The learning house

Jonas Honoré, MSc. PhD-student & Morten Elle, Associate Professor, PhD, Technical University of Denmark, Department of Civil Engineering, Sustainable Urban Management

1. SYNOPSIS

The learning house increases the environmental awareness of the resident by adapting to her lifestyle and providing the right information at the right time.

2. ABSTRACT

Throughout the 19th and 20th-century increased automation of residential buildings has lead to a lack of awareness on the actual effect of the polluting effect of consumption. The accumulating environmental problems urge to change this development. Approaches focusing on energy efficiency alone might ease the pain but they will not cure the patient.

Building automation is gaining ground in residential buildings. The result is the intelligent building, which relies on high-tech applications to accommodate the residents' wishes, while simultaneously optimising the use of resources. Such a building may seem to be a dream-come-true. There are, however reasons for concern. An intelligent home may lead to "stupid" residents: the residents' appreciation of the underlying environmental implications of the use of energy decreases.

This paper presents a concept that is based upon knowledge on energy-technology, user interfaces and information:

> *The learning house, raising the residents' awareness by interaction, influences and increased action competence.*

The concept describes a learning building in which the building learns (adapts) to the residents' behaviour, based on which it provides relevant information and home-automation.

By supplying the residents with more control and information a basis for an increased motivation to be concerned about otherwise hidden aspects of the use of energy is created. This involves designing advanced building-systems as well as reorganising the existing energy-infrastructure to support desegregation of energy-products and finally designing a user-interface for the learning house, thus enabling the resident to live in it without using a manual.

3. INTRODUCTION

This paper deals with the difficulties concerning sustainable housing – technical- as well as infrastructure- and resident- related problems. The results presented are obtained from an ongoing ph.d.-project approximately 1_ years underway. The project is being carried out at the Technical University of Denmark, Department of Civil Engineering.

Implementing energy efficient technology in housing might lead to quite large energy savings but even if the technology is flawless in a technical sense, a better integration of the technology with the residents' behaviour will increase the efficiency further. There have been many examples of this and as a result there is a general wish for less burdensome tasks as there is an increasing automation of tasks in every day living.

However, we believe that the house of the future should not be an intelligent house that takes care of the problems and tasks itself but rather a learning house that will address issues for the resident to decide upon.
Needles to say that designing a technology that will enable the house to learn from the residents as well as providing the resident with the right information at the right time is no easy task, even less so when you take into account the restrictions given by the existing technology and infrastructure.

Information and understanding of abstract environmental problems will solve some problems but it will not be sufficient to change the daily lives of the residents. For this to happen much more than information is needed.

In this paper the concept of the learning house is introduced and an overview of different aspects of the concept is given. Greater detail will be given to the fundamentals of the learning house, explaining how the concept is constructed by combining knowledge from such different areas as research in lifestyle and human computer interaction. This will be followed by building related examples of what the practical implementation of the learning house could look like. Finally a conclusion on what the concept of the learning must be on the basis of the research so far and an overview of what still needs to be done will be drawn.

4. CONCEPT OF THE LEARNING HOUSE

As far as we know the learning house has not yet been build, so the learning house is a concept aimed at saving energy, other resources, and minimising pollution in general. The concept also addresses increasing the household-life quality. This system is supposed to support the resident not only with regards to controlling the household functions and choosing the right energy-system, but also in general enlightenment – lifelong-learning.

The concept of the learning house integrates a number of perspectives on sustainability, education and life-quality. Such an interdisciplinary concept is difficult to manage and implement in existing infrastructure, building technology, and social structures. A model has been suggested that might help to give an overview of the concept and its many facets. In the table below the rows represent the most important variables that the learning house has to adapt to. In the three columns is listed what could be described as the theoretical basis of the concept of the learning house. The contents of the table are keywords describing an aspect of the theoretical area in question that is influenced by the “building-variable” in question.

It is not possible to have one system that will function well in all the possible combinations of this model. Hence, a range of systems must be developed that covers different aspects of the learning house. Especially the very different demands on technology, dictated by infrastructure in an urban versus rural setting, will be hard to contain in one system. Likewise the very different lifeforms of residents leads to a demand for a flexible system and especially user interface. It is however not the purpose of this project to define the learning house system - it is to define the *concept* of the learning house. Below we will go into greater detail with concepts listed in table 1, starting with technology, interface and information.

