaning the house has for him.

Many kinds of studies have been made to explain the energy consumption dynamics from a socio-cultural point of view but they received not so much attention in designing energy policies, with a general outcome that nowadays contributes to our energy crisis.

Studying the “house” system, it appears that the word “home” has different meanings based on economy and technology but mostly linked to aesthetical aspects and to the creation of the so-called “coziness” (Wilhite, et al. 1996). People obviously perceive and experience *coziness and comfort* in different ways, and this reflects also on energy implications and technological preferences. Moreover, we should remember that often people do not question the apparent coincidence between consumption and well-being as our western society system took for granted (Shove 2003) and exported as a synonymous of modernity in growing economy countries. However, changing individual behavior is not such an immediate and easy process and social science has been focusing on it for some time. The result of many theories has been that the relation between the attitude and the behavior is not so direct and easy. A positive attitude towards savings does not imply an economizing behavior toward consumption or towards awareness in the technologies choice (Holden and Norland 2005).

Regarding the human-technology interaction, it is fundamental to introduce the "Domestication" concept. The *Domestication* theory is an approach in science and technology studies (STS) and media studies that describes the processes by the innovation implied/used in them.

Linked to various routines in lifestyle, we can recognize three house *domestications* (Aune 2007) affecting the energy private use. Aune (2007) classifies them as "House as haven", "House as a project" and "House as an arena for activities". They symbolize different experience of comfort. The "*house as a project*" represents the group of people that have the exigency to redecorate and make changes inside the house because it has to mirror their way of being and consequently their way of feel their habitat. It has to match their own identity, so they can spend money just to adjust the internal environment to their leisure. This way to conceive the house represents the modern concept of wellness and consumption, too, as the energy saving is something relative to a symbolic function. May be the increasing of the availability and of the possibility to customize the high-efficiency technologies' offer, it could be an incentive to push this category to choose them when they decide to renovate their house.

The "*house as an arena for activity*" is on the opposite position. It realizes the house as a place to live together and to use practically. This group does not use any new technologies if it is not necessary. Whatever it can be easily converted to a more efficient energy use appealing to their high level of consciousness, developed by their everyday of life based on fixing rather than changing.

The category we presented as the first, the "house as haven", falls in between the last two. It may be thought as the thermal comfort situation in the house, so this group is not continuing redecorating neither fixing, rather just paying attention on maintaining the habits of the house community. It is the ideal conception of the house, have what you need when you need it.

Also, energy consumption is not just an economical rational activity enabled or constrained by technological solutions (Aune 2007), as we believed for many years after the oil crisis in 1973. Energy policies have to take into considerations at least the biggest differences in conceiving the practical and symbolic house. Considering the user as a rational agent, may limit the knowledge about people's motivations and it may make it difficult to tailor an eventual strategy of influence on his behavior.

What we would gain presenting this STS theory is the introduction in our model of some factors that could influence the user comfort and consequently the user's strategy in individual energy consumption. Those factors could be esthetic, practical or random. basically represented as a delay in investing in new technologies.

2. THE CONTEXT

2.1 Data gathering and technical information

The system we will study is the building. As every system, several inter-related components characterizes it and the user could be considered as an active element of the building, an element that can be not systematically controlled, rather educated and informed. This system is separated from the surroundings by a boundary side that is the building envelope. Through this envelope, the system and the surrounding exchange some energy fluxes in both senses, depending on the energy quantity required, produced and consumed inside the same building and the one coming from the external environment. The total energy of the system and its surrounding is obviously "conserved" so the building can easily be thought as a thermodynamic system, thus following all the thermodynamics rule.

A thermodynamic process is the energetic evolution of a thermodynamic system proceeding from an initial state to a final state. Typically, each thermodynamic process is distinguished according to what parameters, as temperature, pressure or volume, are held fixed. Furthermore, these processes are grouped into pairs, in which each variable held constant is one member of a conjugate pair. In this context, we will take into consideration just one couple of conjugate thermodynamic variables, the temperature-entropy ones: in fact the volume of the building is supposed to be constant and just the thermal parameters could change. Starting from the building envelope, let us approach an energy audit by means of its description.

The building envelope includes the following physical components: foundation, roof, walls, doors and windows. All these characteristics need to be identified in terms of area (m2) and resistance to heat flow, R-value (Km2/W). The last parameter is the measure of the *insulation* properties of certain building insulation materials: the higher the R-value, the greater the insulation. The most used parameter to evaluate surfaces insulation is the *transmittance* or U-value, it could be considered as the inverse of the Resistance R. The U-value describes how well a building material conducts heat, in other words, it measures the rate of heat transfer through a material of known thickness over a given area under standard conditions (temperature gradient of 24°C, at 50% humidity and in no wind conditions). Therefore, the lower is the U-value, the grater the insulation. The dimensions, performance and compatibility of materials, manufacturing process and details, their connections and interactions are the main factors that determine the effectiveness and durability of the building enclosure system.

Although these parameters offer a useful mean for comparing the performance of different solution's choices, other factors need to be considered in maintaining a certain thermal comfort. First of all, the orientation of the building is essential in order to determine how to manage the quantity of solar radiation coming from the outside and to have the right level of light inside the house, not to mention to take advantage of the position for solar panels installation. The best position for panels is to be faced on the south side where the sun rises and to be slopped to obtain the maximum of solar radiation waves.

Very important also is to have plants of every floor and prospects of the construction available, specifying the end use of each zone of the house and the possible presence of a system shade around the house, like trees or other buildings.

In this context, the architect plays a fundamental role when creating a good shape for the house, which means that the volume should be considered with relation to the treated floor to avoid thermal losses (so a compact house is better) and to preserve the air quality (so high ceilings are more desirable). After those assumptions, it is obvious that the number, the width and the orientation of transparent surfaces cannot be left to chance!

For northern or cloudy places, it should be important to keep light and warm inside, while for southern places, on the contrary, the building needs to be planned in order to be able to contain the warming effect of the solar radiation in summer time. That is why it is necessary to plan or to check the transparent surfaces in relation to the opaque surfaces and treated floor area, in order to maintain uniform lightness and to choose on which side of the house to put the most of them.

Calculating the primary energy demand is the main objective while estimating every kind of consumption, no matter which the plant or the process efficiency to produce end-use energy. The main measure used in this calculation is the *Degree Days* (DD). Considering a mean comfortable internal temperature of 19°C, the temperature differences between inside and outside are calculated (Δ) and then such a delta-Δ is split over the heating period characterizing the geographical zone, expressed in days. In this way, the transmittance or U-value for every kind of surfaces is defined for each part of the country.

Next point would be to maintain a good air quality in the ambient we live in, considering the CO2 level in the air and the smells coming from the kitchen or the restroom. Carbon dioxide is a good comfort meter because it gives an unbiased evaluation of air saturation, so it could be planned when and how to change the air.

The ventilation system is more and more necessary, both in a natural and mechanical way. By ventilation, it is meant a voluntary air exchange induced by opening windows when you can feel no more comfortable or install a mechanical system working for ensuring air recycling then ejecting the exhausted one and phasing it with fresh air. Ventilation has not to be confused with the infiltration rate, that is something that is not possible to control, except with a good insulation planning on windows and roof. Normally, it is possible to consider a fixed air-change rate, normally calculated as 0,50 h-1, while the infiltration rate give us an index about the air permeability of the building. This is the first kind of approach, the structural one.

Once we have analyzed the building frame in every part of it, we can then try to investigate the energy needs of people living inside.

2.2 Building performance’s economic evaluation

After building or retrofitting an apartment or a whole building, often the user is left alone. No one else will ever inform him on the economic evaluation of the building performance, but for the bill that he will regularly have to pay. Only by such accounting documents or reports, he could not understand were to act in case of high expenditures. Unfortunately, the long building chain is still divided into separated compartment, and this effect increases the difficulty in predicting the life-long performance of a building.

Consequently, even costs due to deterioration represent an element that is worth to be evaluated. This way, we conceive the designation of “life-cycle costing” and “whole life costing”. The difference is determined by the fact that different categories of interest pay attention to different periods of the life of a building.

