CONTROL OF INDOOR CLIMATE SYSTEMS IN ACTIVE HOUSES

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ABSTRACT

The term of "Active House" recently developed, addressing houses that target a balanced optimization of indoor environmental quality, energy performance and environmental performance. According to the idea of not only being energy efficient and eco-friendly, Active Houses equally focus on indoor environmental qualities, in particular daylight and air. With their tendency towards intensive sun penetration, natural ventilative systems and generally intensive connections to the exterior, Active Houses challenge the balance of technical and individual indoor climate control.

The paper in hand presents and discusses challenges and findings from six model Active House homes in five European countries:
How to design and run heating, cooling control systems in Active Houses.
How to balance hybrid ventilation systems in Active Houses.
How to open the houses to the delight of sunlight but effectively protect against overheating.
Finally how to balance technical control and still encourage spontaneous individual interference.

From 20010 to 2013 six model homes in Active House Standard have been erected and monitored in five European countries, funded by the company of VELUX. The authors have been deeply involved in design, erection and post occupancy performance monitoring of these model homes.

KEYWORDS

Active Houses, Indoor environmental control, daylight, hybrid ventilation

1 INTRODUCTION

The term of "Active House" recently developed, addressing houses that target a balanced optimization of indoor environmental quality, energy performance and environmental performance. A lively international network, the “Active House Alliance”, has been founded and numerous pilot projects in a widespread range of nations and climates have been erected.[1]

According to the idea of not only being energy efficient and eco-friendly, Active Houses equally focus on indoor environmental qualities, in particular daylight and air. With their tendency towards intensive sun penetration, natural ventilative systems and generally intensive connections to the exterior, Active Houses challenge the balance of technical and individual indoor climate control.

Funded and very actively accompanied by the Danish roof window manufacturer VELUX A/S there have been Active Houses erected in five different European countries and had them intensively monitored through a period of at least one full year, including energy monitoring, comfort monitoring and social monitoring.[2]

The paper in hand presents and discusses the findings from those six model homes as regards the aspects of technical control such as

- How to design and run heating, cooling control systems in Active Houses.
- How to balance hybrid ventilation systems in Active Houses.
- How to open the houses to the delight of sunlight but effectively protect against overheating.
- Finally how to balance technical control and still encourage spontaneous individual interference.

2 ACTIVE HOUSES

2.1 Goal and Definition

Goal and definition of Active Houses is precisely but still lively and even poetically defined in the Active House Specifications.[3]

The most poetic definition is: *Active Houses are Buildings that give more than they take*.

The lively programmatic definition is, already structured in three fields of equal interest:

Indoor Environmental Quality
An AH creates healthier and more comfortable life.
An AH ensures a generous supply of daylight and fresh air.
Energy
An AH is energy efficient.
All AH’s energy needed is supplied by renewable sources.
Environment
An AH interacts positively with the environment
through an optimized relationship with the local context

Precise quantitative benchmarks as regards indoor environmental standards, energy demand key figures and environmental impacts are defined in Active House Specifications, having already been mentioned before.

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[1] For further information see http://www.activehouse.info (22.08.2014).
[2] For further information see http://www.velux.com/sustainable_living/demonstration_buildings (22.08.2014)
[3] Active House Specifications, 2nd edition, http://www.activehouse.info/download-specifications (23.08.2014)

It’s this balanced approach of Indoor Environmental Quality, Energy and Environment that makes the Active House quite unique amongst other building standards and which, indeed, brings along some challenges, not least in technical control systems.

2.2 Specific Features and Physical Challenges of Active Houses

Following the balanced three tier approach of Indoor Environmental Quality, Energy and Environment leads to specific features and physical challenges of Active Houses, which can be addressed as benefits as well as threats:

Usually, an Active House is generously daylit, it is generously supplied with fresh air and it connects significantly to the out-of-doors. Thus, seen positively, it‘s fast and strong reactive to the healing sun, to the warm breeze, to sounds and smells of nature. Seen negatively, it is fast and strong reactive to the burning sun, to heatwaves and storms, to external noise and air pollution.