Table 1. Concept of the learning house

The learning house	Technology	Interface	Information
Learning	Thought-through	Thinking	Communication
Number of residents	Size of the house	Structure	Faceted
Lifestyle	Layout of the house	Individuality	Complexity
State (New, existing, renovation)	Control	Extension	Supervision
Placement (Countryside, City, Suburb)	Individual or shared	Macro-Integration	Choice of resource
Type (Single family, apartment...)	Scale	Micro-Integration	Basis

5. TECHNOLOGY

The concept of the learning house incorporates the many different types of energy efficient technology with information and communication technology in order to give maximum control to the resident with minimal use of resources. In this section we will take a closer look on the interaction of technology and the residents.

Intelligent houses

Monitoring of buildings and automation of energy-related tasks as well as a number of other tasks is becoming widely spread in office-buildings. Besides the possible gains in energy-efficiency it is possible for a small number of people to service large building areas and quickly discover malfunctions and possible dangerous situations. [Loe, 1996]
In many cases these intelligent building-systems make it difficult for the users (the employees) to influence for instance the heating or ventilation system. There has been a tendency to optimise the building for an average non-existing person and not the actual users who might want a climate that was quite different from the average.

In newer systems this problem has been addressed and to some degree remedied, giving the user much more individual control. Some systems even have profiles of all users so that their preferred settings follows them around the building. [McGregor, 1994]
In the not so distant future we might even be able to buy a suit that has all the functions of an office today. Smart clothing with wireless communication promises us that the working-place follows and adapts to us instead of the other way round. [Hum, 2001]

The concept of the learning house is based on stronger involvement of residents in energy and building related issues through the use of information and communication technology. This requires development of advanced technology, which at the same time is very user-friendly.
As the results presented in the following section will show, there can be a significant difference between solving problems with or without involvement of the resident.

Active residents

Energy efficient technology is important but equally so is the residents' way of using this technology. The significance of the residents' environmental awareness was examined in a study of 4 sustainable Danish projects. [Honoré, 1998]
The projects examined do not consist of ordinary buildings. All of them are constructed using environmental building technology - not just one type of technology but a wide range of different technologies are used in all of the projects, addressing a broad number of environmental issues.

2 of the 4 projects are public housing, 1 consists of private homes and 1 is a co-operative project[1].

An analysis of the projects was performed on the basis of a basic model, involving 4 layers of actors and 3 geographic layers:

Table 2. Model

Actors	Geographic
Consultants	The building
Public administration	The building site
Building professionals	The surroundings
Residents	

In depth interviews were conducted with representatives from all groups of actors. All in all more than 30 interviews were conducted for the 4 projects. Furthermore reports and construction plans were taken into account.

Active Residents or Active Technology

Having collected data for the 4 projects a pattern emerged. A rough division into two types of projects is possible.

Table 3. Types of projects

Active Resident Projects	Active Technology Projects
Vaarst Vestervang	Skotteparken
Hjortshoej	Froedalen

The projects with *active residents* were initiated by the residents themselves, which gives the residents a strong insight into the sustainable techniques used in the buildings as well as an understanding of why these specific techniques were chosen – simply because they had been involved in the choice themselves. Furthermore the technology in these projects seemed to be of a more basic if not low-tech nature compared to the sustainable technology of the projects with *active technology*. In the latter type of projects engineers and other professionals chose the technology. This shifted the criteria from low/easy-maintenance to technology with the greatest resource- and cost-saving potential.

The conclusion is that projects initiated and run by residents have the lowest negative environmental impact. Furthermore the residents are generally very satisfied with their homes including aspects, such as the disposition and size of the home, the indoor climate and the materials - but they are also looking for ways to further improve the sustainability of their homes.

Table 4. Resource consumption in the different projects

Project\Resource	Heating kWh/occupant/year	Electricity kWh/occupant/year	Water M^3/occupant/year	Solid waste Kg/occupant/year
Skotteparken	3593	1400	41	206
Froedalen	4500	1200	38	247
Hjortshoej	2057	777	20	48
Vaarst Vestervang	3786	1080	31	105 (54)*
Danish average	7974	1821	59	305
“Environmental space” 2030	3141	718	32	-

* 54 kg/occupant not counting the solid waste that is incinerated.

