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Comfort and energy in future buildings : illustrations in Residential field

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OUTLINE

EXECUTIVE SUMMARY

Evolution in qualitative demand for future residential and commercial buildings is expressed through very various and, sometimes, non-compatible, tendencies.

However, all these demands have to be satisfied in a common environment of, one more time, different constraints.

The synthesis of both demands and constraints is very specific to national contexts. For example, the concept of "sustainable building" is different from a country to another, depending on the availability of resources (space, water, energy,...).

Concerning the triangle "building - comfort - energy", our analysis for France seems to be applicable to Western Europe : demands and constraints are organized around 6 main themes :

- a wider comfort (multi-sensitive, psychological, services and life convenience),
- more flexibility (intermittent housing, adaptation to the market evolution, adaptable comfort to different rooms, activities, occupants),
- respect - and, if possible, improvement - of occupants' health.
- a limited environmental impact,
- compatibility with a refurbishment market,
- economical performance for commercial buildings with a specific theme for residential ones (to give housing and comfort to impoverished occupants).

It is not easy to give a good answer to such a variety of demands and constraints. However, the paper deals about 2 possible applications of these themes to future buildings :

- a special attention is given to "environmental respect" in a residential project.
- a house in a flat, a car connected to a house

SYMBOLS AND ABBREVIATIONS

LCA : Life Cycle Assessment
DEI : Direct Electric Heating
DHW : Domestic Hot Water
CIB : International Center for Buildings
EER : Energy Efficiency Ratio
EHQ : Environmental High Quality
LPG : Liquid Propan Gas
DSM : Demand Side Management
IAQ : Indoor Air Quality
LV : Low Voltage (25 V)
VAT : Value Added Taxes (for "inc. VAT" : including VAT)
UV : Ultra Violet

NO_2 : nitrogen dioxide
CO : carbon monoxide
SO_2 : sulfur dioxide
CO_2 : carbon dioxide
K : thermal conductivity in $W/m^2.°C$

Within the framework of our medium term program for the development of offers for the Residential and commercial fields, we needed to consider the question about changes in demand and constraints about buildings and their consequences concerning electrical comfort. This analysis was carried out mainly within the context of the Residential sector, deliberately considering the point of view of the final customer, in other words the person "using" this comfort. The analysis has to be wider than the only comfort theme.

1. Six themes to be retained

A large number of forecasts and/or society studies carried out either within EDF or across France and Europe [1, 2] are available to help define themes that will be important for the buildings of tomorrow (most of which are already important). The conclusions has to be discussed but we to summarize it by items :

Social trends :

- population ageing : → problem of resources
  → shock of dependence
  → aged workers
- professional life more chaotic and de synchronized
- more free time, but by smaller bits → more mixing between private and professional life
- more individualism (not egoism) :
  → more independent workers
  → more freedom and tolerance in private worlds and more rules in public worlds
  → personalized offers
- fragile increasing of ethic values

Buildings trends :

- more refurbished buildings than new ones
- reinforcement of regulations :
  → integration of environmental effects in buildings regulations
  (especially, efforts concerning the lowering of energy consumption in buildings will increase)
  → reinforcement of "safety behaviors" about healthy and security items
- the buildings' skin and associates techniques are the main field of technical evolution
- the second one will be the indoor air quality (connected with comfort and health)
- in France, the question of the emergence of an industrial way of construction of new buildings remains
- buildings will be (partially) energy production plants

Inside equipment trends :

- part of them able to communicate with the inhabitant, other inside equipment, and repairers
- more individual
- more "immaterial equipment"

Concerning the more important items for the "building of the future", we tried to summarize these " macro-trends " in a few major themes that already exist, although their nature (constraint or demand) or importance (health) might change in coming years. These six themes are :

1.1 Personal fulfilment

- increased and expanded comfort, in a very wide sense : at the moment, the concept of comfort is centered essentially on temperature needs, but will become considerably wider in the future.
    - comfort will become multi-sensorial and will include acoustic and visual (lighting) comfort. It will also include psychological aspects (stress free environment, natural lighting, sounds).
    - consumer comfort will be better regarding the equipment's working (interfaces, realibility)
    - it will include standard conveniences (ease of use of an appliance, reliability, control) and consequently will therefore encompass the "usage → services" transition, and communication systems making these new services possible.
- recreation, pleasure
- in a safe environment.

