We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Low-energy buildings – scientific trends and developments

Dr. Patrik Rohdin¹, Dr. Wiktor Glad² and Dr. Jenny Palm²

¹*Energy systems, Linköping University*

²*Tema T, Linköping University
Sweden*

1. Introduction

Over the past twenty years primary energy demand in the world has increased drastically, while during the same time demand for electrical energy has increased even more. This, in combination with the impact of global warming, is forcing policy-makers to formulate goals to meet this threat. The EU Commission has recently stated that one of its highest priority tasks is to address global warming, with special focus on reducing greenhouse gases. The EU Commission states in the directive for energy efficiency in the built environment that the building sector must decrease its use of energy to reduce CO₂ emissions. In addition a goal for energy efficiency within the Union states that a 20% increase in energy efficiency shall be met by 2020. The Swedish parliament has also set a national goal for space heating, which states that by 2020 the use per floor area should be reduced by 20% and by 2050 this figure should be 50% compared to use during 1995.

To be able to meet these goals, many different activities must strive towards the same goal. One major part is the building and service sector, which accounts for about 35% of total Swedish national energy use. A large part of that use is concentrated in cities, which underlines the importance of working with such areas. The connection between CO₂ emissions and the use of energy is also an important motive for promoting a more efficient use of energy and reducing the total energy demand. This means that there is a need to choose the correct primary energy and energy conservation measures as well as to reduce the total electrical usage in the built environment.

Furthermore, the consequences of global warming are introducing changing conditions to be met by future buildings with increasing temperatures, and for Sweden increasing precipitation as well. In IPCC (2007) the temperature increase is predicted to be 1-2°C with an increase in precipitation by 20% for the 2020-2029 scenarios relative to 1980-1999. For the long-term scenario until 2090-2099 the predictions are of the order of 4-5°C. Effects like this should be included in the analysis of future energy systems and design criteria, since it will reduce heat demand and increase the risk of overheating in buildings. Poor indoor environmental conditions in buildings is an important factor which costs large amounts of money in healthcare and administration, while a well-functioning indoor environment plays

an important part in a convenient and modern life. It is also important to include the environmental impact from building materials.

One key component in achieving a more sustainable building sector is to introduce different forms of energy-efficient or renewable buildings. In this chapter a review of the literature published within the Web of Science databases on low-energy houses, passive houses, zero-energy houses and passive solar houses is presented. The aim is to analyze trends in the scientific literature concerning sustainable buildings and to discuss which issues have been in focus and which have been neglected in earlier studies. This will create a basis for discussing knowledge gaps and future research needs. Our scope is to focus on the development of research on dwellings.

2. Field overview

The field of low-energy buildings is broad and complex. The first article included in this review is from 1978. A total of 83 relevant hits were found within Web of Science for the seven search words (1) low-energy buildings; (2) low-energy architecture; (3) low-energy house; (4) passive house; (5) passive solar building; (6) passive solar house; and (7) zero energy house. The number of unique hits for each search word is seen in Figure 4.

The trend of increasing interest in low-energy buildings can also be seen in the increase in production of scientific papers within the scope of this review, see Figure 1. During the last five years the number of publications has moved up from about one or two per year to between eight and ten. This should also be seen in the light of an increase in the general production of papers, but at the same time it shows that there is strong focus on low-energy solutions for the built environment in the scientific community too.

Fig. 1. Overview of the number of publications each year from the first article reported in a journal in Web of Science in 1978 to today (2010). The red line indicates the five-year moving average.

We have used the Web of Science database when we searched for relevant articles. This database is dominated by journals with a technical focus, which may partly explain that when examining the structure and focus of the reviewed articles in terms of the main method used it turned out to be a highly technical field. But we also noticed that within these journals examples of broader articles including policy issues, interdisciplinary studies and economic studies have become increasingly common in the last few years. But the main part of the field still remains technical in nature, with focus on building energy simulation (BES), component studies of thermal walls and solar applications and measurements, see Figure 3. There is also a strong tendency for the field to employ case studies and experimental setups either in laboratory form or as in real constructions, see Figure 2.

Fig. 2. A distinction between different types of article within the review. The categorization is not unambiguous since several articles may be relevant for more than one of the suggested groups.

Fig. 3. The relative difference in number of publications using different methods. This distinction is however not unambiguous since several papers can be argued to have more than one of the above suggested methods.

Fig. 4. The relative magnitude of hits within the review on different search words.

3. Main methods cited in the reviewed papers

This section will present an overview of the method characterisation used in the review and introduce the concepts of the different methods. The main methods identified in the articles are: (1) Computational Fluid Dynamics; (2) Building Energy Simulation; (3) Measurements; (4) Interviews; (5) Questionnaires; (6) Statistical; or (7) Environmental or Life Cycle-Focused Studies.

3.1 Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) has been extensively used as a scientific tool in many application and research situations since the 1950s. The use is widespread in many fields, such as aerodynamics, hydraulics, combustion engineering, meteorology, electronic cooling and biomedical engineering, and in predicting the external and internal environment of buildings. In Versteeg and Malalasekera (1995) the authors give a rather broad definition of CFD: “Computational fluid dynamics (CFD) is the analysis of systems involving fluid flow, heat transfer or associated phenomena such as chemical reactions by means of computer based simulation.”

The use of CFD to simulate ventilation and air movements in rooms is becoming more and more common. One of the earliest publications where CFD was used to simulate air flow in rooms was made by Nielsen in 1974. Due to the increase in computer resources, the use of CFD as a scientific tool has increased and continues to increase as it is possible to solve more complex and challenging problems. As the cost and time needed to perform real experiments in many cases are high, CFD has become more and more extensively used. This method is of course of special interest for cases where it is not possible to obtain measurements, such as situations where the object has not yet been built. However, to ensure the validity and reliability of CFD models, measurements are still very much needed. An often-used approach is to compare results from numerical simulations with measurements; if the results coincide, a numerical approach in predicting similar situations may be used.

3.2 Building Energy Simulation (BES)

Building Energy Simulation (BES) is a frequently used tool to predict energy use in buildings within the academic sphere as well as in the design process in the construction industry. Similar to other types of simulations, BES is a numerical experiment using a mathematical model. The aim is to predict or forecast a future or an otherwise presently unknown situation. For energy simulation programs, issues such as predicting energy use, either in a future building not yet built, or after a change in a system has been made in a present building, are of interest. In Bergsten (2001) a comparison of different energy simulation software is presented, and a classification of the software is made depending on whether it is a general simulation program or has multi-zone capabilities and if it is static or dynamic. The software compared, considered the most important energy simulation software used in Sweden, Norway and Denmark, were Bsim 2000, BV2, EiB, IDA ICE, Energikiosken, Enorm 2000, Huset, OPERA, Villaenergi, VIP+ and Värmeenergi (Bergsten, 2001). In Crawley et al. (2005) a more extensive review of the performance and capabilities of building energy simulation programs is presented. The review includes BLAST, BSim, DeST, DOE-2. IE, ECOTECT, Energy-10, Energy Express, Ener-Win, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES<VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS.