This paradox of very different possible perceptions of the same physical qualities finds its equivalence in the possible and yet contradicting expectations towards the qualities of technical control systems, between full automation and individual behaviour.

2.3 The VELUX model homes 2020

From 2010 to 2013 six model homes in Active House Standard have been erected and monitored in five European countries, funded by the company of VELUX. Altogether, this “model home 2020” program was the biggest and most practical concerted research action in the field of Active Houses. The authors have been deeply involved in design, erection and post occupancy performance monitoring of these model homes.

Detailed information on the research program of model home 2020 can be found at http://www.velux.com/sustainable_living/demonstration_buildings

Home for Life, Denmark

Green Lighthouse, Denmark

Sunlighthouse, Austria

LichtAktiv Haus, Germany

Carbon Light Homes, Great Britain

Maison Air et Lumière, France

3 DISCUSSION OF INDOOR ENVIRONMENTAL QUALITY TARGETS

3.1 Comfort versus Health

Indoor Environmental Quality, often but improperly referred to as Indoor Comfort, is a major issue of today's building design research. Design decisions towards Indoor Comfort are intrinsically linked to the energy demand of buildings. And, which is overseen too often, Indoor Environmental Quality is not only about comfort but it's very much about health. This correlation is gaining importance rapidly, with today's urban lifestyle leading to 95% of the lifetime being spent indoors. Thus, it is important to discuss Indoor Comfort very much together with Indoor Health.

Indoor Comfort is a state of mind, based on a set of physiological, psychological and physical parameters. You may speak of the physio-psycho-dualism of comfort. Furthermore, Indoor Comfort very much varies with the level of personal expectations and with the level of personal possibilities. And finally, Indoor Comfort gives instantaneous feedback: A person per definition feels uncomfortable in the instant moment it feels uncomfortable.

Indoor Health is expected to be much less psychologically based, but being much more based on physiological settings which themselves having their roots back in evolution of mankind. The basic physiological needs cannot be changed and triggered to the same extent as comfort expectations can be. And unhealthy indoor environments do not give such strong and instantaneous feedback than uncomfortable environments do.

Thus: In building design indoor health is a “must have” issue and indoor comfort is a “nice to have”. To have both is perfect and nothing less is the aim of modern sustainable building design.

3.2 Indoor Thermal Comfort & Health Targets

3.2.1 The physiological thermal comfort definition according to Fanger

Traditional 20th century indoor comfort research focused on the physiological aspect only. Fanger et al. developed a physical model for thermal comfort starting from the 1960’s, being now worldwide established and forming the basis for HVAC design around the globe.

The model is based on the assumption that thermal comfort derives from an equated body’s heat balance together with a limitation of the sweat rate and a limitation of the skin temperature. Within this model, general thermal comfort can be described as a strict function of six physiological and physical parameters: activity level, clothing level, air temperature, radiant temperature, air humidity and air velocity. Additionally four phenomena of local discomfort are described, again on physical level. The Fanger-model was validated by numerous experiments with groups of test persons in climatic chambers and is implemented into international standardization, such as ISO 7730 and ASHRAE 55. [4, 5]

3.2.2 The physio-psychological thermal comfort definition according to Humphreys

As an important improvement, exhaustive empiric comfort research has been carried out by Humphreys et al., investigated thermal comfort not merely as a function of physiological parameters, but as a both physiological and psychological status. This additional approach is known as the Adaptive Principle, leading to the following findings: People are not passive receptors of their thermal environment, but continually interact with it. People become adjusted to the conditions they normally experience. People therefore must be studied in their everyday habitats. Discomfort arises from insufficient adaptive opportunity. The Principles of Adaptive Comfort have been derived from and validated by field studies in all climate zones of the world, with over 200.000 comfort-votes. Very recently they have been even implemented into international standardization, with the limitation of validity to non AC, but free running mode buildings, again in ISO 7730 and ASHRAE 55 and EN 15251.[6]

3.2.3 Indoor Thermal Environments and Health

Against to the comprehensive research outputs on indoor thermal environments and comfort, there’s a significant lack of research outputs on indoor thermal environments and health. The new question arising is: Is it healthy to continuously stay in the thermal comfort zone?