1.2 Greater flexibility.

Families and consumers no longer belong to clearly defined categories, their needs are changing quickly (even over the time scale of a week, for example in the kitchen rudimentary microwave cooking on week days makes way for traditional family cooking at the weekend). The home and its uses must be adaptable to a variety of increasingly short life cycles (re-composition of families, late departure of teenagers, long term residence of the elderly with the return to cohabitation of several generations in the same home, work, leisure and training at home, periods of professional inactivity).

In the commercial field, flexibility of the inside spaces in a condition of success in order to follow market's trends.

1.3 Protecting (or even improving) the health of occupants.

It is today a huge and increasing market. Demand concerns :

- the realization of the need of "health capital" (deals with the current quality of air (IAQ) and water in the home
- also includes more extreme forms including looking after the elderly at home and increased medical services in the home.

But resources are limited and could lead to convergence towards medical assistance and tele-medicine (caring for elderly people and sick at home).

Health is also a factor which could either lead to the popularity of a product or its commercial ruin. Precautions will be more important concerning this theme, and it could be a raison of decreasing of creativity and innovation in future buildings (see buildings trends).

1.4 Greater sensitivity about protection of the environment.

It is a very complex and multicriteria subject. Considering the residential field :

- in the global sense, in France, this has not yet created a demand from final consumers who are not yet ready to pay (either by making personal efforts or with money). Therefore, at the moment the impetus is provided more by the policy adopted by local authorities with the result that the building regulations are regularly becoming stricter, and by the involvement of public clients in the construction of "sustainable buildings". However, it is important to be aware that the nature of this theme will change within a generation, this constraint should start to change at the demand of the final user. Increasing awareness should go outside an institutional framework to reach the consumer stage, since we are now the first generation concerned about the impact of our

actions on future generations. We have also to consider as a positive point what we called the "fragile increasing of ethic values" (see social trends).
- in the local sense, there will be a backlash soon under the "neighbors look".

In the commercial field, this point is extremely important : a commercial - or industrial - activity have to prove that its behavior is ethically correct, and this includes respect of environment.
In most of cases, High Quality Environmental Buildings are made by publics policies and some private companies for residential and tertiary buildings (as high school, offices...)

Of course, first quality of Environmental High Quality (EHQ) building is its low consumption in natural resources, namely energy and water. The building of tomorrow have to consume less energy and to produce part of its consummations.

1.5 Refurbishment of buildings

Commercial buildings are not all adapted to current commercial activities (especially office buildings) : they need to be refurbished. French Residential buildings are renewed at very low rate (80% of the buildings that will exist in 2030 are already built today). It is more difficult to guarantee comfort and high energy performance if the building is not well designed. It is technically and economically difficult.

1.6 Constant economic constraint

Permanent concern of the Commercial sector, and also a strong constraint in the Residential sector that becomes acute with the increase in exclusion among a section of the population. This is the most difficult theme of all. Not only because economic constraints are drastic but because, solutions are much more dependent on non-technical factors than in other cases.

This analysis (highly concentrated on the Residential sector) is more difficult to carry out for the Commercial one. The themes are eventually the same, but they are all related (more or less strongly) to a permanent economic requirement that concerns all items :
- flexibility, if it makes it possible to adapt to markets more quickly (and therefore at lower cost),
- comfort, if it improves the "productivity" of occupants,
- and obviously the "investment - operation - maintenance (reliability)" combination.

Here again, this "demand" should accommodate to strong constraints reflected by changes in regulations (environment, health), and by the nature of the buildings (mainly a rehabilitation market).