It should be noted that Skotteparken and Froedalen are heated by district heating while Hjortshoej and Varst Vestervang both have a wood-furnace. With regard to CO_2-emission this gives the 2 projects with active residents an even smaller negative environmental impact compared to the projects with active technology.

The Danish average consumption in table 4 is based on figures from Statistics Denmark and the Danish Building Research Institute. [SBI Report 242, 1995] [Statistical 10-year review, 1996] [Statistical Yearbook, 1996]
The figures on “environmental space” in the year 2030are based on a report by Friends of the Earth Denmark (NOAH) published in 1996. [NOAH, 1996]
The concept of environmental space origins in the idea that all people have the right to equal shares of water, food, air, land and other resources within the carrying capacity of the earth. In practical terms it is used as a per person measure for sustainability.

The case studies show that residents' that are more aware of environmental issues and wishes to deal with them have a substantially lower use of energy than residents do in average in Denmark. [Honoré, 1998]
In other words: integrating the wishes of the active residents in the building process improves the sustainability of the household significantly. However this may not be feasible on a larger scale. After all, how many of us will build our own homes? The majority will move into an existing home.

Instead of building new sustainable houses for all another approach must be developed. Information and communication technology provides us with some of the tools needed to involve and “activate” the residents. What we have learned from the 4 projects in Denmark is that we wish to use information and communication technology without building *active technology*-houses and to facilitate “activation” of the residents.

Infrastructure

Good interaction between residents and technology is not enough. The learning house needs to be able to adapt to the existing infrastructure and operate within the margins that the infrastructure dictates. This is however not just a technical problem. The residents still need to be a central part of the decision-making, which can be achieved by integrating resource-awareness in the infrastructure. This must be done in part by desegregating energy-services into components based on different supply-situations and with varying prices. Such a strategy should also increase the residents’ awareness of consumption and if done correctly also of the environmental aspects of consumption. Research in Norway indicates that just adding some additional information on an energy-bill can lead to a 5-10% decrease in energy-consumption. [Wilhite, 1999]

Today most of our consumption is not directly perceivable. Almost all forms of energy-services are delivered automatically without our supervision. Even the billing process can be automated so that all the resident gets to see is numbers on a bank-statement. To use this number as a link between ones consumption and environmental impacts is impossible. It is hard enough to link this number with the daily use of energy and any possible concrete energy-savings and the economic benefits of such savings.
Note that we are not arguing to shut down our modern infrastructure and reintroduce wells for water, coal for stoves and garbage heaps. We are arguing that the historic removal of labour in order to supply these necessities together with an increase in population and consumption has made it more difficult to explain why resource-management is important and what it is in detail that we need to change in our daily lives.

Initially the suppliers of energy-services may see the opportunity to use an increased flow of communication between themselves and residents as a way to facilitate a transition from a traditional supplier role to that of a consultant on how to best satisfy the residents’ need for energy-services. [Guy, 2001]

Thought-through - Learning vs. Technology

Through the choice of technology for the learning house it must be ensured that learning is possible. Not only by means of communication technology but also by means of energy-technology. Besides being efficient and well integrated the installations that require to be operated by the residents must be logic with respect to the overall system. This includes avoiding the creation of new problems when trying to solve another. For instance using UV-light to purify sewage-water so that it may be used for watering plants. This might solve one problem but will create another – a relatively high-energy consumption compared to a traditional sewage-plant. Unless there is a strong lack of clean water this solution should be avoided and other methods considered - collecting rainwater for instance.