First research steps have been made by Wouter van Marken Lichtenbelt (van Marken Lichtenbelt, 2011), and Christel M.C. Jacquot (Jacquot, 2014) indicating a possible positive health aspect of periodically leaving the strict comfort zone.

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[4] ISO 7730, 2005
[5] AHRAE 55, 2013
[6] EN 15251, 2007

3.2.4 Personal Thermal Comfort Expectations

It has to be understood that human indoor comfort expectations and indoor comfort targets are intrinsically tied to the possibly achievable level of indoor comfort. Thus, comfort cannot be discussed as an independent variable: The demand level rises together with the supply level.

Numerous investigations on comfort sensation in free running mode buildings revealed a systematic connection between the existing outdoor comfort, the personal adaptive options and the indoor comfort expectations: The neutral temperature (i.e. the temperature preferred by the inhabitants) significantly depends on the mean outdoor temperature. This dependency is most significant under ‘free-running mode’ conditions (no heating, no cooling)

Bridging to modern homes, especially to Active Houses, it’s an important question, which elements of a house are perceived “forgiving” in the tradition of free running mode buildings and which ones are perceived as “demanding” in the tradition of HVAC buildings. Existing results, not at last from the model home 2020 program reveal a close correlation of thermal comfort in Active Houses with the adaptive comfort model of Humphreys et al. as set in EN 15251. Thus, the Active House Specifications define indoor thermal comfort according to the EN 15251 benchmarks.

3.3 Indoor Lighting Comfort & Health Targets

As regards lighting there’s young but comprehensive research on both comfort and health available and has found its way into standardisation already. Besides the author published his PhD on the topic of Quality and Quantity of indoor daylight supply.[7]

It is known that apart from visual comfort with its characteristic 500 lx minimum illumination level there are significantly higher requirements from the perspective of alertness and circadian rhythm, reaching up to a demand of 1.000 lx up to 10.000 lx at the retina.

Furthermore it is known that health aspects of light do not only correlate with illumination levels but intrinsically with the spectral distribution of the radiative intensity, which tends to be significantly changed by daylight passing glass panes.

As a result, daylight must be regarded as a major indoor comfort and health issue. Daylight design should guarantee levels of daylight factor of 5% and above. Furthermore, the penetration of indoor space by direct sunlight is an important issue. And finally, periodically skin exposition to spectrally unfiltered sunlight is a must have.

3.4 Indoor Air Quality Comfort & Health Targets

As regards indoor air quality it is necessary to differentiate between the aspects of a) building design and b) the aspects of interior design, materials used in interior design and finally usage itself. From the point of view of building design the ventilation rate is the major parameter of air quality, with air quality being measured by the CO2 concentration level or by the VOC concentration level. In the Active House specifications the relative CO2 concentration level above outdoor CO2 concentration is defined as the benchmark.

[7] Holzer, Hammer (2009)

4 BASIC ASPECTS OF INDOOR ENVIRONMENT CONTROL SYSTEMS

4.1 Logic Structure of Control Systems

Technically every control system consists of at least the basic elements illustrated in the flow chart below:

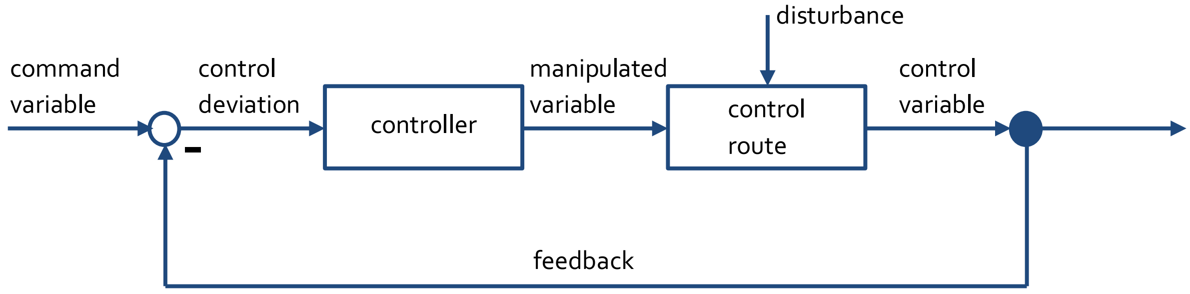

Figure 1: flow chart of an automated technical control

At the beginning of the control system the command variable represents the desired set point of the specific quality that shall be controlled, e.g. the setpoint of the room's air temperature. At the end of the control system the control variable represents the actual value of the specific quality that shall be controlled, e.g. the room's air temperature.
The difference between them is the control deviation, being reported to the controller, being the "brain" of the control system, translating the control deviation into the manipulated variable, e.g. the flow temperature and/or the flow rate of the heating circuit.
The manipulated variable is introduced into the control route, which is the full system of interdepending phenomena that finally influence the control variable, not at least including the disturbances, e.g. the outside temperature. In case of an indoor environment control the control route is nothing less than the house itself, even including its users and their hardly predictable behaviour.

4.2 The range of users' intervention

Practically, an indoor environmental control system may be
1. fully automated without users' intervention
2. automated with users' intervention as regards setpoints
3. users' manual operation
4. automation plus manual operation,
   guided by feedback from the automated control system

5 LEARNINGS AND RECOMMENDATIONS

Based on the experiences of the six VELUX model homes 2020 together with experiences from other post occupancy monitoring, the following chapters sum up the major learnings and recommendations as regards the technical control of indoor climate systems in Active Houses.

5.1 Heating Control Systems

All six model homes have automated, thermostat-controlled heating systems, in the majority of the houses on basis of single room controllers. The controllers work without problems or disturbances and inhabitants never reported problems with this system.

It’s our recommendation always automating the heating on a thermostat-controlled basis with single room controllers. The single-room controllers allow specific temperature setpoints for different rooms, what is especially beneficial in case of sleeping rooms. If single room controllers are in operation, the traditional coupling of the heating system’s flow temperature to the outside temperature may be replaced by a demandside-controlled flow temperature, which turns out beneficial, since in passive solar driven homes the occurrence of maximum heat load doesn’t necessarily come along with the occurrence of minimum outside temperature.

5.2 Ventilative Cooling Control Systems

The six model homes are located in middle/northern Europe, from 48°N to 57° northern latitude. Thus they haven’t been equipped with technical cooling, but with Ventilative Cooling by night ventilation.

In the model homes Ventilative Cooling was a major issue in building design and turned out working up to the high expectations in reality – if automatically controlled. The combination of automated window opening and automated sunblind, controlled from room temperature, outside temperature and solar irradiation did the job.

Ventilative Cooling, if automated, did stand the test. Experimental operation without night ventilation during summer heat waves resulted in up to five degrees higher indoor temperatures than with night ventilation under comparable outside climate conditions.

Monitoring proved that when people overrode the building automation as regards Ventilative Cooling and sunblind control they only made it worse. It’s our learning and recommendation to automate ventilative cooling together with sunblind operation. Additionally, heat protection could be an issue to user information. See chapter 5.6.

5.3 Natural and Hybrid Comfort Ventilation Systems

All model homes are equipped with automated windows for both Ventilative Cooling and comfort ventilation. Many of the houses are additionally equipped with mechanical ventilation systems.

Apart from Ventilative Cooling the automated windows have been controlled according to indoor VOC levels. This, again, did work without any complaints during the warm seasons. In the winter season good performance and acceptability was recorded from pivot hung, horizontally oriented ventilation openings, positioned in the upper regions of the walls. They proved to be much better adjustable and much less draft risky than side hung windows with vertical orientation.