	Residential	Commercial
Personal fulfillment		
Recreation, pleasure	demand	/
Increased comfort	demand	if increasing productivity
Safety	demand	demand
Flexibility	demand	economic necessity
Health	demand	legislation
Environment	global constraints, local changes → tomorrow's demand	legislation
Refurbishment	constraints	constraints
Economic constraints	= exclusion : constraints	underlies all demand

Tomorrow's buildings will not be a combination of these various trends since it is easy to see that they are not all compatible with each other. Nevertheless, they will be affected by all of these influences : therefore they will be even more comfortable, they must be adaptable through greater flexibility to changing needs of their occupants and managers, they must better protect the health of their users, they should be less damaging to the environment during their construction and operation, all this must be possible starting from improvements to buildings many of which already exist and under acceptable economic conditions, particularly for homes, sufficient imagination must be shown so that comfort solutions adapted to all budgets can be defined.

2. Examples of solutions provided by electrical uses in the future

2.1 Uses

We will give a few examples of electrical products currently being developed, but this is far from covering the entire possible range of future uses of electricity.

2.1.1 *Windows*

A great deal of progress has been made in recent years in thermal aspects of windows, but, in the future, the addition of electricity will enable them to perform new functions such as :

- control of solar flux, for example with electrically controlled "electrochrome" windows that can limit solar inputs and therefore improve comfort in the summer and/or reduce energy consumption for cooling for an air conditioned building. In winter, zone control is possible to limit glare without reducing light flux.
- variable privacy with electrically controlled liquid crystal windows. These products are available for indoor windows, and, in the future, can be used to control vision outside (materials with electrical transition) or to choose the level of intimacy (imagine a bedroom that can be seen during the day but concealed at night).
- active acoustic protection (already used for Commercial applications in ventilation) capable of "filtering" some noise (motor low frequencies) to keep only pleasant sounds (high pitch frequencies of children playing, or birds singing).
- a heating window, which can already be used to avoid the "cold wall" effect or to provide back-up heating, and in the future will be able to heat an entire room, and possibly to store and produce energy.

2.1.2 *Heating*

The existing range of heating products is already very wide and can satisfy many expressed needs (inertia or reactivity, integration or appearance, etc.). Therefore, the objective is not so much to create a lot of new products, as to significantly improve what has already been developed (reliability, implementation, costs) for example such as :

- inertia and storage radiators using heat storage materials based on phase change (better integration by the variety of shapes and improved compactness),
- heating floors with a fine concrete screed or faster to construct,
- easier to install and more aesthetic heating ceilings,

and make better use of the possibilities of the Joule effect to create products capable of overcoming weaknesses in the current range :

- transparent radiating or very thin panels (less than 1 cm), even more easily integrated.
- heating coatings : glue for the bathroom floor tiles, the carpet in the games room, a bath which keeps the water hot, armchair fabrics, desktop writing pad, computer mouse, etc.

- multi-function emitters : heating mirror (pleasant booster heating for the bathroom, non-misting mirror), heating doors and windows (easy to integrate products adapted to renovation), decorative elements (sculptures, cornices), etc.

2.1.3 *Ventilation*

Today, ventilation of homes is not always satisfactory. There are many different needs, considering the necessary improvement to Indoor Air Quality (health, energy consumption, comfort). However, the foreseeable improvement in available products is relatively poor, and this is undoubtedly one of the fields in which R&D efforts should be made. Electricity is expected to be useful for :

- health, with qualitative preliminary treatment of incoming air, for example UV or pyrolysis, and ventilation control as a function of the composition of indoors air,
- energy efficiency with the use of thermodynamic systems between incoming air and outgoing air, and ventilation as a function of the composition of indoors air,
- comfort with preliminary heat treatment of incoming air.

2.1.4 *Lighting*

In the same way as for windows, many technical improvements have been made to lamps over recent years. The following gives a few examples of improvements expected in the future, apart from the appearance of more energy efficient light sources :

- create complete light environments through the control and variation of light flux, color and color rendering. At the present time, the virtual window already provides "natural" lighting in rooms without any daylight.
- move light fittings on a wall at will (these systems are already available in some shops, based on Low Voltage power supplies through conducting panels).
- optical fibers will be capable of transporting light in wet rooms (showers), or places with difficult access.