This way, we finally got to the concept of “life-cycle costing” as a subset of “whole life costing”. “Life-cycle costing”, or LCC, is conceived as limited to the period of interest of single operators, while the “whole life costing” one analyzes a building all over its life.

LCC is an estimation of the monetary costs of the funding, design, construction, operation, maintenance and repair, component replacement and sometimes demolition of a building.

It may be applied to new design or existing structures, allowing in this case to estimate residual life and value. As different maintenance operations take place at different times, incremental costs are converted at present-day value using a discounted cash flow approach. LCC tries to predict when the elements of the buildings will deteriorate and will be replaced and what the discounted cost (that is at present-day value) of each intervention will be.

2.3 Technical solutions for energy savings

New technologies and small structural interventions can improve the energy efficiency of the house.

First, one could change its boiler with a condensation boiler that can allow installing a smaller power size and having a higher efficiency. In addition, it could be possible to change the fuel with a higher calorific power and low carbon density one.

Enhancing the insulation of the hot water system distribution for heating space with radiators or fan coils, trying to maintain a 70°-80°C of the water or 45°C of the air. Introducing a buildup heat system can decouple production and utilization and allow dimensioning the heat generator power not on the peak, favoring the intermittence production, too.

Then a thermal solar system can be introduced for DHW or a PV panel can feed the auxiliary electricity demand.

In general, the problem we face is that there are many efficient new technologies and renewable sources application to increase efficiency in building end use. We started thinking of the big discrepancy between technology achievable efficiency and its real application. Many different researchers tried, and are trying to explain, such a phenomenon from different points of view.

During the 25th International Conference of the System Dynamics Society, many articles about this topic were presented: studies and simulation on the construction phase (Groesser and Bruppacher, Decisions in the Construction Process of the Residential Building Environment: Development of a Static and Dynamic Model 2007), on the planning phase of a building stock involving many different professional figures belonging to the building chain (Groesser and Ulli-Beer 2007) or on new technologies commercialization (Miller and Sterman 2007).

Anyway, there was no specific assessment on the relation between the end-user still living and continuing to live in a place that probably needs to undergo an efficiency intervention. We started from an existing reality, an existing building that we try to describe dynamically in its structure composition, to understand why the end-user decides to improve the energy efficiency, maintaining a certain scheme or completely changing the composition of the system. We choose to study the relation between what is the technical performance of the building and how the user feels about it. Therefore, we will describe the general structure of the problem and the choices we made to face it.

2.4 Hypotheses and limits

Concerning the individual behavior approach, we refer to some literature individual action theories. We choose one in particular, the *needs-opportunity-abilities* model developed by Gaterleben and Vlek (Gatersleben and Vlek 1998). They explain the need as a lack of something, a requisite, a desire, a function, that people feels to be a physical or psychological requirement to pursue in order to maintain or improve their well being. The external conditions or facilitations that allow reaching our needs, our objectives are the opportunities. Opportunities can be thought in terms of availability of services or goods that we may need, accessibility to them in terms of information, price and technological development. The capacity to succeed procuring them is given by individual abilities. They can be financial capabilities, skills, cognitive or physical means and space-temporal possibilities. Needs, opportunities, capabilities are individual characteristics, are influenced by macro system factors, that we will explain in the following.

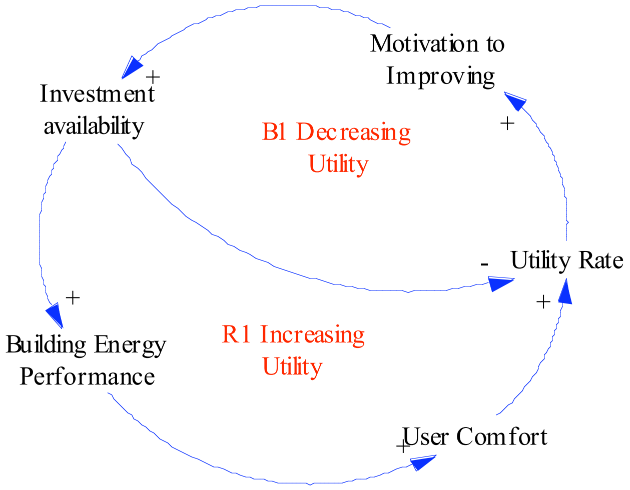


Figure 2.1 Basic Feedback loop of the model hypothesis

We can assume that the main end user’s need is comfort, assessed on physical-thermal comfort perceived and economical comfort linked to savings. The ability is in developing the motivation to improve or the positive attitude in improving the building system. The economic availability to investment is the opportunity to reach our objective. On a static cause-effect point of view, we could see to those three points as a consequential chain. So that, the individual uses opportunities and abilities to reach his needs. In fact, opportunities develop needs (the opportunity to have more money take out the needs to have more services, as exerting a power). After all the development of new opportunities and consequently new needs is what in economy, they teach us about consumer behavior. Purchase choice between different goods changes in relation to our utility curve. However, we can have more or less goods in combination but we can be on to the right-hand parallel curve if we have more too spent. Then if we really want to reach our quality of life, we develop some abilities, improving our means or opportunities. This virtuous cycle is regulated by the decreasing utility on improving: when the comfort addition by improving the energy performance is less than the expenditure to reach this increment.

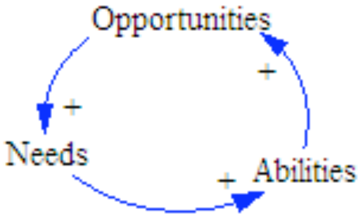


Figure 2.2 Needs-opportunities-Ability feedback loop

Obviously, without this balancing feedback, the need-opportunities-abilities will explode, and it will be the contrary of sustainability. Following this basic schema and completing it, we will arrive on a complete picture of the problem and its limits.

3. THE MODEL

We already talked about the need for an holistic approach, thus a systemic point of view, in order to analyze our non-linear, complex and dynamic system.

Our analysis starts from the consideration of the so called "three *e"* (or the e-cubic) concept, which basically underlines the three areas of economy, ecology and energy that are the needed disciplines to understand our system. Our history has taught us that treating these tree fields separately and considering them as "not communicating", did not lead to any solutions. Just now we are starting to pay consequences about this fact.

In fact, a single local optimum solution would probably imply exploiting until the end those resources we should also strive to maintain, or in other words: improving our production rates, so to increase revenues, for the economic area; stop producing CO2 emissions and respect bio-differences and natural cycle for the ecological area; enhancing the energy sector. Under this point of view, logging old-growth forests straightforwardly becomes a case of "jobs versus environment", as if the economy could exist without a healthy environment, or the environment could remain healthy if people had no jobs. Economic events affect workers, consumers, taxpayers, and investors; they are not separate species competing for survival in a zero-sum world The global optimum would be surely different under a holistic point of view!

We can divide our analysis in three however tightly coupled macro areas: *Building Energy Performance*, *User Comfort* and *Motivation Improving*.

We describe User Comfort as a direct function of the Building Energy Performance, since there is evidence, as already said in previous paragraphs, of the fact that comfort mainly depends on thermal characteristics inside the house. At the same time, we will also take into consideration different user attitudes towards subjective aesthetical standards and their influence. Therefore, we will suppose a user to be not completely rational about energy savings, as instead many models quite optimistically do.

In general, comfort has a trend with a decreasing marginal utility regarding aesthetical measures, while it has an increasing utility in energy efficiency improvement, by looking forward to cutting the bills to pay. The investment availability or capacity is the biggest leverage towards increasing a utility function feedback in building performance. A *sticking to routine behaviors* factor will be eventually introduced while treating with renewable resources introduction as well as savings. *Routine at home* is something people do not want to change.

Like the comfort, the motivation towards improvement is defined as a composition that takes into account also those effects normally intended as exogenous, as public incentives and saving capacity of the those families (considered as having average earnings and purchasing power). It is necessary to point out that in our analysis we could only count on available and real data just concerning the building energy performance evaluation as well as also about the laws and norms that regulate this sector. For the rest of our model assumptions, we have limited to some psychological theory in literature or some basic reasoning which brought us to devise some simple hypothesis.