Size of the house - Number of residents vs. Technology

The average size of homes in Denmark is approximately 50 m_ per person - quite a large area for one person to live in. The reason for this is mainly the fact that many people live alone. It is in fact the most common

household size in Denmark. Therefore much can be saved by a greater adaptation of the size of the house to the number of people living in it. This is closely related to the export of some household functions to common-areas in a dwelling. This is given more attention below. [Ministry of Foreign Affairs, 1996]

Another but similar approach is to build with great variety within a project. This makes it possible to move to an apartment more suitable to the resident's needs without having to make to big a change in the life of the residents. Also this will positively affect the number of different age groups represented in the project, provided that a great variety is seen as positive.
In Egebjerggaard a Danish project west of Copenhagen many different types of buildings were build in close proximity. Not only different in size and architecture but also in types of ownership and use (a mix offices and dwellings). The results are also mixed. It turned out that it was difficult to get companies to use this area, but the residents were very happy to live in this area. This can be illustrated by the small number of residents leaving the area in relation to the number of residents moving within the area. [Honoré, 1998]

Layout of the house - Lifestyle vs. Technology

The layout of the learning house must reflect what the house is primarily used for and to what degree it is being used. Is it a functional house with many residents and guests or is it a representative house, which primarily displays the values of the residents? This has a great impact on the layout of the house. Is the kitchen placed in the central part of the house and is it a communications-base or is it hidden in one end of the house out of sight and mind? This type of adaptation to the lifestyle of the residents will of course also have great influence on the size of the house and the type of house.

Control - State vs. Technology

Obviously the cost of a full implementation of technology needed for the learning house concept will be smaller in a new rather than an existing house. This is true especially for the integration of a user interface and automation-system with traditional energy-supply and control-technologies. Information and communication technologies might somewhat easier be added at a later state with the utilisation of wireless data-transfer and compact devices. [Philips, 2000]
The point is that only in new homes especially designed with the learning house-concept in mind will it be possible to harvest the full benefits of controlling e.g. heat and ventilation on the basis of user behaviour and preferences. Simply because of the lack of possible integration between energy-systems and IT-systems in most existing homes – the existing energy-systems are in many cases based on manual heat-regulation and the house could only be a learning house by a complete change of the energy-system.
The difficulty of transferring a traditional non-learning house in to a learning house is illustrated by the overwhelming focus on new buildings when it comes to demonstrating technology in intelligent housing. [City of Malmö, 1999]

Individual or shared - Placement vs. Technology

By exporting some functions of the household to common-areas in a local community of houses great advances can be made because of the opportunity this gives for comparatively smaller houses as discussed in the previous paragraph but it might also strengthen the social bonds in the local community. This is a prerequisite for engaging residents in different aspects of sustainability as well as more down to earth problems.
This applies to such common functions of a household as washing of clothes and dishes but can be extended to such different areas as having dinner with neighbours as well as composting and watching television. If this is done in a suitable manner a decrease in energy-consumption may be obtained. Obviously this idea conflicts with the ideal of many people: to have their own machines and privacy for increased comfort and availability. However as the number of single-person households increases so does the desire to seek company outside the household. In fact alternative lifeforms with greater social-commitments are increasingly popular among senior citizens in Denmark. [Ministry of Housing and Urban Affairs, 1999] [Vedel-Petersen, 1988]

Scale - Type vs. Technology

The type of building will have some influence on the chosen type of construction as well as materials energy-technology, which again will influence the possibilities of implementing the concept of the learning house. The implementation in a large project with several hundred apartments has quite different opportunities than a single-family house on the countryside.

In large projects it is possible to incorporate special large-scale networks (community networks) in which the residents can communicate (free of charge) and also obtain significant reductions on the prize of communication with the outside world.
The difference between large projects and rural houses becomes even more apparent with regards to the choice of energy-technologies and as result also with regards to automation of these. In a single-family-house the heating system can be optimised to the exact requirements of the residents while in a large project the system must be able to a much broader spectrum of temperature requirements. This greatly influences the flexibility of e.g. controlling night temperature setback.

6. INTERFACE

A vital part of the learning house concept is the interface between the resident and the house including the technology in the house. By studying the area of human computer interaction we seek a system that enables the resident to quickly learn and decide how the house should be operated.

User Interfaces

Human Computer Interaction

In the future we might not even have to flick a switch to operate the lights. Voice recognition and even recognition of gestures will enable the intelligent house to facilitate and even predict our every desire and act accordingly. In order for this to work a new kind of interface is needed.