2.1.5 *Household appliances*

Apart from the continuous widening of the "low consumption" range, the other trend in household appliances is increased communication ability to dialogue with :

- the user by means of Fuzzi logic : for example, the surface cleaning robot may suggest : "the kitchen floor is dirty, I could wash it tonight ",
- other purposes : collective control, DSM,
- outdoors : call the repair or maintenance service, shopping through the Internet.

The latter point announces the "usage → service" transition : instead of buying a clothes dryer, we rent the "washing" function and transfer a number of responsibilities from the user to the supplier : the equipment must have a long life (it belongs to the company hiring it out), it must be reliable (maintenance included in the service), and it must be recyclable (the company hiring it out recovers it at the end of its life).

This change is perceptible in household appliances but could be a useful channel towards the commercial development of new products, such as air conditioning systems or de-localized energy generation/storage systems.

2.1.6 *Comfort control*

Comfort is a psycho-sensorial concept which means that it is an extremely difficult subject to describe (different concepts of comfort for different individuals), and even more to quantify. Nowadays it usually includes only its sensorial aspect, and only considers heat as quantified by a temperature.

Considering heating alone, we already know that temperature gradient, air speed and heat flow parameters are all important, if only as a function of the nature of the emitters and their locations, these parameters will not all have the same "equivalent value". In the future, it will be necessary to take account of the various senses involved and the impact of psychical perception. Without actually defining an individual comfort map, we will be able to classify the preferences of 80% of the population in categories compatible with their needs for comfort : these categories will make use of the parameters mentioned above (temperature gradients, nature and location of emitters, etc). A development program is being carried out at EDF in order to define these categories.

Therefore, it is easy to understand that it is not easy to control comfort provided by a use of electricity. However, in the future, it will be necessary to control several usages harmoniously at the same time, for DSM and for comfort. The concept of "ambient comfort" or "climate" will appear and in the future we should be able to control a comfort scenario, for example such as "cinema ambiance" when we want to watch a film : less intense and warmer lighting, higher temperature, use of quieter appliances, installation of active noise absorption systems.

Therefore, control is an essential field for tomorrow. Many technical developments are still expected, but their success depends very much on their acceptance in society. Two points are essential for this acceptance :

- the control mode, for which two trends are developing :
    - self-adapting mode, as transparent as possible for the user. The controller will receive inputs from sensors unnoticed by the occupant and through a minimum of non-quantitative information supplied by the user (it's all right, it's not all right, it's too warm). EDF is currently developing a self-adapting heating manager that "learns" the habits of the home occupier in a few weeks (I don't eat at home on Mondays, I get home at about 19h00). This prototype is working well technically, but is faced with two generic difficulties :
        - it must be possible to include an unanticipated scenario by a remote controllable override mode (I'm not very well, I'm coming home).
        - the controller "master" must be identified, even though there will be arguments about the controls (it's already too hot for Dad, but Grandma is always cold and wants it warmer).
    - remote controls, associated with reactive uses with low inertia, for everyone who does not want to delegate or whose lifestyles are too irregular (60% of Paris executives don't know when they will get home in the evening, to the nearest hour).
- the simplicity of interfaces : although touch screens had some success a few years ago, and although the keyboard seems well accepted nowadays, no one type of interface has taken a clear lead over the others. A great deal of progress is expected in voice recognition and transfers should be expected between developments made to improve the lifestyle of the handicapped and control of uses related to indoors comfort.

3. Concepts of future buildings

3.1 An example design of an electrical and environmental home

In 1998, EDF organized an architecture and engineering competition for a detached house (the dream home of most French families) [11]. One objective was to demonstrate that electricity can serve as main energy into an environmentally friendly home. In the French definition [13], environmental quality of buildings involve both the outdoor (in terms of pollution, depletion of resources...) and the indoor environment (comfort and air quality).

Moreover, the purpose was not to build an experimental house or to use technical solutions that were not yet existing. On the contrary, the objective was to design a modern house equipped with equipment available on the market and not requiring any special developments.