There have been recordings form occupants noticing the noise from the actuators during the first weeks after moving to the place, but getting used to the sound soon.

It’s our learning and recommendation to automate ventilative cooling together with sunblind operation. Additionally, heat protection could be an issue to user information. See chapter 5.6.

As regards hybrid ventilation it was a significant learning to properly and strictly define the setpoint when automated natural ventilation stops and mechanical ventilation with heat recovery takes over. From theoretical analysis and from practical experience a one hour mean value of between 12°C and 14°C outside temperature proved to be a good choice as regards energy optimization as well as regards comfort.

Finally, there turned out a specialty of automating windows, which is also true for automating sunblinds: The automated operation of both windows and sunblinds is instantaneously visible to occupants. Unexpected ‘behaviour’ of the control system causes instant discomfort and complaints, which is very different from e.g. a heating control, which cannot be recognized in a comparably immediate way.

5.4 Daylight Supply and Sun Protection Systems

It’s a major target of Active Houses to extensively supply the rooms with daylight. Daylight Factors of 5% and higher are aimed at, for good reasons. See chapter 3.3.

Thus, Active Houses tend to have windows oriented not only driven by energy design rules, but by daylight design rules, which can be sometimes contradictory and what always leads to significant glazing. As a result, Active Houses are fast reactive towards direct sunlight. An effective and automated system of movable shadings is obligatory for achieving good summer comfort.

Sunblind control performed best when correlated to the outside irradiation, which certainly have to differentiate between the compass orientations.

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Therefore, sunblind control must be designed deliberately correct, using the solar irradiation at the specific façade as a trigger for shutting and being equipped with a time lag of a quarter of an hour in case of shutting and half an hour in case of reopening.

5.5 Building Automation together with user information and individual control

The model homes have been equipped with extensive monitoring and control devices. Users have been informed via significantly big, wall-mounted info screens, informing about actual and historic levels of air temperature, VOC, humidity, energy consumption and supply and others.

In the beginning there have been reportings from users feeling overloaded by all the options of the system, but after getting used to it, those complaints disappeared. About half of the users set to not changing any setpoints apart from simple room temperature. The other half actively used the options for personalizing the control system.

Based on the already mentioned learnings on the users' sensitivity towards automation of the 'visible' devices as sunblinds and windows and based on the learnings on users' difficulties to intuitively operate the houses towards heat protection we consider the idea of suggestive control system feedback being a good choice.

The idea behind suggestive control system feedback is to automate the basic functions and additionally inform the user on firstly the reasons behind the automated actions taken and on secondly additional actions the user might take to achieve best comfort.

For example, during a hot summer day, the system would shut the windows and shut the sunblinds, while the info screen would say: "It's a hot and sunny day. In Order to keep the house cool, the sunblinds and ventilation openings have been automatically shut and will stay shut until irradiation and temperature will lower. It's recommended to keep the manually operated windows and doors shut and to avoid unnecessary internal heat loads."

Designing such a suggestive control system feedback could be a challenging and rewarding subject to an engineer-psychologist-cooperation.

6 CONCLUSIONS

The evaluation of the six Active Houses of the model home 2020 program revealed an overall good performance of the indoor environment control systems.

- Heating control caused no problems.
- Ventilative Cooling Control should be automated, with combined operation of automated windows and sunblinds. Individual operation won't work.
- Hybrid comfort ventilation calls for a strict switch point between automated window ventilation and mechanical ventilation.
- Daylight Supply and Sun Protection can be well balanced with effective sunblinds, again automated. Control algorithms have to be 'understandable' to the users.
- Beyond technical automation it's essential offering intuitively manually operable (not only manually telecommanded) devices such as windows, doors, awnings.
- Building Automation together with user information and individual control offers additional chances balancing the gap between automation and individuality.

7 ACKNOWLEDGEMENTS

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