Following this line, we have considered the three physical effects of thermal comfort, lighting comfort and air quality as having the same level of influence on overall user comfort, even though on each of them there will necessarily be a different economical weight.

3.1 General structure and main variables

We started our analysis by sketching out the casual maps that describe the building and user dynamic relationships. A first point to consider is the thermal comfort inside the house, influencing both the building performance, the user comfort, and eventually constituting the cause for a new investment towards energy performance aspects.

We considered the level of heat inside the internal environment as regulated by different heat transfers: we named this level *Internal Heat*. Except for the heating system, we can distinguish inflows which increase the Internal Heat, and outflows decreasing it, as it is also possible to find evidence about while examining the texts of many norms; in other words: gains and losses. Considering the insulation level of the envelope of the house, in terms of the transmittance values of opaque (0, 8 W/m2) and transparent surfaces (3, 2 W/m2) and their size, we also identified the transmission losses coefficient, *HL*. While for ventilation losses, *Hv*, we take into consideration the leakage fraction (0, 5 h^-1) depending on the quality of window frames. Thus, by considering the difference between *Internal Temperature* and *External seasonal Temperature*, the heat transfer will then be an outgoing or an incoming flow.

On the other side, heat gains are also coming from people's physiological heating production (about 27W per person), small electrical applications (about 347,7 W), artificial lighting use (31W) and solar gains (according to our available climate data in Rome, published in UNI 10349). Solar average gains change with relation to the hour of the day and the month. The main impacts on solar radiation gains, excluding the basic house orientation, are given by the *shadow impact* due to trees presence close to the house, the curtains, and the horizon coverage, due to the presence of others buildings. The characteristics of the glazed surfaces are also an important factor in transferring solar radiation inside.

The heat accumulated in the house, converted into Kelvin, adds or subtracts to/from the Internal Temperature (Tint). This in turn influences back the Δ Temperature (Tint-Text), thus determining a Natural Heat transfer from or to outside the building. This creates the first balancing loop in our model (**B1**, *Thermal Losses and casual gains*), as reported in Fig. 3.1.

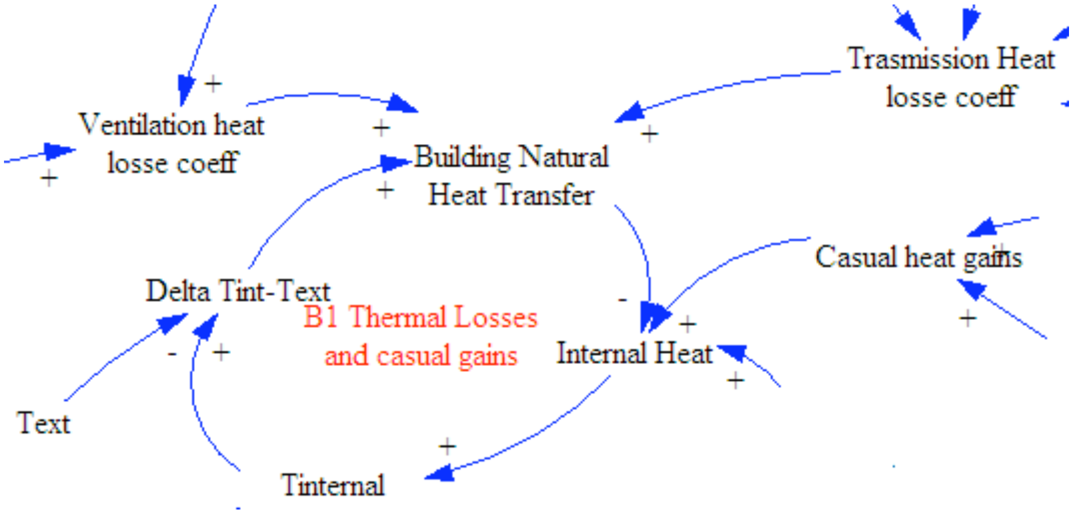


Figure 3.1 Thermal losses and casual gains balancing loop

Internal Heat grows by casual heat gains thus increasing the *Internal T*, but it will also increase the ΔT, thus enhancing the natural heat transfer towards the outside (during wintertime) and balancing the internal heat at the same time. When instead the external T will be higher than the internal T, referring to a 293K as internal standard comfort temperature, the Δ will be negative, thus meaning a change in direction of the natural heat transfer, through the building, from outside to inside. In both cases, which take into account seasonal effects, if Internal temperature, or Internal Heat, gets influenced only by casual gains and losses, that means that it would be more or less equal to the external T. Consequently, the user may feel the need to introduce a heating or cooling system. Thus, as it happens in most of the houses have, we introduced a thermostat mechanism which tends to regulate the internal temperature if the set point (or standard comfort temperature - 293K), is different from the Internal Temperature. As before, a ΔT between the *Set Point T* and Internal T will be the information we will now focus upon. Higher will be the Internal T, thanks to the heat accumulated in the house, lower will be the ΔT set point Internal. So would be the artificial heat contribution, meaning a heat quantity given, or subtracted, to the room. This is the second (**B2**) balancing loop influencing the internal T, the *Artificial Intervention* (Fig. 3.2).

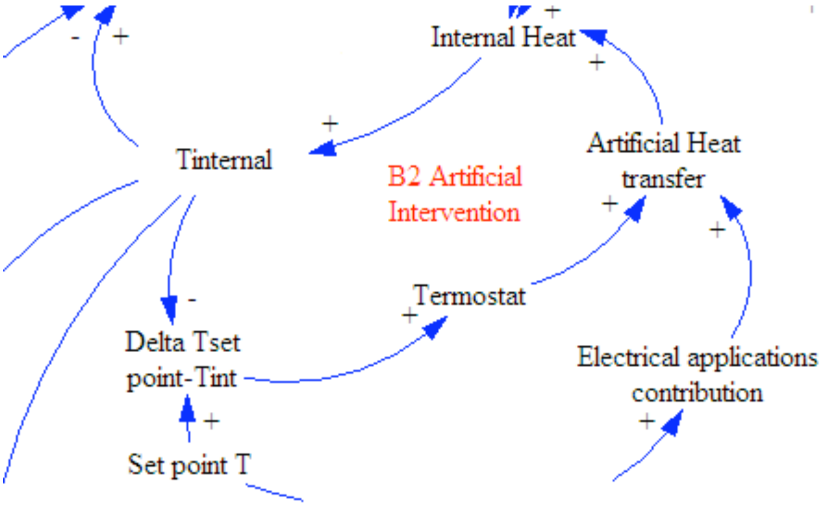


Figure 3.2 Artificial Intervention on Internal Heat balancing loop

Quantitatively speaking, we consider a 320 cubic meter house, with a *Surface/Volume ratio* of 0,968 and positioned in a medium climate zone, as in Italy, where Rome is. The annual thermal requirement is set at 180kWh/m2, and a primary energy requirement is at 250 kW/m2 per year. The thermal useful power plant (independent gas heater for space heating and DHW) is about 30,4 kW. The starting Internal T is about 278K (just 1,6 K less than the external one) and the heat transfer loss coefficient is set at 245 W/K, considering both ventilation 52,4W/K and transmittance heat transfer 192W/K (U-windows = 3,2 W/m2K and U-walls = 0,8W/m2K).

The effect of solar radiation on Internal Temperature tends to increase it in terms of few decimals degree during daytime. According to summer meteorology conditions, Internal temperature could reach more than 298 K, and the user may thus find it necessary to install some electrical devices as conditioning air systems. We modeled the adoption of a 3,1kW heat pump. This will function when the heating system is switched off and the internal temperature is higher than the set point. We set the air-conditioning contribution at 295K, as the desired temperature.

Humidity from outside also has a latent effect on internal temperature, meaning that it does not increase it effectively rather produces such a sensation in the user, thus amplifying extreme conditions, as very cold or very hot, and giving leisure or an uneasy thermal feeling. Therefore, we modeled a *Perceived Temperature*, too. It will be kept separate from the effective internal temperature, and calculated according to the percentage of humidity entering in the house, proportionally to walls and windows permeability parameters.