3.1.1 Requirements

The requirements were to design :

- a house for "**living** in" offering a pleasant lifestyle to a family of 4 persons within a living area of 150 m².
- a **flexible** house. The design of the house had to allow an upgradable internal area capable of matching new lifestyles (e.g. work at home) and the change in the family structure,
- **a comfortable** house in many respects :
  - ◊ indoor temperatures in summer and in winter ("four seasons" comfort),
  - ◊ acoustic, with respect to outdoor noise equipment noise, and also indoor noise,
  - ◊ visual (view outdoors, natural lighting),
  - ◊ Indoor Air Quality.
- an **environmentally** friendly house through:
  - ◊ a reduction of its impacts of the environment, from its construction to its demolition. In particular during its life - low energy and water consumption,
  - ◊ its integration into the surroundings.
- **low energy operating** costs.

3.1.2 The design project

The winning team (Pierre Lombard, Architect and Olivier Sidler, Consulting Engineer) adopted a global approach to optimise the selected solutions. They offer a very coherent and integrated project in which each technical and architectural choice is important. An overview of this project is shown on the *Figure 1*.

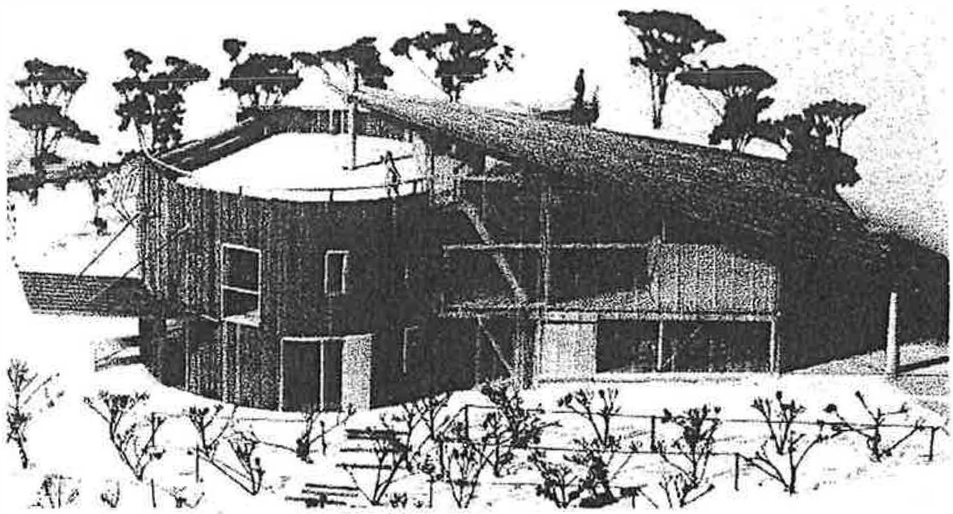

Figure 1 : An overview of the prize winning house (P. Lombart, Architect & O. Sidler, Engineer)

3.1.3 The solutions proposed

Architectural choices

The prize-winning house integrates a **bioclimatic** architecture :

- house is oriented so as to maximise solar inputs in winter.
- large well-oriented vertical windows, construction of a large integrated veranda at the south so as to benefit for solar radiation in winter while providing protection from it in summer (upper part covered and insulated, top and bottom openings enabling free cooling ventilation at night).
- plants used to improve comfort in summer : trellis with deciduous plant cover providing shade over the top of the veranda.
- house oriented to protect it from the dominant cold winds (redirected by the sloping roof),
- construction of buffer rooms at the north (garage, workshops, attic, cellar,..)
- cylindrical main volume (exchange area less than for a cube, for the same volume).

Thermal comfort

The house presents an extra insulation : outside thermal insulation and triple glazing,
The thermal inertia is high and choices (fine automatic control for heating) have been made to have a good energy management. This set of choices results in natural cooling of the house.
Heating is ensured by :

- electric radiating ceiling (good comfort and high energy efficiency),
- complementary very efficient fireplace,
- regulation.