3.3 Measurements

Studies of indoor climate and energy efficiency often include measurements of temperature, moisture, air velocity, turbulence intensity, carbon dioxide, radon and other pollutants in addition to power and energy. When measuring spatial distributions there is a problem with creating a comprehensive view as it is time-consuming and is costly. Measuring the climate in a room with arbitrary accuracy is virtually impossible because it would require too many data points. It is also true that it will be time consuming and expensive to measure over long periods of time. Measurements as evaluation instruments are of course invaluable, but the very nature of the measurement in itself does not give any idea of the future, as it only says something about the past. At this stage different types of models are needed in order to make statements about the future. All measurements are also affected by different measurement errors. These vary greatly depending on the type of equipment used and the manner in which measurements are made.

3.4 Interviews

Interviewing is a common data collection method in social science qualitative research, among with observations and document analyses. The aim of qualitative inquiries is to explore the qualities of phenomena and provide data to gain deeper understanding (Lincoln and Guba, 1985). Using interviews to acquire data is usually preceded by a process of letting the problem at hand determine what type of inquiry is suitable and how the problem is best explored. A structured interview could in some cases generate similar data as a questionnaire, while a more open-ended, semi-structured interview requires more attentiveness and flexibility from the interviewer but can provide detailed descriptions and interpretations of phenomena in the world (Kvale and Brinkmann, 2009). While quantitative data concern more or less of a studied entity, qualitative data concern similarities or dissimilarities. Analysis of interviews is descriptive, but the purpose is to reach beyond the description of the questions in the interview. The analysis means that, through reflection,

the researcher abstracts from the description and searches for patterns and dysfunctional ties in relation to earlier studies or theories (Kvale, 1996).

3.5 Questionnaires

Questionnaires are an important part of survey research since this is the most common data collection method. Structured interviews might sometimes be similar to questionnaires with standardized answers although they may be closed or open-ended. When the objective of the research is specific, for example to determine which factors influence a certain phenomenon, a statistical analysis of data from questionnaires might be used. Recently, assumptions taken for granted in survey research have been questioned (Krosnick 1999). Response rates, pretesting of questionnaires and questionnaire design are among the contested aspects of this research. Research has shown, for example, that low response rates might show more accurate results than studies with high response rates (Visser et al., 1996).

3.6 Document studies

Analyses of written texts are important research tools in, for example, content analyses. Other types of analyses using texts as the primary source of data are discourse and argumentation analyses. The various types might be used differently in different fields of research. For example, linguists use discourse analysis to find syntax and choice of words in relation to contexts and focus is on language as a power tool, while social scientists might focus on discourse analysis as a tool in itself to reveal social practice (Bergström and Boréus, 2005). This is often referred to as critical discourse analysis (Fairclough, 2003). These texts might be minutes, records, protocols, letters, articles, books, newspapers, journals found in libraries, on the internet, in public or private archives and files, etc. Some texts are superior to other data collection methods in terms of reliability since they are real-time documentations of a phenomenon, compared to interviews which construct phenomena during the interview. Also, large amounts of written texts enable researchers to do structural analyses in relation to a research question (Lincoln and Guba, 1985)

3.7 Statistical

Statistics is a whole scientific field with several subfields, but in general, statistical methods include ways to collect, process and draw conclusions from statistical figures to enable, for example, sampling and analyse differences (Körner et al., 1984). Focus is on empirical data and statistical methods are used in both natural and social sciences. Descriptive statistics include mapping and providing information, while inferential statistics aim to present causal explanations and factors that influence a certain phenomenon. The basis for explorations is elements in a population (Moses, 1986). Populations and elements might be individuals but can also refer to material or physical entities. A census is a study using whole populations, but usually a sample of a population is selected in order to limit the research due to resource constraints. Social and economic sciences use questionnaires or observations to collect data, while the most common data collection method in natural sciences is different types of observations. Data can be analysed using computer programs such as SPSS.

3.8 Environmental or Life Cycle-Focused Studies

Different types of environmental or life cycle-focused studies form an eclectic category of research. A definition of life cycle assessment is “compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle” (Guinée, 2002). Industrial ecology covers a similar field of exploration (Frosch and Gallopoulos, 1989). Some of these methods claim to have a “holistic” approach but in reality it is impossible to include all environmental aspects “from cradle to grave” and methods with this approach might be criticized because they promise too much. Also, a “system” approach is common among the different methods and may receive the same critique (ISO, 1997). The definition of system boundaries is a constant issue of debate. Another critical point in these analyses is the validity of data (Cooper and Fava, 2006). Common concepts included in energy-related research with these approaches are “embodied energy” (Odum, 2007) and exergy (Dinçer and Rosen, 2007). Social issues and phenomena that are hard to put in figures are generally missing in these studies.

4. Articles by method

In this section the articles from the review will be presented under a characterization of the method used in the paper. As previously stated, this is not an unambiguous characterization but should be seen as a way of grouping the studies reviewed within this chapter. Below a short presentation of the studies is made and a discussion of the main lessons learned will follow.

4.1 Computational Fluid Dynamics

In this section only two studies are represented. The first study was made for conditions in Japan. A constructed CFD code is made to study the transient effects of a thermal storage wall. The authors suggest that this technique may be viable for low-energy houses with hybrid systems (Onishi et al., 2001).

In Karlsson and Moshfegh (2006) the authors present an overview and results from a low-energy building built in Lindås, Sweden. The authors use CFD to study the air velocity and temperature pattern in one of the rooms in the building. In addition, building simulation is used, in the form of ESP-r, to study dynamic effects. Furthermore the paper investigates the importance of high-performance windows, and concludes that this is an important factor, both to decrease energy use and for the thermal environment. The paper also discusses the problem of overheating during summer.

4.2 Building Energy Simulation (BES)

Building energy simulation is a commonly used tool for predicting energy use and other parameters for buildings and to conduct parametric studies in different forms. A total of 18 papers are cited in this section. In Ohanessian and Charters (1978) a thermal simulation of a solar passive house with a Trombe-Michel wall is presented. The technique as well as measurements and simulations are presented, and an energy savings potential of about 40% is demonstrated for the passive solar house.