To calculate the Perceived Temperature we use a specific indicator named *Humidex*, mainly adopted in Canada, which takes into account six levels of perception of temperature and humidity, from the indifference to dangerous situations, in which is recommended to stop every physical activity and wear something light.

Therefore, the Perceived Temperature is proportional both to Internal Temperature and Humidity but is also influenced both by the activity level inside the house as well as from the user's clothing level. This collection of effects acts on the user thermal comfort as described in the following.

If the Perceived Temperature is much lower (higher) than the internal T, user comfort will decrease, increasing (decreasing) the activity and clothing levels.

In turn, clothing and activity will balance each other in order to find an equilibrium (**B5**, *clothing-activity*), both influencing back the Perceived Temperature (**B6**, *clothing perception* and **B4**, *activity perception*). Responding to thermal feelings, user comfort would affect internal temperature perception expressing a desired perceived temperature, that is the optimum temperature one would feel, which could be higher than the standard comfort temperature because of humidity amplification.

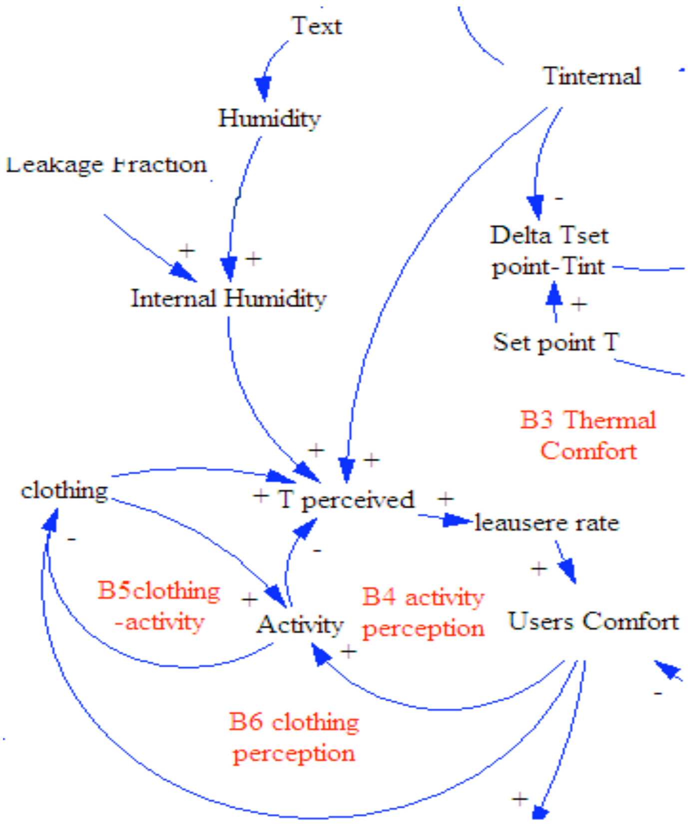


Figure 3.3 Perceived temepratute effect on Users Comfort

During wintertime, the perceived temperature is more similar to the internal temperature than during summer time: in our model we will consider this variation effect just for temperatures higher than the set point.

Such a “starting situation” in our simulations would reflect a mean efficiency configuration. Considering the house shape ratio, S/V around 0,9, and the climate zone, it would mean an energy performance for wintertime, or primary energy requirement during wintertime, about 100Wh/m2 per year. The U-windows should be around 1, 6-2 W/m2K and the U-walls around 0,3-0, 45 W/m2K. These limits are evaluated as good from 2010 January the 1st, according to the new decree 2008 march the 11th of the article no.1 of the no. 296 law at 2006 December the 27th.

Concluding,, we also supposed to have other three important feedback loops. The first one is the *lighting balancing loop*, **R2**. It considers the influence on comfort deriving from light use and presence in the house. Starting from the quantity of light coming from the sun through windows during the day, we have a certain Internal light which in turn produces a sort of "light effect" on User comfort. We assumed a positive relationship between them, meaning that if the internal light increases, the light effect improves, too, thus producing a positive action on user comfort (in terms of his mood). Obviously, when it is dark or when the internal light is not sufficient during the daytime, it may be necessary to require for more lighting. Therefore, if the users comfort due to the light-effect increases, there won't be any need for more light, while on the contrary, the user will perceive a decrease in his comfort function. The use of artificial light modifies Internal light effect on user comfort, as shown in Fig. 3.4.

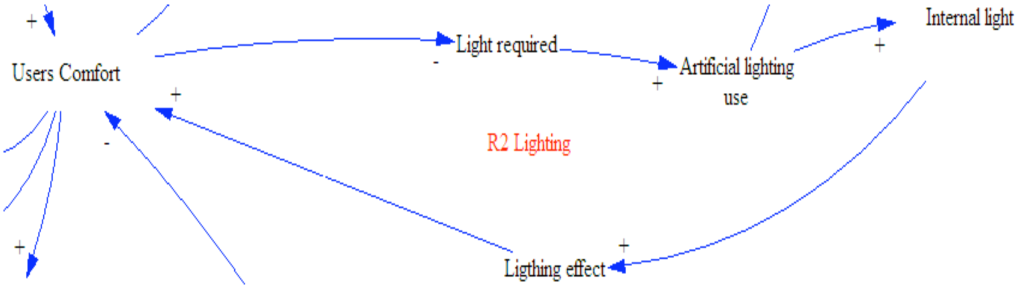


Figure 3.4 Reinforcing loop Lighting effect on User Comfort

This reinforcing loop (**R2**) will be limited by electrical costs, as we will see in the following.

Further to thermal comfort and lighting effect, also air quality affects the comfort function. It is necessary to take into account that the number of people in the same environment will increase the CO2 concentration in the air, thus influencing user comfort for air quality. User will consequently be prone to consider primary air inlet quantity, thus implicitly creating, as mentioned above, a double feedback structure: the reinforcing air quality effect on CO2 level in the air, and the *ventilation effect on ventilation losses balancing loop* (**B7**). The first is limited by a primary air inlet use effect, which means inserting fresh air into the environment. The second has quite an ample effect on thermal losses: if it increases, thermal losses will increase too, thus negatively affecting Internal T, and acting back again on the user comfort.

Closing the loop on *thermal comfort* (**B3**), User comfort is thus depending on the following main factors: T perceived, lighting effect and air quality. Energy performance is in line with the desired T setting, as well as with the primary air effect on losses. Comfort and energy performance are thus depending on each other: over time (of course, depending on stochastic weather conditions), to a certain comfort level corresponds an energy performance value, in terms of desired temperature. Reaching and maintaining a certain thermal comfort value over time is thus a matter question of resources consumptions.