Since the sixties much has happened to the computer but not that much has happened to the interface. Ivan Sutherland at MIT developed one of the first graphical user interfaces in 1963. The interface consisted of boxes that could be moved around a computer screen. A few years later (1965) the mouse as we know it today was developed at Stanford Research Laboratory and only a few years after that the first interfaces with tiled 'windows' appeared. So even if the computers of today have changed dramatically in processor speed, storage capacity and many other aspects the interface has not developed that much. [Myers, 1996]

A new concept has emerged that might drastically change the way we interact with computers. Tangible user interfaces relies on physical objects that must be manipulated in order to control the computer. Part of the idea behind these types of interfaces is the fact that our learning capability is strengthened when the learning process is combined with physical activity. Tangible interfaces might also help users that are not familiar with computers overcome the "fear" of doing something wrong. The apparently obvious way to avoid errors is of course to read the manual but this is not really an acceptable recommendation in real life:

> Time is valuable, people do not want to read manuals, and they want to spend their time accomplishing their goals, not learning how to operate computer-based systems. [Myers, 1994]

Automation / information technology

In order to operate (or just live) in the learning house without having to read through thick manuals the interface must be very advanced and intuitive. Even more demanding is the adaptation to resident behaviour, which requires some sort of artificial intelligence. It might seem a bit over the top to use such advanced technology in our homes. To some it might even be frightening. There has been some speculation as to whether development of new technologies might pose a threat to humankind. It might seem like something from science fiction but even some of those working with advanced technologies are a bit worried. [Joy, 2000]

This nightmare scenario should not lead to the conclusion that automation and electronics in general are bad to install in ordinary homes. Instead we should harness the technology and use it to achieve what we cannot achieve today without extraordinary measures or extraordinary awareness and interest in environmental matters. The idea is to bring this state of mind to a greater number of residents.

As we have argued the interaction of house, infrastructure and resident must be managed in a quite complicated user interface. Developing the perfect user interface does however not solve the problem of involving or

activating the resident. To ensure this involvement and activity a concept is needed to manage the constantly evolving conditions in both infrastructure and behaviour of the residents.

Thinking - Learning vs. Interface

In this case thinking illustrates that the interface needs to be smart or have some kind of artificial intelligence in order to learn from the resident. Learning is also required for the resident first of all learning how the house works and how to operate it. This must be as easy and intuitive an experience for the resident as possible and at the same time as flexible and extensive as possible.

As the resident learns so does the system leading to a change in behaviour an activities, which the system must open up to in due, time step by step. In some cases the resident may have a very small commitment to learn anything from the system and wishes to be serviced or use the more basic functions of the system. Then a learning-by-doing approach must be established. Other residents may wish to bury themselves in manuals, schematics, and special occasion-requests learning most commands by heart and fully utilising the capacity of the system. [Moltke, 1997]

Structure - Number of residents vs. Interface

Some years ago a great deal of attention was directed at so called personal agents that promised to sweep the internet for information based on a specific users preferences. The agent was supposed to adapt and learn from what the user was actually doing on the Internet and then use this information to present the user with more of the same or similar webpages. The personal agents could not quite deliver what was promised, however there is still ongoing research in this area and the agents are now being used in more specialised contexts – the learning building might be one of these.
If there is only one resident the personal agent will adapt to this persons wishes and use of the interface. But with more than one resident the personal agents must ensure that the interface is adapted to each individual resident. This will not solve conflicts between the residents' wishes, but hopefully it will make it more apparent what the problem is.

Individuality - Lifestyle vs. Interface

Designing a user interface that will fit with residents characterised by different lifeforms, lifestyles, and styles seems to be an almost impossible task. The key to success must be that the interface and the system it represents is able to adapt to the individuality of the resident using it. It would be a shame if tiresome tasks were replaced by giving monotone orders to a "stupid" interface. So the interface must recognise the individual resident and be able to predict what the resident wishes to do at any given time. This prediction must be based on gestures, tone of voice and of course a large database of previous similar situations. However it is also important that the system does not exclude all options or information that it predicts will be irrelevant to the resident. This could lead to a narrow-mindedness of the resident, which is exactly the opposite of the general purpose of the learning house. To avoid this great attention must be given to facilitate learning.