Ventilation and Indoor Air Quality

Considering the little progress made in existing techniques (as CO_2 sensors, treatment of incoming air) and the higher cost of more efficient techniques (as dual flow), ventilation is controlled by a conventional mechanical ventilation system with regulated humidity. The materials used inside the house do not require any surface treatment (slate or linoleum floors, untreated wood for the veranda,..)

Domestic hot water

- use of economic showers and reductions in the length of the distribution network
- use of solar energy (3.3 m^2 sensors, double tank - solar tank + additional electrical tank, systematic preheating of water by the solar tank). Technical efforts have been integrated to limit heat losses due to the storage and the distribution (short, star, insulated network).

Household appliances

- priority has been given to the use of appliances without standby (computers, microwaves) or if not possible with simple or controlled cutoff devices,
- appliances have the Class A (low energy consumption).
- natural area for drying the washing,
- induction plates on the cooking hob (low energy consumption, no inertia) and extra insulation around the oven.

Lighting and visual comfort

- large amount of natural lighting. For further comfort, remaining lighting needs have been provided by multiple points with a variety of light fittings, but all based on a design compatible with the use of compact fluorescent lamps to reduce consumption by a factor of 3 to 5 (simply replacing conventional incandescent lamps by compact fluorescent lights without changing the light fitting degrades the degree of visual comfort).

Acoustic comfort

- Outdoors noise : fresh air through the veranda (noise buffer area), and windows with triple glazing,
- Noise related to equipment operation : appliances with excellent acoustic attenuation, heating mode chosen without noise.
- Noise inside the home : mobile partitions between rooms made from materials with high

sound absorption, use of acoustic bricks with hollow compartments.

Flexibility

The house in this project is organised for use by a family of 4 persons with two children. Frequently used areas can easily be modified : the open kitchen can be concealed by a curtain, the office area can be isolated by a removable mobile partition,... The different use of annexes also opens up future possibilities : independent apartment for children and teenagers, a second home with independent access.

3.1.4 Energy performance of the project

The *Figure 2* gives the estimated energy consumptions concerning the laureate house. The energetic results are compared to a regulation reference which is constituted by regulatory requirements and/or common practices. Estimations have been made for the different uses concerning the individual residential sector : heating, cooking, DHW, appliances and lighting.

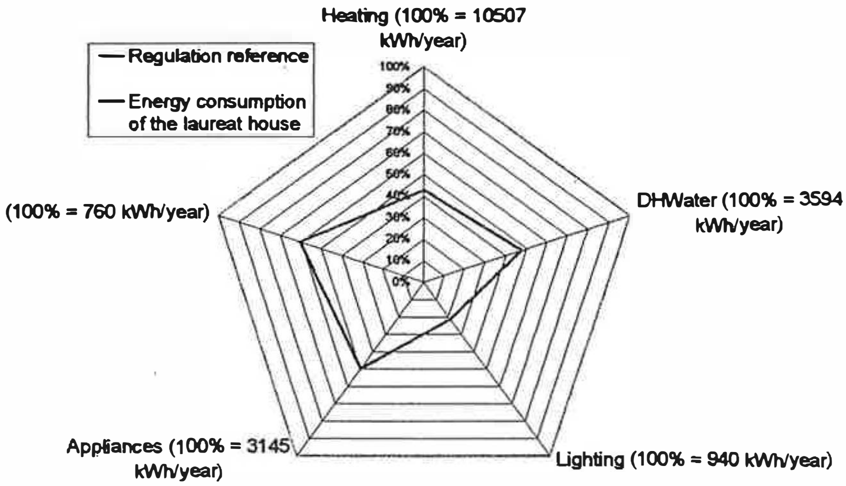

Figure 2 : Energy consumptions for the winning house

Globally, energy consumption is reduced of more than 50% in comparison with the regulation reference.

The construction cost (including unheated annexes) is about 216 478 euros (inc. VAT) for an inhabitable area of 125 m^2.