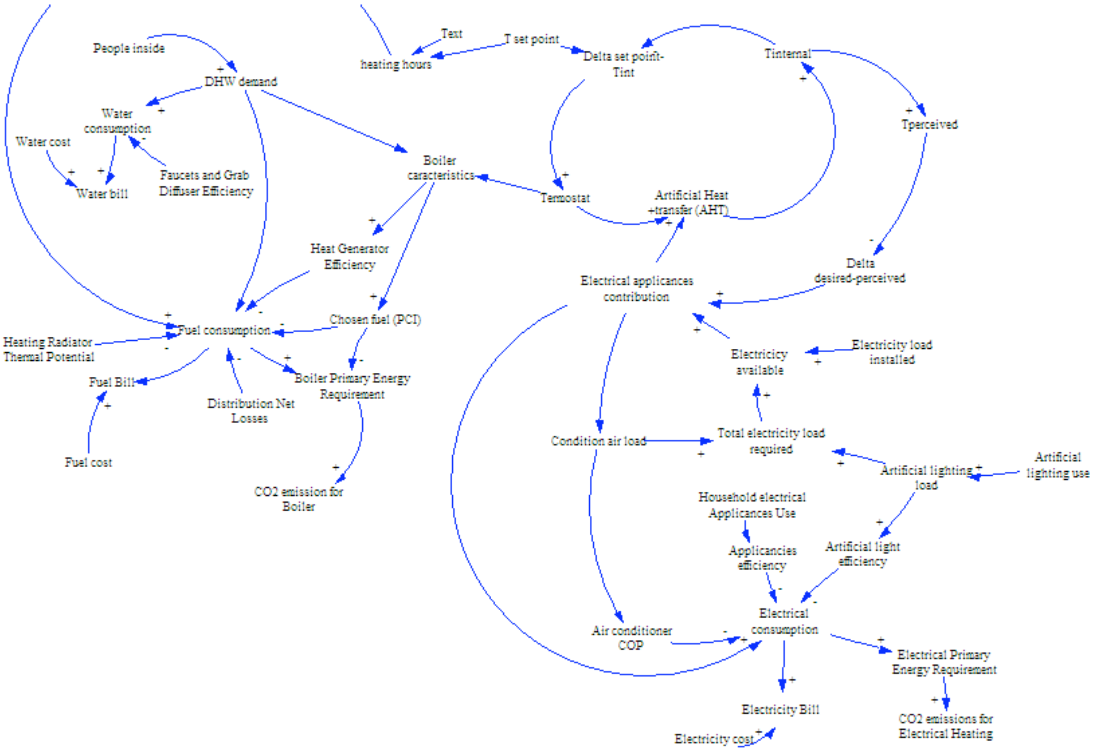


Figure 3.5 Overall consumption causal map

Consumption behaviors will be determined by considering both the time of use and the characteristics of the implemented technologies. Those characteristics will be the same that have to be taken into account when planning for an energy improvement or change, as in the case when the user would for example increase its comfort or reduce its consumptions. We analyze in brief which are the connections between the technical performance of the technologies and their consumption. Next correlation would be between maximum consumption one could sustain, savings capacity during the time and the state of technology in use.

Starting from an existing situation, everyone, on a short term, tends to consume in strict relationship to his economic capacity, that is his capacity to pay the bill per billing period. If one would save on consumptions, he could either use less energy or invest in higher performance technologies. In the first case, one would prefer a lower comfort to save money by cutting energy consumptions. In this situation, there would be scarce to no motivation to invest, rather there may be the intention towards setting a lower T desired in order to save money. The second scenario offers a long term saving opportunity, but it needs a certain initial investment. We will thus analyze the feedback loops that model the motivation towards investments. We have six structures that explain the mechanisms behind a decision to investment in order to obtain improvements, and two different behaviors that emerge.

The first behavior is the one aiming to invest in order to achieve lower expenditures due to energy consumptions in the long term. Our analysis starts by keeping the comfort value at a fixed value (ΔC= cost), holding it at the same level as before the investment (note that saving by lowering consumption would have implied a lowering in comfort percentage). Therefore, the main positive incentive on motivation is the saving capability. This is influenced by an average monthly income and by some short-term expenses like the bill to pay due to energy consumptions. When income increases, it increases economic possibilities, while when the second grows, it weakens such economic power. If the savings capability grows, the motivation to improve will increase. Consequently, the investment availability will lead to different choices: plant substitution or Insulation investments or end/use appliances improvement or, at last, even to the introduction of renewable energy technology installation.

It is expected that each one could lead to energy savings or to cutting consumptions. The evaluation of the energy savings brought about (ΔE), in relation to the correspondent unitary investment (ΔI), will be the reference value (ΔE/ΔI) on which to decide which intervention to pursue and in which magnitude it will be realized. Highest would be the ΔE and lower the ΔI, better would be the choice. We should remember that the objective would be lowering the bill to pay, (S). This action will increase the savings capacity and come back to motivation improvement. We name this feedback reinforcing action as *Consumption on investment* (**R3)**. In this analysis, we leave the comfort as fixed, so *comfort on investment* loop (**B8**) will bottle up the motivation to improvement, because the utility rate on investment will decrease when the investment grows (the ΔC/ ΔI rate has a decreasing trend).

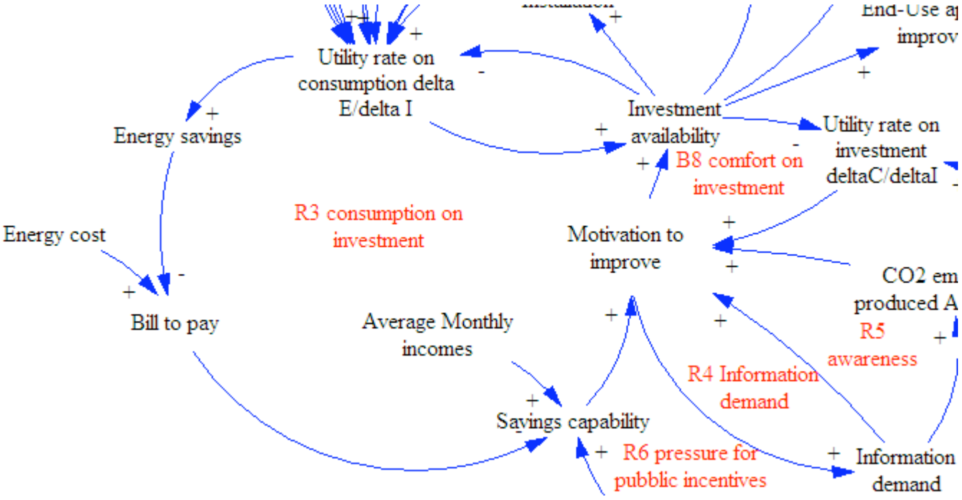


Figure 3.6 Investment availability and motivation to improve feedback structure

The second behavior aims to invest in order to enhance the comfort percentage (C). The opposite hypothesis (as related to the first behavior) is thus to fix the consumptions to the same level (ΔS= cost). On this side the rate ΔC / ΔI should be positive in order to increase the motivation. The choosing criterion on the different investment possibilities would be always the one that would have the best rate of energy savings on investment unity ΔE/ΔI. Therefore, by maintaining the same consumption S, the better the energy savings rate, the higher the increase in acceptable comfort . The *comfort on investment* loop is balanced by the same utility rate (ΔC / ΔI), the ΔI in fact, should have a growing trend for each comfort level reached in addition. Moreover, we should remember the economic possibility to sustain interventions at high levels.

Motivation to improve does not just fall in between these two loops, the comfort one and the consumption one, rather it is the hub of most every loop in our overall causal map. We can in fact see that the motivation to improve is also linked to Information Demand. If information demand increases, the motivation to improve increases, too; the same holds on the contrary: if one is very motivated, he would be prone to ask for more information (**R4**, *information demand*). Information demand is something that derives from the user's interests to improve his comfort. If we consider the time spent on searching information (T) to get to know how to improve comfort, we can say that the information request would increase more if information was easily traceable ($\Delta C/\Delta T$ should be high). Dissemination on good results or on energy performance programs from enterprises and public administrations is the way to cut time research. To close the loop, information demand could lead to enhance public incentives on energy savings, providing dissemination actions. Dissemination lowers the time spent on research, increasing the utility rate on time (**B9**, *Information research balancing loop*). Information demand creates awareness too, especially on CO2 production during end use phase of the building. This awareness could be another aspect describing the "motivation to improve" (**R5**, *awareness loop*). Finally, public incentives made because of people interest, will increase the savings capability, having a positive impact on improvement decision (**R6**, *pressure for public incentives*).

Those two solutions differ on a comfort point of view, which is at the base of the motivation towards investments, together with saving capability through salary. Again, saving capacity is the main way one has, in order to realize its need of comfort.

3.2 Modeling user comfort

A Pareto choice would call for an approach to user comfort from a thermal comfort point of view, considering the big expenditure for heating and cooling space. We will thus proceed by analyzing different scenarios. However, in the following, we consider comfort as a function of the Internal Perceived Temperature.

We can distinguish three different attitudes towards comfort. A minimum level of comfort and a maximum level of consumption characterize every user. The Consumption (S) to Comfort (C) ratio (S/C), describes a situation in relation to a certain state of technology and the end use of it. We can imagine this rate as having a logarithmic trend of growth, and assuming only positive values. We can think that a maximum level of consumption will confer maximum comfort to the user, while the minimum level of comfort will produce the minimum expenditure to maintain it. Therefore, we have a range of possible choices, each one is given by a couple (S, C).