Extension - State vs. Interface

As we mentioned in the Control-paragraph the information and communication technologies will not be the obstacle most difficult to overcome if you are to implement the learning house concept in an existing building. An incomplete integration due to the restrictions set by an existing house must of course be reflected in the interface. This demands a very flexible interface that will function even if only smaller parts of its potential are being used. Especially with regards to integration of different energy-systems there is problems in having only partial control of the energy-consumption. Especially since the system will not know what is going on with the parts that is not integrated. A concrete example is integration of ventilation and heating. In the learning house the house will check if the ventilation is on or the windows are open and adjust the heating accordingly. In an existing house the ventilation-system and windows might not be integrated and the house will not know when or how to adjust the heating-system. Instead it might have to rely on differences in temperature or other data available.

Macro-Integration - Placement vs. Interface

The Interface should support the transfer of functions from the house to common-areas. For instance the interface might be used to book a washing machine and later tell when your clothes are done. Similar possibilities can be used for organising social events (dinner, party, lecture-groups etc.).
Integration with the infrastructure is another important aspect that needs to be considered. In areas with CO_2-neutral district heating the focus can be transferred to saving electricity in stead. In rural areas the learning house should support reduction of the need for heating since this is often supplied with oil or electricity and therefore a greater environmental (and financial) problem.

Micro-Integration - Type vs. Interface

Control of central heating system cannot be directly included in an apartment but should be highly integrated in the interface of a single-family house. In a highly insulated house the heat from appliances play an important role in heating the house. The actual requirement of the heating-system might be so small that an electric-heating system is the best solution for the environment. This would make the integration in apartment and single-family house much more similar. Integration of ventilation will however remain significantly different in houses with natural ventilation compared to apartments with mechanic ventilation.

7. INFORMATION

If the house is to learn from the resident and the resident from the house then information must flow both ways through the interface. But information is not just information. Even with the right information at the right time, delivered through the right interface things might still go wrong if there is no frame with which to associate the given information. Another basic challenge is to analyse which kinds of decisions, people have to be involved in. By looking at the concept of the learning organisation we seek to find answers these problems.

The Learning Organisation

The learning organisation is a concept: management of change.
In 1990 Peter Senge published the book “The Fifth Discipline” which has made a large impact on management of organisations. In this book Peter Senge defines the meaning of a learning organisation:

> An organisation that is continually expanding its capacity to create its future. For such an organisation, it is not enough merely to survive. ‘Survival learning’ [adaptive learning] is necessary. But for a learning organisation, ‘adaptive learning’ must be joined by ‘generative learning’, learning that enhances our capacity to create. [Senge, 1990]

A shorter definition reads:

> *A learning organisation is an organisation that has made it its primary cultural feature to learn from experience.*

In the concept of the learning organisation there is a number interesting points in relation to the learning house. Some of them are briefly discussed below:

Communication

Any communication consists of content as well as a process. It is not sufficient to know what needs to be said. It is also necessary to know how the manner in which to say it. This shows the limitation of application of modern information technology today. A technology that gives the user lots of information and even if it is the right information at the given time it is probably not given in the right manner. The information is often out of context or from a source with which the receiver has no basis of understanding

Influence

Human beings only desire to learn if they are given the opportunity to use what they have learned. Therefore it is necessary to trust human beings to use their knowledge in action. And they must be allowed to make mistakes only to learn even more. Again this underlines the weakness of technology specifically automation of tasks that might not be very exiting to do but by doing them the resident achieves motivation for knowledge on how to do

it smarter and cheaper. The key is to choose which tasks technology should do and which the residents must do themselves in order to balance the basis for motivation with eliminating mindless tasks that only consumes time. A balance that is influenced by the level and quality of information communicated in the organisation / house.

Information

In a learning organisation systems have been established in order to disseminate, divide and distribute knowledge and experience (the organisational memory). Obviously this does not only apply to the house but also to the infrastructure making the task of getting the knowledge and experience to the resident much greater but hopefully also much more fruitful.

In a learning organisation there is curiosity, desire to experiment and challenging of established routines. Learning is typically directed towards learning by solving problems. The set of ideas on which the tangible user interfaces builds fits quite nicely in to this requirement. Breaking habits and new ground is critical but not something that comes natural in an automated household. The technology must be designed to be explored – that is robust and intuitive.