In Clarke et al. (1998) an integrated model of a low-energy building is presented. The case study is a city centre building in Glasgow, where an optimum mix of low, passive and active renewable energy technologies is sought. The main method used is the well-known simulation software ESP-r. The paper describes results from simulation and outlines a method by which “the replication potential of beneficial outcomes can be assessed”.

A methodology for computational support during all phases of a design process with a focus on energy is presented in Shaviv (1996). The paper combines a procedural simulation approach with a knowledge-based heuristic approach in one integrated system. The overall aim is to provide architects and other actors in the design phase with a tool that can be used throughout the entire process (Shaviv, 1996). Holm (1996) also focuses on architects and the status of low-energy architecture in South Africa is presented. Chlela et al. (2009) discuss the design phase and a new methodology for design is proposed. Instead of parametric studies of design criteria using building energy simulation to optimize building envelope and HVAC, a Design of Experiments approach is suggested. The methodology is tested on three French cities with cold, moderate and hot climate. The models show “rather good results” for the annual heating demand and final energy use for the building as a whole. However, less accurate results were obtained for the cooling demand. The authors point out that further improvements may be made on the model.

In Lomas (1996) an application study of thermal simulation programs for passive solar house design from the U.K. is presented. This type of simulation program has been extensively used within the passive solar program in the U.K, and is also used in: (1) domestic and non-domestic building design studies; (2) in the assessment of innovative material and design techniques; (3) development of design guidelines; and (4) the design and interpretation of building monitoring studies. This makes it important that the programs must be reliable when it comes to: (1) the changes in energy demand of the building when making changes to the building such as changing window size; (2) the energy savings as a result of a design change, this to be able to predict pay-off times or other investment criteria; (3) the absolute energy demand of the house and the internal temperatures, this to be able to compare with energy targets and for example the risk of overheating, etc. The paper presents among other things (1) a methodology for structuring inter-program variability studies; (2) an overview of the U.K. application study project; and (3) a proposal of a Simulation Resolution (SR) concept. The authors argue that the SR could be taken as an estimate for the best (smallest) value that can be achieved for U.K. domestic buildings. The value provides a basis for estimating the significance of thermal predictions by this type of transient simulations. In the study ESP-r and HTB2 and SERIES were used.

Kalogirou et al. (2000) use an artificial neural network to predict energy use in a passive solar building. According to the authors, the model presented was able to predict energy use with acceptable accuracy. The model also proved to be much faster than dynamic simulation programs.

Solar heating is central in Badescu (2005) where active solar heating systems for passive houses are investigated using simulation. The suggested systems were tested on a passive house, and a suggested control scheme is outlined. In Badescu and Sicre (2003a) a description of the case is made, which is based on measurements and input from the Pirmasens passive house in Germany. Detailed input in the form of standardized data for a typical German family is used. Badescu and Sicre (2003b) reports on a model for predicting the thermal behaviour of this passive house. The topic of the paper is evaluation of

renewable energy in the context of passive houses. The renewable energy alternatives in focus in the paper are (1) passive solar heating with large windows facing the south; (2) active solar collectors for space heating and heating of domestic hot water; and (3) ground heat exchanger to preheat the supply air. The authors argue that the computational effort of transient simulation for this type of problem is valuable.

Feist et al. (2005) introduce and summarize the Passive House Standard and results from the EU project “Cost Efficient Passive Houses as European Standards” (CEPHEUS). The aim, according to the authors, is to “provide an acceptable and even improved indoor environment in terms of indoor air quality (IAQ) and thermal comfort at minimum energy demand and cost”. This is achieved by improving the thermal performance of the envelope in such a way that the heating system can be simplified, thus keeping costs at a minimum. One important factor of the high-performance envelope is that the temperatures on the inside surface are close to the room air temperature and thus the radiation asymmetry is small. This enables high thermal comfort by the use of supply air heating instead of conventional radiator systems that usually compensate for both down draught and radiation asymmetry. If the thermal properties of the wall are low enough it is also possible to only use the IAQ-based supply air for heating, without exceeding 50°C which is a possible temperature to supply air without complications. The thermal transmittance for the wall is proposed to be $<0.15 \text{ W/m}^2\text{K}$ for Central Europe; for air tightness a value of $<0.6 \text{ h}^{-1}$ at 50 Pa; and for heat exchanger efficiency $>75\%$. For a climate in central Europe a requirement of less than $15 \text{ kWh/m}^2\text{a}$ is also set and a maximum power demand of 10 W/m^2 . A more detailed description of values for different building components is found in Feist et al. (2005). The CEPHEUS project includes 221 housing units from five countries that comply with the passive house standards. The aim of the projects is, according to the authors, “to demonstrate the technical feasibility (in terms of achieving the target energy performance indices) at low extra cost (target: compensation of extra investment cost by cost savings in operation) for a variety of different buildings, constructions and designs implemented by architects and developers in several European countries.”. Results in the study show no correlation between types of heating system and mean indoor temperature. Supply air heating was found suitable for passive houses. A comparison between the passive houses with other newly built conventional buildings show a reduction in useful energy by 56%, final energy 52% and primal energy by 56%. The thermal comfort is reported to be good to very good for these buildings built in central Europe.

In Persson et al. (2006) the authors investigate the influence of window size on the energy balance of low-energy buildings. The aim of the paper is to “investigate how decreasing the window size facing south and increasing window size facing north” would affect energy demand. A building energy simulation tool (DEROB-LTH) was used in the study. The authors conclude that the size of the energy-efficient windows does not have any major influence on heating demand during the cold season. However, the authors show that window size is important during summer, as it will affect the solar gains during this season. The main conclusion of the paper is that, according to the authors, it is possible to build windows in a more traditional way even in low-energy buildings and thereby gain better indoor lighting conditions. Al-Sallal (1998), a case study for a one-storey house in Fresno, California, also focuses on windows. Here the effects of window size on passive cooling, and passive heating in day lighting are investigated for hot, arid regions. Wall (2006) investigates the first Swedish passive house project, twenty terraced passive houses in

Lindås, Gothenburg. The houses were constructed to meet the target peak power of 10 W/m², and were to use supply air heating. The focus of the project was low transmission losses ($U=0.16$ W/m²K) and low ventilation losses, which meant using a high-performance heat exchanger (80%) and a high degree of insulation. Special focus was also applied to get the buildings airtight. The average airtightness at 50 Pa was measured to 0.3 l/s.m², and should be compared to the common praxis in Sweden, 0.8 l/s.m². In addition to these passive measures a solar heating system was installed to provide about 40% of the heat needed for hot tap water. The paper also include a parametric study of space heating and power demand as a function of set point for heating and cooling, infiltration rate, etc. The simulations are compared to monitored energy performance for the building. The author concludes that the air tightness of the building envelope is essential to meet the targets of 10W/m² and the low heating demand of about 15 kWh/m².a.