Consider the curves below. First attitude would be: while maintaining the technology we already have, we can either move A on this limited part of the curve, thus deciding towards augmenting the comfort (towards the right) and consequently augmenting the consumption, or move A (towards the left) in order to cut expenditures and consequently coping with a lower comfort percentage.

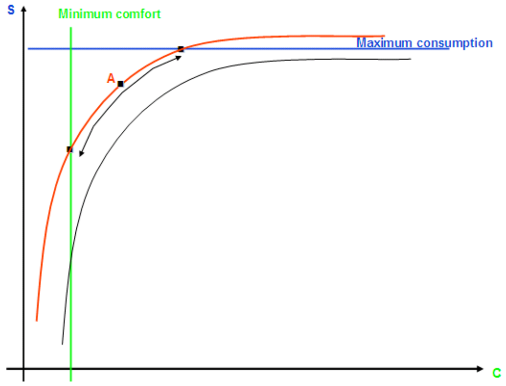


Figure 3.7: Curve for expenditure and comfort

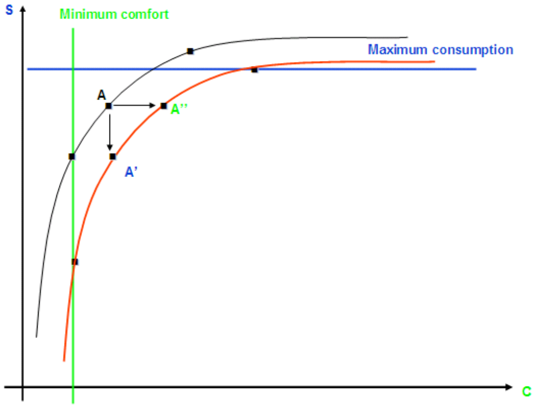


Figure 3.8: Changing technology

Also, we could choose to change technology, thus jumping on a different S/C curve, more convenient than the first according to the values (S, C), as technology would be more efficient. If we wanted to maintain the same comfort value by lowering expenditures, we move from A to A', (second attitude), while if we wanted to augment the comfort and maintain the same level of expenditures we would likely move from A to A" (third attitude).

At this point, we can analyze what is the comfort trend towards Thermal Perception or the Perceived Temperature. We imagine a user comfort curve as a "bell" curve with a concavity oriented towards the ground and an increasing trend that lowers each Kelvin until a maximum value. We consider a Perceived Temperature range of 20 steps, from 287K to 307K and an optimum temperature perceived of 295K. We name it as T desired and it corresponds to a 100% of comfort.

Comfort percentage starts from a 7%, corresponding to 287K, then it grows about 9, 5% per K until it reaches a perceived temperature value that we consider as the minimum acceptable value in a heated space. This value is 291 K and it corresponds to a 65% of comfort. The acceptable perceived temperature range is from 291K to 295K, respectively corresponding to 65%, 77%, 89% and 100% of comfort. Therefore, after 295K or the max comfort point, the curve starts to decrease coming back to a 7%, which means 307K of perceived temperature.

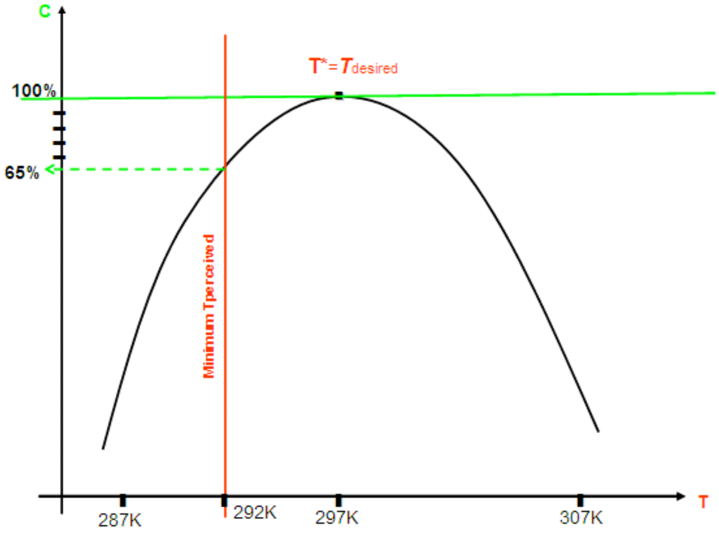


Figure 3.9 Comfort trend on Perceived Temperature variation

At the same time expenditure curve S would be the same depending directly from the T perceived obtained in the house. It is the effect of plant performance, insulation level, solar radiation perceived. By leaving fixed the technological state of art, increasing the T perceived, as we saw before, means increasing our consumptions. Therefore, the consumption trend would be a curve limited by the technological characteristics of our building system, with a growing rate decreasing per each K reached.

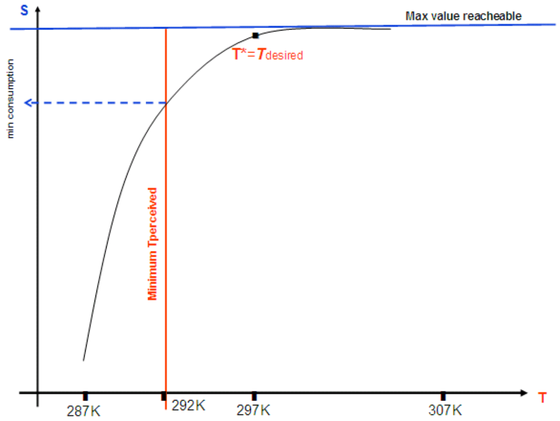


Figure 3.10 Expenditure level and maximum temperature perceived

We can have different hypothesis for our scenarios: we can see for example how, starting from a 65% comfort and fixing certain heating systems characteristics, our consumptions increase to reach higher comfort levels. In fact, we should remember that the Perceived Temperature is a good index for thermal comfort, and it depends on the building's characteristics.

As we model the thermal system in the house, we may mode the hypothesis of having a constant Temperature all year long. The thermostat function would then act to maintain the internal temperature around 20 degrees, or 293 K, all day long.

However, shared heating systems generally work, as an average, over eight hours per day, commonly from 12 a.m. to 8 p.m. but if we model an own heating system, the heating period could be set in relation to schedule occupation of the house, by their inhabitants' habits. Due to the eventual discontinuous state of work, the heating system could thus loose some efficiency; anyway this is the most adopted solution for a good compromise between consumption and comfort. Therefore, we could obtain a gentle oscillation in internal temperature between day and night, amplified by solar radiation presence. When the problem is moved from supplying heating to cooling, we apply an air-conditioning system to maintain temperature to a desired perceived level.

Even if the set point temperature during wintertime is around 293K, in summer time generally people prefer higher temperatures, at least around 295K. In fact, what we should consider is that during wintertime clothing and activity in the house have a strong influence. If the temperature inside is around 293K, one is well clothed when is at home and during the night when temperature generally decreases, it is possible to use heavy blankets. During summer time, we would prefer to dress something fresher and lighter, so temperature would be better set at some degrees more than in the wintertime, also due to the fact that sudden changes in temperature (while for example entering a very cold building from a warm outside weather, may cause even health problems.

Moreover, people who prefer low temperature during wintertime would have the same order of low temperature during summer time, independently from external temperature. On an extreme case, one could have constant temperature all year long and this would be the worse condition of consumption. Therefore, we could consider little oscillation in comfort during the same day corresponding to the little oscillation of temperature perceived, included in the available range. Each Temperature reached will increase or decrease the comfort of some points. The trend of marginal comfort related to marginal increase of temperature, thus decrease. This observation will be useful to study the comfort behavior over time, considering the adoption of a state of the art technology. We expect, like in real life, that the comfort and the stress will be perceived in several ways, so it seems to be much more real to analyze a distress function.