Behaviour and learning

Within the concept of the learning organisation it is recognised that behaviour determines the way we learn and at the same time learning determines the way we behave. This has a great impact on the concept of the learning house. The interface must be able to adapt to the resident's behaviour in order to provide the right information and establish a form of communication that enables the resident to learn. The idea is then to make sure that what the residents learn influences their behaviour in positive direction seen from energy-efficiency point of view. In other words we seek a positive circle of learning and change of behaviour.

Communication - Learning vs. Information

Information in the learning house is not just about the house giving advise to the resident and adapting to the residents behaviour. It is also about establishing channels of communication between experts and residents. The Internet has already made it easy for people to communicate across large distances, but to often the information obtained is of low value because of the uncertainty and difficulty in trusting basically unknown people. It might be sufficient for entertainment, but certainly not if you need advice on choosing a new furnace or windows. So the existing network of environment experts must be used to create a trustworthy knowledgebase that can be consulted on small and large environmental issues.

Faceted - Number of residents vs. Information

Households with many residents need another type of information than households with just one resident. There are many reasons for this. Different patterns in consumption, and different possibilities for flexibility in heat and ventilation control to name a few. The possibilities and restraints are somewhat similar to the differences between urban and rural housing discussed earlier. There is of course also a limitation in the amount of information a person can digest. The information-load should therefore be adjusted to number of residents actively using the system.

Another important issue regarding the number of residents is the way that decisions are being made in the household. In a single-person household it is obvious who makes the decisions and the information can be directed at influencing the decision-making. In households with more than one resident conflicts will arise and the system must focus on delivering information that can facilitate the resolution of these conflicts.

Complexity - Lifestyle vs. Information

What is most important to the resident? Economic or environmental issues? Chances are it is something quite different. Whatever it is, knowledge of the residents' favourite subjects will open a door for other bits of information. If the resident is not at all interested in the environment the learning house must limit information concerning pollution and put more focus on other issues for instance potential savings or increase in comfort.

Supervision - State vs. Information

Many of the advantages of an intelligent house system concern the automation and supervision aspects of the house on a daily basis. There is almost no limit to the number of things you might (or might not) wish to have

supervised. An obvious starting-point is measuring the energy consumption and comparing it to a predicted consumption taking weather conditions and usage of the house in to account. Other possibilities includes monitoring of other resources, temperature and other indoor climate parameters, leakages in piping, burglar alarm, food, children, pets, and a range of offers from external partners such as the local grocery-store or the power-plant.
How the information is delivered and when or if it necessary to disturb the resident is up to the artificial intelligence of the system and its analysis of the records of residents needs and wishes.

Choice of resource - Placement vs. Information

The information offered to the resident must reflect the different opportunities arising from a house in the city in contrast to a city apartment. A resident in a rural learning house might primarily use the interface to obtain gardening tips. Thus the system should provide information on different methods of avoiding hazardous pesticides. Another resident in an urban apartment might use the system to check up on the status of public transportation indicating time of departure, which could be used for the house to remind the resident in due time to engage the "low-power-mode" when actually leaving.

Basis - Type vs. Information

There is almost always something to improve on in order to save energy or optimise comfort in a house. The many alternatives rely heavily on the type of house and the state it is in. By taking the type of house in to account it is possible to reduce the quantity of available options quite drastically. Not only will it make it easier for the resident to choose from the relevant options it opens up to understanding the options in grater detail.
This does not apply to energy efficiency technologies only but also to general advice on how to do things more effectively, cheaper, or environmentally friendly.

8. CONCLUSION

The learning house is a concept of managing infrastructure, residents and advanced energy-efficient technology. The purpose of the learning house is to facilitate low consumption of resources, utilisation of high efficiency technology, and first of all a change of the residents behaviour based on an awareness of sustainability. In order for this to become feasible many advances must be done with regards to technology especially recognition-devices and software (e.g. artificial intelligence) as well as the user interface of the learning house. Another great task ahead is the selection and qualification of what information and in which form it is delivered to the resident. Equally important is the context in which the information is communicated. The energy-infrastructure might not be as easy to change nor will it be as rapid but changes will occur as they have already done. Hopefully some of the keywords in the continuing development will be increased flexibility and a higher level of information and education with a touch of interactivity.