3.2 A futurist concept : a house in a flat, a car connected to a house

Several ideas drove us to this concept :

- necessity to find the detached house's convenience in an urban flat,
- old dream of a flexible lodging able to follow family changing and growing,
- integration of new activities in lodging, especially manual works,
- necessity to decrease air pollution in urban areas,
- coupling of local and centralized ways of generation of electricity.

The first idea comes from future electric cars moved with fuel cells. Dr A. Lovins, from Rocky Mountain Institute [14], makes two observations :

- american cars are running only 5 % of a daytime,

- every year, US car industry produces for internal market an amount of cars giving a level of power equivalent to the existing US electric plants annual production.

He imagines that fuel cells cars could be used as small electric power plants during the other 95 % of the daytime.

During the same time, architects François Seigneur and Sylvie de la Dure [15] and EDF work on a concept of building able to receive cars inside of every flat in order to answer to the needs listed in the first part of this paper.

The possibility to run his car inside of the flat gives a lot of convenience :
- easier and safer mobility for elderly people, handicapped people and children,
- easier handling in a private (shopping) or professional context,
- safety storage of cars and its contents,
- no more underground collective parking understood as dangerous areas by inhabitants and collective house managers,
- possibility to park inside the car when it is not possible to dig underground parking.

The "inside individual garage" is a new kind of room able to partly solve problems of flexibility in lodging :
- new possibilities of storage,
- the place for the "second part of the kitchen" : storage of food, apparatus, rubbish's,
- workshop, bedroom for granny visiting children, apartment for elder children, room for parties,
- use of the stored car as a room : auditorium for music, office, occasional bedroom, place of rest,

This new intermediate room facilitates the coupling of a local and mobile way of generation of electricity (electric fuel cell car) and a centralized system. Imagine a double network on a local scale : electricity and hydrogen :
- a fuel cell car is able to fill its hydrogen tank in the building or outside in the block,
- the fuel cell car is able to deliver electricity on a local network when staying at home.

Architects Seigneur and Deladure conducted the study of the concept in refurbishment of dwelling in the historic center of Marseilles for social housing. It was not possible to dig an underground parking, and the place for "car-elevators" was founded in the place of classic inside stairs. Other studies for new collective houses conclude that the "car-elevator" cost is mainly covered by the economy of the underground parking.

Figure 3 : Example of a professional use

We described several advantages of this concept, but we have to discuss about its weaknesses :

- we checked that the concept is not opposed to possible evolution of urban transportation : that is true if the car is a urban one with an area of work of a few km. The larger car, the one for holiday for example, is stored a few kilometers away.
- the main criticism is coming from a medical point of view : our life is a more and more sedentary one. It is better to promoting walking than proposing ways of life avoiding it. We have to walk more, even with 20 kg of groceries.

This concept of housing will be studied for real projects of new dwelling in order to build one.