The distress function is seasonally characterized by the ratio between two factors: the uselessness accumulation time and the difference between the minimum acceptable comfort temperature 291K, during wintertime or the maximum acceptable comfort temperature during the summer time 295K, and the real perceived temperature. The perceived temperature is the result of humidity effect and the physical temperature of the person that is influenced by physical activity and wearing. After a certain time after which perceived temperature is different than the minimum or maximum value and depending on the level of distress reached, the user will take a decision to act. He has different possibilities that we will analyze in next chapter.

As result from the reality, the accumulation time during the winter is longer, meaning that the internal perceived temperature can be easily controlled by the plant use.

4. SIMULATION RESULTS

Below are shown the parameters used for the simulations. to the values are in line with European norms and standard parameters.

Starting conditions	Single House
Volume	320 m3
Active surface	100m2
S/V	0,968
FTA	180kWh/m2a
FEP	250kWh/am2
m2_transparent	20 m2
m2_opaques_external	160m2
Transparent_transmittance	3,2 W/m2K
Opaque_Transmittance	0,8 W/m2K
Ht_thermal_losses_coefficient	192,8W/K
Air change rate	0,5h-1
Hv_ventilation_losses	52,8W/K
Ht+Hv_total_losses	244 W/K
Thermal_Power_installed	25,6kW
TP_Effective_power	23,04kW
TP Efficiency	90%
Minimum utilized power	9kW
Working_hours_of_the_plant	8h
mc/hr_metan_gas	1.1-2,6
Air condition	2*9000BTU or 5300 W
AC_Effective_Power	5000 W
AC_Efficiency	0,95%
Powerusedfrom the heatpump	1480 W
COP	3,4
Winter set_point Temperature	293K
Summer set_point Temperature	295K

Table 4.1 Starting simulations parameters

The “starting scenario” assumes as an hypothesis a single house context, not in line with the actual law norms; it shows a typical situation in which Internal Temperature varies between the standard temperature of the set point, 293K, and a night value, due to the offset of the boiler. In fact, the latter is set to work for 8 working hours mainly during the daylight. This oscillation is given by the low values of the house frame transmittance, both for opaque surfaces and for transparent ones. . The effect is a high distress value.

We set a maximum distress level to 10 distress points and a distress threshold value of 5 points, meaning that the acceptable discomfort in the house is mainly due to weather oscillations and uncertainty.

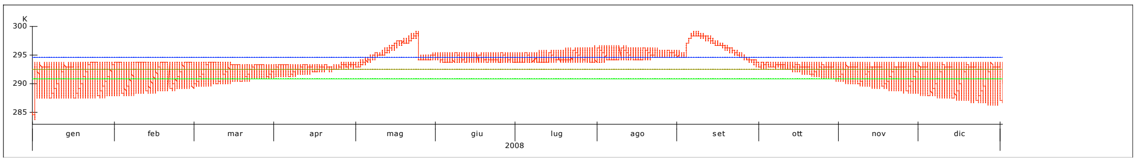


Figure 4.1 Winter and summer discomfort trend and Internal Temperature perceived during the year (*Starting condition*)

The original comfort value is lower than the target value of 65% that we chose as acceptable. Below, we report the behavior of a 2-month bill respectively for heating, for conditioning and for the total consumptions over the billing period (2 months). The last one also contains electrical consumptions for lighting, household appliances and DHW consumption that we consider quite constant respectively around 119 euro and 65 euro per two months.

1	321,90 €
2	178,07 €
3	0,00 €
4	0,00 €
5	104,02 €
6	327,36 €

1	0,00 €
2	0,00 €
3	98,30 €
4	166,06 €
5	11,06 €
6	0,00 €

1	506,48 €
2	362,65 €
3	282,88 €
4	350,64 €
5	299,66 €
6	511,94 €

Table 4.2 Space heating, air conditioning and total bill in the Starting scenario

A comparison between the consumption bill and the saving capacity would help us understand how physical distress is related to economical benefits. The economic background of the user is characterized by a monthly income of 2300 euro per month and by some fixed expenditures he may have (this has been considered in order to make the picture as much real as possible). Therefore, the effective saving capacity, before paying the bill , is 650 euro per month. From this situation, we start to experiment with different kind of policies in order to improve the comfort level or decrease the distress.

According to policies, we can thus think about the first simple choices the user can think about when he finds himself in difficulty with regards to his thermal feeling: such choice can be either increasing or decreasing the set point temperature according to external Temperature. This would result in a comfort driven action that could bring to an instantaneous wellness perception, but cannot solve the discomfort if this is limited to a few hours time window. According to our model, the user decides to raise the internal temperature only a few times in the coldest periods (red line in Fig. 4.2). In fact considering that the acceptable mean level is 5 distress units, and that the discomfort after the set point raising action remains above this value, we can talk about a saving attitude. This is the decision that basically will drive the kind of user with a saving capacity of 650 euro per month, and also having other expenditures during the year. The only effect we can perceive is a light increase of the maximum temperature during the daylight, as the user does not change the boiler timer.

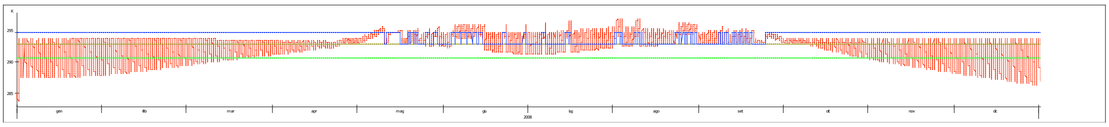
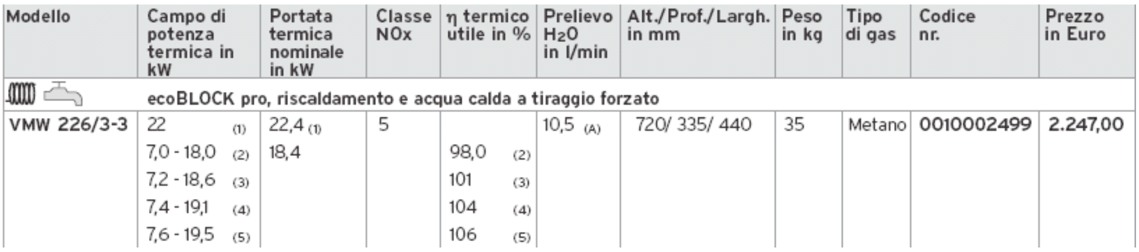


Figure 4.2 Distress for winter time and summer time and corresponding Perceived temperature modified (*Changing set point scenario*)

As we explained, the distress variation is quicker and the distress limits are lower for summer time ; in fact the changes we make in the set point temperature are different during summertime days and hours of the day, especially in private houses, where using air conditioning is an easy option. Next step would be to simulate different investment choices, as the user comfort remains on a law-compliant value or has a law-compliant saving capacity.

According to the saving policy: first, the user thinks about changing the boiler, rather than a structural change about the envelope insulation. With a fee of 2200 euro, the user changes his normal boiler with a condensation boiler, having better performances and being smaller in size.



Modello	Campo di potenza termica in kW	Portata termica nominale in kW	Classe NOx	η termico utile in %	Prelievo H_2O in l/min	Alt./Prof./Largh. in mm	Peso in kg	Tipo di gas	Codice nr.	Prezzo in Euro
	ecoBLOCK pro, riscaldamento e acqua calda a tiraggio forzato									
VMW 226/3-3	22 (1)	22,4 (1)	5		10,5 (A)	720/ 335/ 440	35	Metano	0010002499	2.247,00
	7,0 - 18,0 (2)	18,4		98,0 (2)						
	7,2 - 18,6 (3)			101 (3)						
	7,4 - 19,1 (4)			104 (4)						
	7,6 - 19,5 (5)			106 (5)						

Table 4.3 Technical characteristics of the first investment

The effects of this change is to maintain the comfort to the same level as shown in Fig. 4.4, having at the same time some expenditure reduction.