Material selection in passive solar buildings is addressed in Thomas et al. (2006). The paper presents a combination of analytical, experimental and computational studies for selecting affordable materials and designing buildings with the aim of high thermal comfort. The models are validated using measurements in two housing complexes in Egypt.

In Karlsson et al. (2007) the authors make a comparison between three different energy simulation codes, and use a low-energy building as a case. All three models use dynamic models to calculate energy demand for heating and indoor temperature. The low-energy case is a well-known and extensively measured low-energy building in Lindås, Sweden. A parameter of interest in the paper was the small difference between the software's in terms of deviation of energy use. Thus, the paper shows that the relative importance in terms of choice of software is small compared to the large difference in terms of deviation between different households within the studied low-energy buildings. The deviation between software's is shown to be as low as 2%, but the deviation between different households ranges from 6,000 kWh/year to 12,000 kWh/year with an average of 8,020 kWh/year. Furthermore, occupant behaviour, heat exchanger efficiencies as well as air flow control are shown to be important factors. The authors also stress the need for more detailed information about activities and more input data from manufacturers.

In Wang et al. (2009) the authors present a case study of zero-energy house design in the U.K. Zero-energy buildings are defined in the paper as "a building with a net consumption of zero over a typical year." This means that the energy use for heat and electricity is reduced at the same time as this demand is met on an annual basis from renewable energy supply. The renewable can either be building integrated or part of a community renewable energy supply system. A combination of TRANSYS and EnergyPlus is used in the paper, where EnergyPlus is used for building envelope design and TRANSYS for the installations as well as the renewable energy system design. The conclusion of the study is that it is theoretically possible to build zero-energy houses in the U.K. The study also suggests a methodology for the design process where three steps are summarized: (1) analysis of the local climate; (2) application of passive design methods; and (3) investigation of various systems for supply and installations such as PV, wind turbines and solar hot water to optimize the design.

Zhu et al. (2009a) present an energy and economic analysis of a zero-energy house and compare this with a conventional house in Las Vegas. Two houses were built side by side, one zero-energy house and one baseline house, and energy performance measurements were made. The energy contribution from the different components in the building was

obtained using Energy10 and eQUEST3.6. The results from these two models gave similar results. The study concludes that four components were clearly economically under given constraints: high-performance windows, compact fluorescent lighting, well insulated roofs and AC units with water-cooled condensers. If financial support was included PV tiles were also considered to have good financial return. Thermal mass walls were found to be too costly. Walls are in focus in Zhu (2009b) where a detailed energy-saving analysis of a high thermal mass wall is presented. This is demonstrated in an actual construction project and compared to a conventional wall. It is shown that for this wall construction the heating use in the building was much lower, but the load slightly higher. According to the study this is due to the effect that more heat is stored during the day than can be returned during the night, increasing the cooling demand. The simulation software used is Energy10 and the experimental part of the study was carried out in Las Vegas.

In Heim et al. (2010) the authors investigate isothermal storage of solar energy in building construction with focus on passive houses. A storage system with phase change materials that absorbs heat during the hot period and releases heat during the cold period is analyzed. The material behaviour is studied using numerical techniques. These methods are then implemented in a general building simulation tool, ESP-r. The paper investigates the effect of a PCM wall and the influence on internal surface temperature. The case is compared with a conventional wall without the PCM material. Both diurnal as well as seasonal latent heat storage is studied. The authors conclude that isothermal heat storage may improve thermal conditions on internal surfaces, but emphasize that the effect of the latent heat storage will depend on its structure, phase change temperature range and total latent heat of the phase change.

4.3 Measurements

Measurements as a method for investigating low-energy buildings is another commonly used method for the papers included in this review. A total of 14 papers are connected to this section. In Dallaire (1980) the concept of zero-energy houses is introduced as a bold low-cost breakthrough that may revolutionize housing. The benefits of super-insulated houses are described in a U.S. and Canadian context, and performance and cost of different components are also described. The background to the development of the concept was the increasing prices of oil in the U.S. The paper includes a series of empirical studies, and among other things the importance of keeping infiltration to a minimum was emphasized.

In Starr et al. (1980) a passive solar house research project is presented. The project demonstrates significant savings in energy. The studied house use 82% less energy than the average California house at the time. The importance of thermal mass, window location and direction as well as insulation is shown. The study contains monitoring for over one year, including both winter and summer conditions.

Nieminen (1994) presents results from the Finnish demonstration houses within IEA Task 13 “Advanced solar low-energy houses”. This demonstration project shows an estimated energy use of about 20kWh/m², which was below 10% of the average value for small houses in Finland at the time. The main focus of the project was to reduce space heating demand.

Filippin et al. (1998) present the first two years of experiences from a passive solar house in Argentina. The paper presents measurements and the authors conclude that simulation during the design phase had significant advantages, and the internal gains in the form of equipment use patterns have an important influence on the performance.

Schnieders and Hermelink (2006) present the results from the CEPHEUS project, where the material includes measurements and occupant satisfaction for passive houses. The Cost Efficient Passive Houses as European Standard (CEPHEUS) project here includes over 100 dwellings that have been studied. All the projects within the program exhibit extraordinarily low energy use according to the authors, as they can save 80% of space heating compared to ordinary buildings and the total primary energy use was down 50% when compared. It is also concluded that this is achievable with high performance in terms of thermal comfort both in summer and winter for the houses in the project.

In Liu and Henze (2006b) an experimental analysis of simulated learning control for active and passive building thermal storage is reported. In Liu and Henze (2006a) the theoretical foundation is presented and in Liu and Henze (2006b) the results and analysis are found. The work was conducted at the Energy Resource Center Station in Iowa.

The next article discusses how to address the effects of climate change and thermal comfort while at the same time meeting the design challenges of the twenty-first century (Holmes et al., 2007). The authors demonstrate the effect of a changing climate with increasing temperatures using predictions and outline a series of principles in terms of load management, cooling and heating using alternative systems. The paper also shows some of the effects of solar shading as a way of controlling internal gains, as well as the effect of night cooling and other ventilation applications. They also state that the study shows that high-mass buildings are able to provide a higher quality in terms of "internal environment".