9. BIBLIOGRAPHY

City of Malmö (1999). Quality Programme 1999-03-31. Report on new residential area in Sweden. Bo01 The City of the Future. City of Malmö.

Gram-Hanssen, Kirsten; Jensen, Ole Michael (2000). SBI Bulletin 133. Lifestyle and Energy-demand. Danish Building and Urban Research.

Gundelach, Peter and Kuehn, Susanne (editors) (2000). Energy and Lifestyle; Anthology of a lifestyle seminar in 1999. Sociological Institute, University of Copenhagen.

Guy, Simon, Marvin, Simon and Moss, Timothy (Eds.) (2001): Urban Infrastructure in Transition. Networks, Buildings, Plans. Earthscan, London,

Honoré, Jonas (1998). The Ugly Duckling, The Sound Sustainable Building. Report No. 4, Urban Planning and Urban Ecology, Technical University of Denmark. Lyngby, Denmark.

Hum, Alex P.J (2001). Fabric area network - a new wireless communications infrastructure to enable ubiquitous networking and sensing on intelligent clothing. Article in Computer Networks 35 (2001) 391-399.

Jensen, Ole Michael (2000). "Lifestyle-spaces, faith, reflection of self or lust"; Article in Energy and Lifestyle; Anthology of a lifestyle seminar in 1999. Sociological Institute, University of Copenhagen.

Joy, Bill (2000). Why the future doesn't need us. Article on Wired (www.wirednews.com).

Loe, Eric (1996). Proving the benefits – justifying the costs of intelligent systems. Article in Facilities Volume 14 · Numbers 1/2 · January/February 1996 · pp. 17–25 MCB University Press.

McGregor, Wes (1994). Designing a "Learning Building". Article in Facilities, Vol. 12 No. 3, 1994, pp. 9-13 MCB University Press.

Ministry of Foreign Affairs *et al.* (1996): The Danish National Report to Habitat II, Ministry of Foreign Affairs, Copenhagen

Ministry of Housing and Urban Affairs (1999). Report on the choice of dwellings for the elderly. Ministry of Housing and Urban Affairs.

Moltke, Ivar; Andersen, Hans H.K.; Honoré, Connie (1997). Villa Vision Experiences. Evaluation report on demonstration project. Danish Technological Institute.

Myers, Brad A (1994). Challenges of HCI Design and Implementation. Article in Interactions. January 1999. pp. 73-84.

Myers, Brad A (1996). A Brief History of Human Computer Interaction Technology. Carnegie Mellon University School of Computer Science Technical Report.

NOAH (1996). Sustainable Denmark. National Report. The Struggle For A Sustainable Europe. Friends Of The Earth – NOAH, Denmark.

Philips (2000). Breathing life into the connected home. Website: www.philips.com/kipsbay

SBI Report 242 (1995). Energy And Architecture – A Collection Of Recent Projects. Danish Building and Urban Research.

Senge, Peter (1990). The Fifth Discipline, New York, NY:Doubleday.

Statistical 10-year review (1996). Statistics Denmark.

Statistical Yearbook (1996). Statistics Denmark.

Vedel-Petersen, F.; Jantzen,E.B.; Ranten, K. (1988): Communes. Collection of examples. SBI-report 187, Danish Building Research Institute, Hoersholm

Wilhite, Harold; Høivik, Asbjørn; Olsen, Johan-gjemre (1999). Advances in the use of consumption feedback information in energy billing: the experience of a Norwegian energy utility. Paper from ECEEE Summer Study Proceedings 1999.

10. END NOTES

[1] *Skotteparken*, 14 km west of Copenhagen, 100 apartments, focus on energy-savings. *Froedalen*, 40 km north of Copenhagen, 95 apartments, focus on life-cycle economy. *Andelssamfundet i Hjortshoej*, 15 km north of Aarhus, 5 houses, focus on building materials and social bonds. *Vaarst Vestervang*, 20 km south of Aalborg (in the north of Jutland), 16 houses, focus on heating and indoor climate.