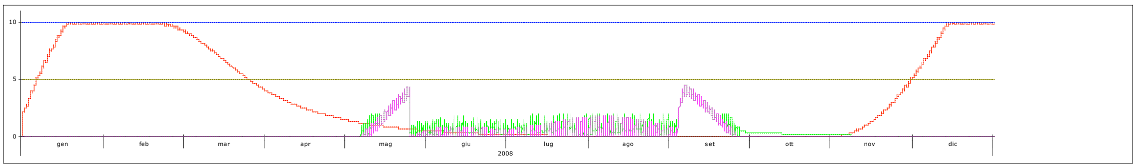


Figure 4.3 Distress after boiler change with a condesation one for savings capacity improvement

1	234,11 €	1	0,00 €	1	47,41 €	1	400,83 €
2	129,84 €	2	0,00 €	2	47,42 €	2	296,56 €
3	0,00 €	3	98,30 €	3	47,42 €	3	265,02 €
4	0,00 €	4	166,06 €	4	47,42 €	4	332,78 €
5	75,77 €	5	11,06 €	5	47,42 €	5	253,56 €
6	238,08 €	6	0,00 €	6	47,42 €	6	404,80 €

Table 4.4 Heating, conditioning, DHW and total expenditure in the boiler change scenario

We can see that with respect to the total bill of the previous scenario, which was about 2314,25 euro per year, the savings are 360 euro per year, since now expenditures reach 1953,55 euro per year. The mean life of a boiler is about 15 years so we can consider a cost of about 146, 67 euro per year. By calculating the net present value of the investment, considering a 213 euro per year flow, using the BCE euribor rate of 4,25% , we obtain a positive evaluation of the investment (NPV is 127,35).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
213	213	213	213	213	213	213	213	213	213	213	213	213	213	213
1,0425	1,086806	1,132996	1,181148	1,231347	1,283679	1,338235	1,39511	1,454402	1,516214	1,580654	1,647831	1,717864	1,790873	1,866986
204,3165	195,9871	187,9972	180,3331	172,9814	165,9294	159,1648	152,6761	146,4519	140,4814	134,7544	129,2608	123,9912	118,9364	114,0877

Table 4.5 Net present value flow for the first investment (Boiler change)

According to the Comfort policy, a comparable choice on the investment side could be to enhance the building envelope insulation. This retrofit activity could be realized in many different ways: we choose an external over-coat insulation panel of 100mm, in order to lower transmittance values to norm references. We could arrive to a wall insulation of 0, 4 W/K transmittance for vertical surfaces. We choose a rock wool panel and we consider an expenditure of 2340 euro, including installation, with a mean life of 15 years. Then, to be coherent, we could improve glazed insulation levels by changing the frames and double-glazed windows arriving to a transmittance value of 1,6 W/K, with an expenditure of 1950 euro for four windows. The bill will be not lowered by this choice; in fact, with the same boiler we consume always the same quantity of cubic meter even if the need is very low. The boiler we started with, has a minimum power of 9,1kW, under which it cannot work.

Even if the payback period on the investment is not comparable with the retrofit life, we have to consider the big improvement on distress, that lead us to a higher comfort, close to our target. The effects of insulation are also extended to the summer period. Without increasing emissions, we obtain a good result in comfort.

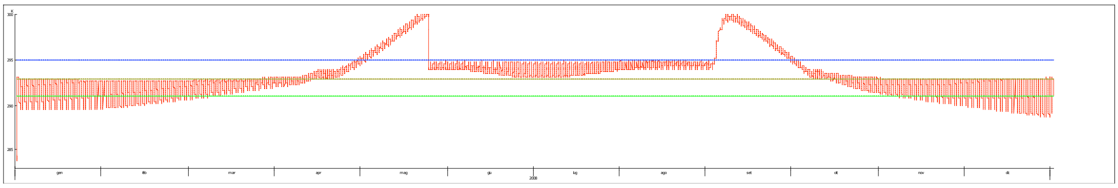


Figure 4.4 Distress trend and Internal perceived temperature for the second scenario (*Insulation improving*)

Fig. 4.4 shows us that the distress curve is decreased within an acceptable range. The internal perceived temperature behavior is more regular and stays inside the comfort range. The two peaks we can appreciate are basically caused by the fact that during May and September the plant would be off set and the air conditioning too.

To complete the analysis, we tried to implement both solutions in another different scenario. Therefore, we expected to have an increase both in comfort and in savings. This policy has a high investment in insulation retrofit (about 5500euro).

By unifying the two different solutions in one policy aiming to comfort and savings, we obtain the following results.

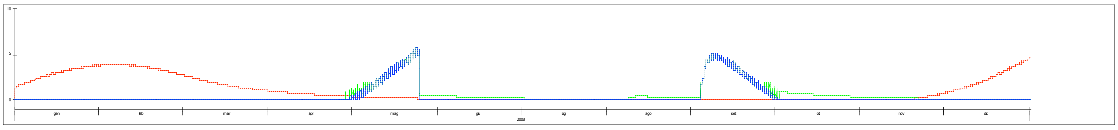


Figure 4.5 Distress trend and Internal perceived temperature for the third scenario (Boiler Change & *Insulation improving*)

The distress goes down to a lower value than the acceptable limit of five distress points, meaning that the comfort value is close to the maximum. The two peaks give us some discomfort especially because of seasonal changes, in which we decide to not applying any control on temperature, as it is quite subject to variations.

1	228,48 €
2	28,69 €
3	0,00 €
4	0,00 €
5	16,91 €
6	236,26 €

1	0,00 €
2	0,00 €
3	98,30 €
4	166,06 €
5	11,06 €
6	0,00 €

1	395,20 €
2	195,42 €
3	265,02 €
4	332,78 €
5	194,70 €
6	402,99 €

Table 4.6 Heating, conditioning and total consumptions for dual choice scenario.

Costs analysis shows a big reduction in expenditure, from the 2314,23 euro per year of the Starting condition, to 1786,11 euro per year. The difference is in the investment amount of 6500 euro. This retrofit choice has quite a long payback period, but it unifies both savings and comfort in the immediate. If we would sustain this period in the time without lowering our capital but reducing our savings capability it would be possible to ask for a loan.

5. CONCLUSIONS

The best case, simulated considering both the distress trend and savings issues is the last one we analyzed. It could be difficult, if the user had no capacity to save, to make such a kind of investment, but actually different forms of loans on energy savings are being proposed by banks as well as taxes incentives are being promoted by Governments.

In order to have a measure of the goodness of the different scenarios, we could compare the trend of the ratio between the bill expenditure (b), (given by the difference between salary and fixed expenditures) and the savings capability per two months (y) after each choice. We can observe, it reaches a 9,3 (b/y) in one year in the starting scenario, due to the low capacity to save, that is about 400 euro per month.

Then we lower to 7, 60 (b/y) with the first boiler retrofit, and to a 7, 98 (b/y) with the insulation retrofit, while, with both interventions we reach 8,5 (b/y) cumulating distress on capacity to save. We should consider in a long-term point of view, that salary would probably grow and that the system of incentives would help the user to sustain the expenditure. In addition, though it may seem not convenient, the passive saving with insulation improving has the best impact on energy performance. It lowers the high primary energy result we obtained in the first scenario, that was about 250 kWh/m2*a and a thermal requirement of 180kWh/m2*a, to 142 kWh/m2*a for primary energy and 103kWh/m2*a for the thermal requirement.

This is due to the effect on thermal losses and permeability of the house, because of the thermal requirement for heating space is given by the difference between gains and losses considering a certain utilization factor. This factor is given by the difference between artificial heating and heating losses divided by casual gains.

Therefore, lowering losses means lowering gas consumption for boiler, so changing insulation means passing from a 1510,98 cubic meters of gas consumed in one year to 1138,53 cubic meters per year. Instead, applying a more efficient condensation boiler, it lowers to 1099, 63 cubic meters. In the end, with both interventions, it could be possible to reach a 829 m3 gas per year. That means less CO2 emissions in the atmosphere.

The main difficulties in this research were found while defining a user comfortdistress. As we started, end-use behavior has always been a sort of "taboo" topic, due to the many variables involved and to all the possibilities an individual user can take, basing his choice on his own feelings and mood. Static models in literature could help us, but also limit us. System Dynamics gives the possibility to open a world of connections: it could in fact be easy to think about but difficult to formalize.

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