Tommerup (2007) presents the results from measurements and discusses how to develop typical single-family houses to meet new energy requirements without compromising on either economy or construction. Tommerup has studied energy-efficient houses built according to the new energy performance requirements in Denmark. The purpose of the project was to demonstrate that it is possible to produce energy-efficient single-family houses that meet existing standards without compromising on economy or construction. Tommerup presents the houses within the project as well as the energy efficiency measures that were applied. A full presentation of energy use, thermal comfort and airtightness is also included. The energy used by these buildings is about 50% to 75% of the typical energy use in Danish buildings in general.

Makaka et al. (2008) present a case study where the building was monitored for a period covering all the South African seasons. The performance of the building was seen to depend mainly on how the occupants used the house. The type of house presented was shown to represent a lower rate of temperature and humidity variations. The thermal behaviour and ventilation efficiency of a low-cost passive solar energy efficient house is investigated. The low-cost houses in South Africa are categorized by poor craftsmanship in terms of energy-efficient design and passive solar features, thermal climate and ventilation efficiency. If this type of design is used, large savings are possible.

Chandel and Aggarwal (2008) have done an evaluation of the performance of a passive solar building. The building is located in the Western Himalayas. The heat losses were shown to be reduced by approximately 35% with passive solar measures. In Wojdyga (2009) the author investigates the heat demand in a low-energy building in Poland. Results from a five-year study of the energy consumption in a single-storey terraced low-energy house are presented.

Maier et al. (2009) combines methods when presenting a comparison of physical performance of a ventilation system in residential low-energy buildings. To analyze the

influence of ventilation systems on comfort, the authors used a combination of measurements and a questionnaire. The measurement part of the project included 22 residential houses in Germany, chosen and equipped with four different types of ventilation systems: (1) natural ventilation; (2) air heating system; (3) mechanical ventilation with supply and exhaust with heat exchanging; and (4) mechanical ventilation with single ventilators. The monitor's parameters were CO₂, relative humidity, air temperature, electricity, gas and heat. The use of the window openings, use of ventilation and number of residents present were also presented. The mechanical ventilation performed better in terms of CO₂ concentration than the naturally ventilated cases.

Feist and Schnieders (2009) explain the concept of the passive house technique and issues such as design methods, components in a passive house such as thermal bridges, windows, junctions of roof and wall, etc., the importance of internal gains and ventilation and air tightness issues. Practical experience is also summarized. In a similar way Nicoletti (1998) discusses low-energy design from an architectural point of view. Form as a tool for energy control is discussed, and several examples and objects such as the University building in Udine, Casa Moncada and a headquarter of a bank in Rome. A special discussion for tall buildings is included.

Kalz et al. (2010) have also done a long-term study. The authors present what they define as a holistic approach when evaluating heating and cooling using building signatures. The study includes a comprehensive analysis of eleven low-energy buildings in terms of energy use and thermal comfort. The long-term study is presented using detailed time series for between two and five years depending on object. In the paper a methodology is described for evaluating heating and cooling concepts, not only by focusing on thermal comfort but also by including the useful energy consumption and energy efficiency, generation, distribution and deliveries.

4.4 Interviews

Two papers are related to this section, one interdisciplinary study of the low-energy houses in Lindås, Sweden and one article investigating the attitude of large construction companies. Isaksson and Karlsson (2006) present an interdisciplinary study of the indoor climate in the low-energy buildings in Lindås in Sweden. The paper presents results from an investigation of the 20 terraced houses in Gothenburg in Sweden. Qualitative interviews with occupants are combined with physical measurements of the thermal environment. The results show that when occupants are present and appliances are used, the temperature can be managed within acceptable limits even during cold days. One main outcome of the study is the importance of information given to households about the functionality of the heating system. In addition to this the authors state that temperature control could be improved. The paper also gives a wider view of how activities within these houses change compared to normal houses where power is less of a problem. Special focus should also be placed on gable houses in terms of thermal comfort.

In Hamza and Greenwood (2009) the impact of the new energy conservation regulations and its impact on low-energy buildings is studied. Data collection was made by semi-structured interviews with a sample representing large construction companies, architectural practitioners and building performance consultants. The authors express that “overall, it appears likely that the legislation is already having a profound effect on the

contractual and procurement arrangements of U.K. construction projects.” In Hamza and Greenwood (2009) a number of interesting impacts of the new legislation is seen on: (1) tendering practice and documentation; (2) procurement practice; (3) post-tender engineering and “value engineering”; and (4) collaborative working.

4.5 Questionnaires

Only one article fell under this category. In Thomsen et al. (2005) twelve demonstration projects within IEI Task 13 “advanced solar low-energy buildings” are presented. The paper includes a brief presentation of the houses. The study is a follow-up study three years after Task 13 ended, and is made in the form of a questionnaire sent to the former participants within the task. The paper states that the measured energy use was in general higher than expected due mainly to unforeseen technical problems but that energy savings of 60% were achieved compared to a typical building. The question of overheating in summer was specifically addressed, and it was shown that with proper planning and design this can be avoided. However, within the project this was a problem in two cases, one in Norway and one in Denmark. The paper summarizes a series of lessons to be learned: (1) Special consideration should be given to heat losses in partitions between apartments in highly insulated buildings; (2) obtaining the needed air tightness of a house requires careful planning and control of seals and barriers; (3) ventilation should be designed carefully with regards to sound and draught; (4) overheating can be prevented in moderate climates by means of thermal mass, solar shading and ventilation, if they are designed properly; and (5) heat losses from ducts and pipes are important and should be minimized.

4.6 Environmental or life cycle focus studies

In this final section nine papers are reviewed. In Chwieduk (1999) a study of thermal modernisation and refurbishment of existing buildings are presented in a Polish context. The paper outlines a view that a transition to low-energy buildings in Poland is a natural progression. It also includes some remarks and recommendations for Polish low-energy buildings.

Tombazis and Preuss (2001) discuss design of solar buildings in an urban context. The study emphasizes the building’s access to natural resources while taking into account the negative influence that may prevail around the site. The associated constraints, according to the authors, are challenging but very interesting and rewarding from an architectural point of view. The paper exemplifies different design options for three different cases. Even though the buildings are different they share some features, such as: (1) well insulated; (2) shallow plan, so daylight is able to penetrate and also to achieve well functioning natural ventilation; and (3) hybrid ventilation systems are used and some form of intelligent control is included. Zimmermann et al. (2005) present a benchmark of sustainable construction. The paper addresses the policy field and has the aim of being a contribution to developing a standard in the field. The paper also shows that buildings designed to the passive house standard may comply with the requirements for sustainable construction if the electricity generation is based on environmentally friendly generation. However, for other parts where a high degree of fossil fuel is used the authors find it much harder to meet the requirements.