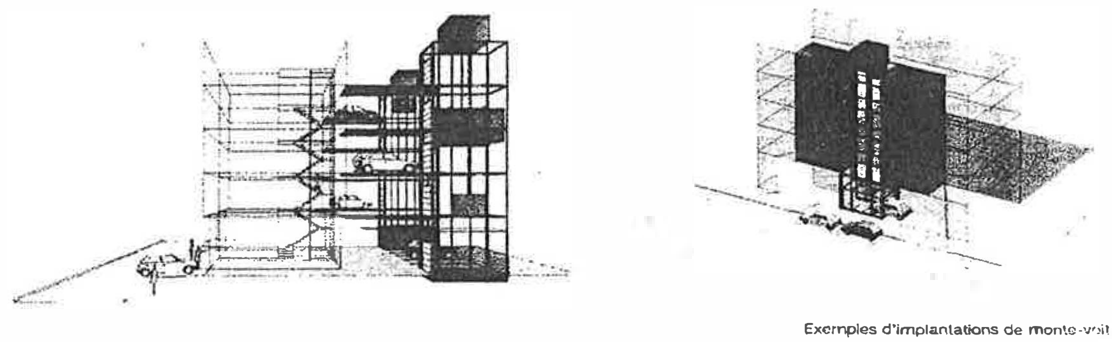

Figure 4 : Example of inside and outside integration of car-lifts

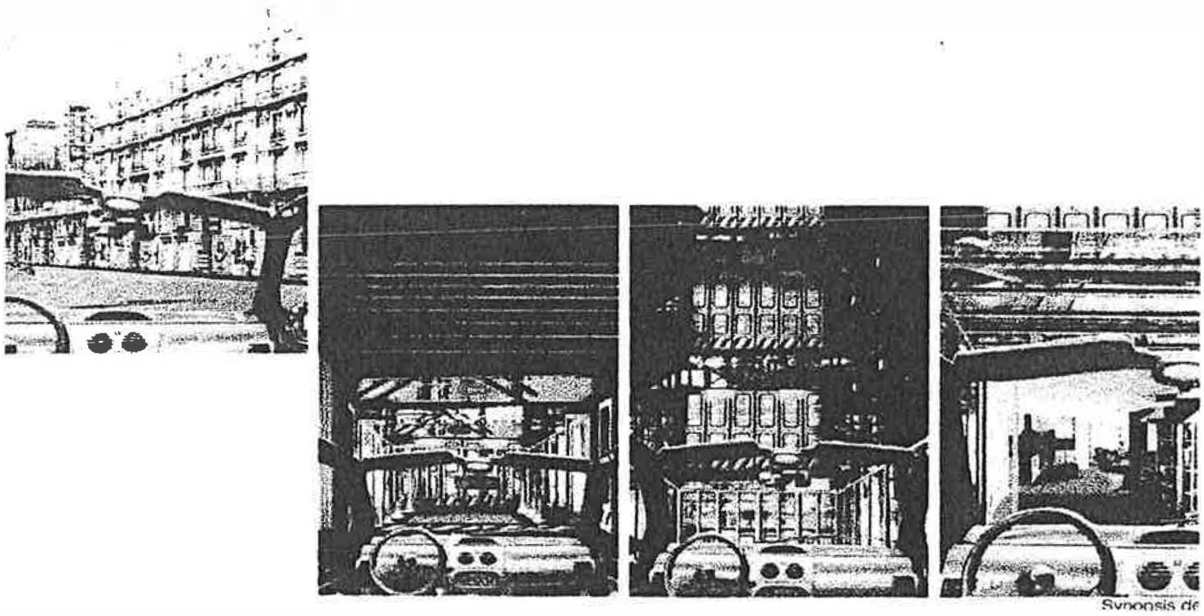

Figure 5** : **Coming inside of the building

4. Conclusions

Electrical applications currently being developed provide a variety of technological solutions to subjects important for comfort in tomorrow's buildings. However these innovations will only be successful if they are psychologically and socially accepted by users (delegation, amount of control, and simplicity of interfaces).

Products currently on the drawing board will undoubtedly provide solutions to demands for increased flexibility and comfort, and to the necessary requirement for increased respect of the environment. On the other hand, protection of the health of occupants and difficulties related to refurbishment of existing housing must be described in larger research programs than today. Finally, there is often still a need for means of bringing these solutions within the reach of economically deprived populations. This is undoubtedly the theme in which we have to progress and which requires the most R&D effort.

On the particular theme of "sustainable buildings" and their energy efficiency, electricity companies have made many development efforts to improve the energy efficiency of electrical uses, with the initial purpose of economic competitiveness. Electricity applications can undoubtedly contribute to the design of EHQ buildings, and some can even improve buildings either by their high energy efficiency, or by their ability to improve the Indoor Air Quality and the quality of water.

However these products, which are more energy economic, are only accepted if their use does not reduce strongly expressed needs for comfort. This compromise is possible, but the investment necessary for low energy consumption buildings and equipment is often higher than for traditional techniques (for the same service provided).

This is the strongest brake in the current context of simultaneous high energy efficiency and energy abundance. However, solutions will have to be found to lower investment costs of products and systems with a high energy efficiency if we want to continue to control global energy costs, in other words these technologies have to be made accessible to the least fortunate segments of our population, and the large amount of know how that electricity companies have built up on this theme has to be shared with developing countries.

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