In Rabah (2005) a design strategy for energy-efficient passive solar buildings in Cyprus is presented. The methodology includes: (1) initial pre-design considerations; (2) initial climate

analysis; (3) determination of passive solar design strategies; (4) analysis of the control zone (comfort, etc.). The aim of the paper is to provide general information at pre-design phases to be able to more effectively implement passive solar energy. Krishan et al. (1996) also focus on the design phase and discuss climate responsible design for two cases, one high-altitude “cold-dry” case and one “hot and dry” case. The paper includes design principles for this “indigenous architecture of two Indian deserts”.

In Thormark (2006) the effect of choice of material on total energy use and recycling potential is reported. The author addresses both the need for reducing energy use as well as the maximization of the recycling potential. Since the embodied energy for a low-energy house accounts for a large part of the total energy use during the life span of the building, it is important to consider the choice of material. The article presents the impact of material choice on the passive houses built in Lindås, Sweden.

In Sartori and Hestnes (2007) energy use in conventional building is compared to low-energy buildings using a review approach. The review includes 60 cases from nine countries, and showed that by far the largest part of energy use is related to the operating phase. The results presented in the paper show that the solar houses proved to be more energy efficient than the houses within the studies that used “green” materials. Furthermore, it was shown that solar houses decreased life-cycle energy use by half compared to a conventional building. A passive house proved to be more efficient than the solar houses in the studies.

In Aste et al. (2010) the low-energy residential settlement in Borgo Solare, Italy is presented. The project is not just an experimental operation; instead Borgo Solare is a real urban district. However, the project may be considered to be an advanced and innovative residential area designed on sustainable architectural grounds. The paper presents a techno-economical analysis of the project. The analysis shows that the higher initial embodied energy in a low-energy building may be paid back well within the life span of the building. In the economical analysis the authors argue that the higher initial costs may be effective in the long term.

In Verbeeck and Hens (2010) a life-cycle inventory of buildings is presented. The paper presents results of a contribution analysis of the life-cycle inventory of four typical buildings. The location of the objects is Belgium. The paper shows the small importance of the embodied energy when comparing energy use during the buildings' entire usage phase. This is also shown to be even more so for energy efficiency measures, when comparing embodied energy of the measures with the reduction in use. Only extreme low-energy buildings may have a higher embodied energy than the energy use during the phase when it is used; for a normal building this represents about one third of the total energy use during the life cycle. The total savings, however, are still shown to be large for low-energy dwellings.

5. Concluding discussion

The attention and research in this field is characterized by a strong increase in the number of articles during the last five years, not least within the scope of low-energy buildings and solar buildings. However, it is also important to note that most of the development in the field is taking place outside the scientific community, in construction companies, national programs and housing companies. The research field, as presented here, is a clearly technical field with a strong

focus on the technologies and development of techniques for improving energy performance of buildings. The number of studies with focus on the end users and how they interpret and interact with this new technology is scarce, but there are examples, such as Isaksson and Karlsson (2006), Schnieders and Hermelink (2006) and Feist et al. (2005), to name a few important contributions. This is a field which is important, especially when several authors, among them Karlsson et al. (2007), stress the importance of the activities and internal gains for low-energy buildings. The relative importance of this factor is so much greater since the losses from the building are so much smaller. It is therefore even more important to understand and be able to predict activities when designing this type of building.

The general trend of publication can also be said to have started to shift if looking at the process from 1978 to the present day. In the late 1970s and early 1980s the focus in the presented articles was in general on single technology investigations or building oriented with energy use and cost as key focus. The main driver was to remove oil-fired burners or to minimize their use, as an effect of the oil crisis. A shift can be seen in this main focus, as a large part of the articles presented in the late 1990s and after 2000 have a more environmental focus with greenhouse emissions as a key focus. This is in line with the general trend. However, what may be of interest is the increasing number of policy articles that argue for low-energy buildings when looking at long-term scenarios for sustainable buildings or regions. The number of publications where sustainable city parts like Borgo Solare in Italy are reported is also increasing. So the general trend may be argued to be moving from single technology and individual case studies of buildings to a more regional and large-scale production of energy-efficient city parts. In Lindås a in comparison small-scale production of 20 terraced passive houses was constructed in Sweden. These houses are investigated from multiple perspectives and some of the material is reported in the references here, such as Karlsson and Moshfegh (2006) and Wall (2006) for a technical description of the implementation and Isaksson and Karlsson (2005) for an interdisciplinary study of the buildings and also Thormark (2006) for a study of embodied energy and life-cycle analysis of these buildings.

For Sweden the buildings in Lindås are important as they mark the starting point for building passive houses in Sweden. Due to that they also represent a starting point in terms of learning to build this type of building with low infiltration rates and a high level of insulation, etc. which requires different approaches from the construction industry in terms of process. One interesting factor is that the German standard for passive houses sees e.g. Fiest and Schnieders (2009) or Fiest et al. (2005), has been adapted to Swedish conditions by a national forum for energy-efficient buildings funded by the Swedish energy agency (FEBY). This trend is similar for several other European countries. One point of interest is how the national standards use the requirements within the German standard in cases such as for Sweden, where the climate is different. For Sweden the certification process has the same requirements on maximum power and energy. These are based on electric heating, using the indoor air quality designed airflow for the building (10 W/m^2) and a maximum energy use of 15 kWh/m^2 . This is of course harder to achieve in a Nordic climate than for a central European climate. This issue is also connected to the issue of thermal comfort in passive houses in Nordic regions, where relatively few studies are reported. However, the issue of thermal comfort in general is something that is becoming more common to investigate, see Feist (2009) for example, but further studies are still very much needed especially for cold climates.

Along with users' interaction and interpretation of low-energy buildings, user satisfaction was expected to be a main focus of articles in this compilation. However, only one (Isaksson and

Karlsson 2005) explicitly tried to explore this. There are no internationally standardized methods to evaluate user satisfaction, but a closed-end questionnaire on indoor climate in dwellings has been developed in, for example, Sweden (Andersson et al., 1988). However, research results from low-energy buildings in Web of Science using this questionnaire are lacking. Also in Germany, questionnaires have been used in research about user satisfaction, but in office buildings (Pfafferott et al., 2007; Wagner et al., 2007). The method has been developed by University of California's Center for Environmental Design Research, Berkeley and according to the authors it addresses "all relevant aspects of occupant satisfaction with indoor environments" (Wagner et al., p. 764). Results show how user satisfaction corresponds to control abilities for users which are supported by results in Pfafferott et al. (2007). Actual temperature and temperature sensations had less effect on user satisfaction in this study. The perceived flexibility of low-energy buildings is something that future research could address. Post-occupancy evaluations of office buildings might offer methodological inspiration.

Research focusing on the construction sector, clients, design teams and the organization of construction processes are in this compilation mainly found in the U.K. (cf. Hamza and Greenwood, 2009; Hamza and Horne, 2007). Although the articles analyse phenomena specific to the U.K. (new energy conservation regulations and low-energy architecture in higher education), some general conclusions can be made. When designing low-energy buildings, more relational thinking is needed because of the increased complexity in the design phase (Hamza and Horne, 2007). Students in architecture might not have sufficient training in this higher level of approaching tasks, which includes critical thinking. Modules are being developed, however, to incorporate and facilitate relational thinking. A new regulation on energy conservation in the U.K. has also proved to support collaborations between design and construction teams, which is considered most welcome (Hamza and Greenwood, 2009). As noted in Hamza and Greenwood (2009), it is important not only to study user satisfaction post occupancy, but also the experiences of design and construction teams, in order to improve present regulations and practice in construction processes. Groups that should be addressed are practitioners, educators and policy-makers and publications in Web of Science journals might not be the most effective way to disseminate this feedback.

6. References

- Al-Sallal, KA. (1998). Sizing windows to achieve passive cooling, passive heating, and daylighting in hot arid regions, In: *Renewable energy*, 14 (1-4): MAY-AUG 365-371
- Andersson, K.; Fagerlund, I.; Bodin, L.; Ydreborg, B. (1988). Questionnaire as an instrument when evaluating indoor climate. In: *Healthy Buildings '88 Stockholm 1988*, Vol 1:139-146
- Aste, N.; Adhikari, RS.; Buzzetti, M. (2010). Beyond the EPBD: The low energy residential settlement Borgo Solare, In: *Applied Energy*, 87 (2): FEB 629-642
- Babbie, E. (1990) Survey research methods (2nd ed.), Wadsworth. 0-534-12672-3 Belmont CA
- Badescu, V. (2005). Simulation analysis for the active solar heating system of a passive house, In: *Applied Thermal Engineering*, 25 (17-18): DEC 2754-2763
- Badescu, V.; Sicre, B. (2003). In: Renewable energy for passive house heating II. Model, In: *Energy and Buildings*, 35 (11): DEC 1085-1096
- Badescu, V.; Sicre, B. (2003). Renewable energy for passive house heating Part I. Building description, In: *Energy and Buildings*, 35 (11): DEC 1077-1084

- Bergsten, B. (2001) Energiberäkningsprogram för byggnader – en jämförelse utifrån funktions- och användaraspekter, Effektivrapport.
- Bergström, G.; Boréus, K. (2005). Textens mening och makt: metodbok i samhällsvetenskaplig text- och diskursanalys. (2., [omarb.] uppl.) Studentlitteratur. ISBN: 91-44-04274-4, Lund
- Chandel, S.; Aggarwal, R. (2008) Performance evaluation of a passive solar building in Western Himalayas, In: *Renewable energy*, 33 (10): OCT 2166-2173
- Chlela, F.; Husaunndee, A. ; Inard, C.; RiedeFer, P. (2009) A new methodology for the design of low energy buildings, In: *Energy and Buildings*, 41 (9): SEP 982-990
- Chwieduk, D. (1999). Prospects for low energy buildings in Poland, In: *Renewable energy*, 16 (1-4): JAN-APR 1196-1199
- Clarke, J.; Grant, A.; Johnstone, C.; Macdonald, I. (1998). Integrated modelling of low energy buildings, *Renewable energy*, 15 (1-4): SEP-DEC 151-156
- Cooper, J.S.; Fava, J. (2006). Life Cycle Assessment Practitioner Survey: Summary of Results, In: *Journal of Industrial Ecology*, 10(4) 12 -14
- Crawley, D. Hand, J. Kummert, M. Griffith, B. (2005) Contrasting the capabilities of building energy performance simulation programs. In *proceedings of international IBPSA conference 8*, Montreal, Canada, 231-238.
- Dallaire, G. (1980). Zero-energy house: bold, low-cost breakthrough that may revolutionize housing, In: *Civil Engineering –ASCE*, 52, 47-59
- Dinçer, I.; Rosen, M.A. (2007). *Exergy: energy, environment and sustainable development*. (1. ed.), Elsevier, ISBN: 978-0-08-044529-8, Oxford
- Fairclough, N. (2003). *Analysing discourse: textual analysis for social research*. Routledge, ISBN: 0-415-25893-6, New York
- Feist, W.; Schnieders, J. (2009). Energy efficiency - a key to sustainable housing, In: *European Physical Journal – Special Topics*, 176: SEP 141-153
- Feist, W.; Schnieders, J.; Dorer, V.; Haas, A. (2005) Re-inventing air heating: Convenient and comfortable within the frame of the Passive House concept, In: *Energy and Buildings*, 37 (11): NOV 1186-1203
- Filippin, C.; Beascochea, A.; Esteves, A.; De Rosa, C.; Cortegoso, L.; Estelrich, D. (1998) A passive solar building for ecological research in Argentina: The first two years experience, In: *Solar Energy*, 63 (2): AUG 105-115
- Frosch, RA.; Nicholas EG. (1989). Strategies for Manufacturing, In: *Scientific American* 261(3): 144-152
- Guinée, JB. (red.) (2002). *Handbook on life cycle assessment: operational guide to the ISO standards*, Kluwer, ISBN: 1-4020-0228-9, Dordrecht
- Hamza, N.; Greenwood, D. (2009) Energy conservation regulations: Impacts on design and procurement of low energy buildings, In: *Building and Environment*, , 44 (5): MAY 929-936
- Hamza, N.; Horne, M. (2007). Educating the designer: An operational model for visualizing low-energy architecture, In: *Building and Environment*, 42 (11): NOV 3841-3847
- Heim, D. (2010) Isothermal storage of solar energy in building construction, In: *Renewable energy*, 35 (4): APR 788-796
- Holm, D. (1996). The status of low energy architecture in South Africa, In: *Renewable energy*, 8 (1-4): MAY-AUG 301-304
- Holmes, M.; Hacker, J. (2007). Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century, In: *Energy and Buildings*, 39 (7): 802-814

- International Organization for Standardization (ISO) (1997). *Environmental management - Life cycle assessment - Principles and framework*. Geneva: ISO
- IPCC (ed. Terry Baker) (2007). *Climate Change 2007: Synthesis Report*, <http://www.ipcc.ch/ipccreports/ar4-syr.htm> (April 21 2009).
- Isaksson, C.; Karlsson, F. (2006). Indoor climate in low-energy houses - an interdisciplinary investigation, In: *Building and Environment*, 41 (12): DEC 1678-1690
- Kalogirou, SA.; Bojic, M. (2000). Artificial neural networks for the prediction of the energy consumption of a passive solar building, In: *Energy*, 25 (5): MAY 479-491
- Kalz, D.; Pfafferott, J.; Herkel, S. (2010). Building signatures: A holistic approach to the evaluation of heating and cooling concepts, In: *Building and Environment*, 45 (3): MAR 632-646
- Karlsson, F.; Rohdin, P.; Persson, M-L. (2007). Measured and predicted energy demand of a low energy building: Important aspects when using building energy simulation, In: *Building Services Engineering Research and Technology*, 28 (3): 223-235
- Karlsson, J.; Moshfegh, B. (2006) Energy demand and indoor climate in a low energy building-changed control strategies and boundary conditions, In: *Energy and Buildings*, 38 (4): APR 315-326
- Krishan, A.; Jain, K.; Tewari, P. (1996). Indigenous architecture of two Indian deserts and modern climatic responsive solutions, In: *Renewable energy*, 8 (1-4): MAY-AUG 272-277
- Krosnick, JA. (1999). Survey Research, In: *Annual Review of Psychology*, 50: 537-567
- Kvale, S (1996). *Interviews An Introduction to Qualitative Research Interviewing*, Sage Publications, Thousand Oaks.
- Kvale, S.; Brinkmann, S. (2009). *InterViews: learning the craft of qualitative research interviewing*. (2nd ed.) Sage Publications, ISBN: 978-0-7619-2542-2, Los Angeles
- Körner, S.; Ek, L.; Berg, S. (1984). *Deskriptiv statistik*. (2. ed.) Studentlitt., ISBN: 91-44-15392-9, Lund.
- Lincoln, Y.S.; Guba, EG. (1985). *Naturalistic inquiry*. Beverly Hills, Calif.: Sage.
- Liu, S.; Henze, G. (2006a). Experimental analysis of simulated reinforcement learning control for active and passive building thermal storage inventory Part 1. Theoretical foundation, In: *Energy and Buildings*, 38 (2): FEB 142-147
- Liu, S.; Henze, G. (2006b). Experimental analysis of simulated reinforcement learning control for active and passive building thermal storage inventory Part 2: Results and analysis, In: *Energy and Buildings*, 38 (2): FEB 148-161
- Lomas, K. (1996). The UK Applicability Study: An evaluation of thermal simulation programs for passive solar house design, In: *Building and Environment*, 31 (3): MAY 197-206
- Maier, T.; Krzaczek, M.; Tejchman, J. (2009). Comparison of physical performances of the ventilation systems in low-energy residential houses, In: *Energy and Buildings*, 41 (3): MAR 337-353
- Makaka, G Meyer, E McPherson, M, Thermal behaviour and ventilation efficiency of a low-cost passive solar energy efficient house, In: *Renewable energy*, 33 (9): 1959-1973 SEP 2008
- Moses, LE. (1986). *Think and explain with statistics*. Addison-Wesley ISBN 0-201-15619-9, Reading, Mass.
- Nicoletti, M. (1998). Architectural expression and low energy design, In: *Renewable energy*, 15 (1-4): SEP-DEC 32-41
- Nieminen, J. (1994). Low-energy residential housing, In: *Energy and Buildings*, 21 (3): 187-197

- Odum, H.T. (2007). *Environment, power and society for the twenty-first century: the hierarchy of energy*. (New ed.) University Press. ISBN: 978-0-231-12886-5 New York: Columbia
- Onishi, J.; Soeda, H.; Mizuno, P. (2001). Numerical study on a low energy architecture based upon distributed heat storage system, In: *Renewable energy*, 22 (1-3): JAN-MAR 61-66
- Osgood, CE.; Suci, GJ.; Tannenbaum, P. (1957). *The Measurement of Meaning*, University of Illinois Press, Urbana, IL
- Persson, M-L.; Roos A.; Wall, M. (2006). Influence of window size on the energy balance of low energy houses, In: *Energy and Buildings*, 38 (3): MAR 181-188
- Pfafferott, JÜ.; Herkel, S.; Kalz, DE.; Zeuschner, A. (2007) Comparison of low-energy office buildings in summer using different thermal comfort criteria, In: *Energy and Buildings*, 39 pp. 750-757
- Rabah, K. (2005). Development of energy-efficient passive solar building design in Nicosia Cyprus, In: *Renewable energy*, 30 (6): MAY 937-956
- Sartori, I.; Hestnes, A. (2007) Energy use in the life cycle of conventional and low-energy buildings: A review article, In: *Energy and Buildings*, 39 (3): MAR 249-257
- Schnieders, E.; Hermelink, A. (2006). CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building, In: *Energy Policy*, 34 (2): JAN 151-171
- Shaviv, E.; Yezioro, A.; Capeluto, IG.; Peleg, UJ.; Kalay, YE. (1996). Simulations and knowledge-based computer-aided architectural design (CAAD) systems for passive and low energy architecture, In: *Energy and Buildings*, 23 (3): MAR 257-269
- Starr, G.; Neubauer, L.; Melzer, B. (1980). Temperature Control by Passive Solar House Design in California, In: *Transactions of the ASAE*, , 23 (2): 449-456
- Thomas, J.; Alghary, S.; Hammad, F.; Soboyejo, W. (2006). Materials selection for thermal comfort in passive solar buildings, In: *Journal of Materials Science*, 41 (21): NOV 6897-6907
- Thomsen, K.; Schultz, J.; Poel, B. (2005). Measured performance of 12 demonstration projects - IEA Task 13 "advanced solar low energy buildings", In: *Energy and Buildings*, 37(2): FEB 111-119
- Thormark, C. (2006). The effect of material choice on the total energy need and recycling potential of a building, In: *Building and Environment*, 41 (8): AUG 1019-1026
- Tombazis, A.; Preuss, S. (2001). Design of passive solar buildings in urban areas, In: *Solar Energy*, 70 (3): 311-318
- Tommerup, H.; Rose, J.; Svendsen, S. (2007). Energy-efficient houses built according to the energy performance requirements introduced in Denmark in 2006, In: *Energy and Buildings*, 39 (10): OCT 1123-1130
- Verbeeck, G.; Hens, H. (2010). Life cycle inventory of buildings: A contribution analysis, In: *Building and Environment*, 45 (4): APR 964-967
- Versteeg, H. K. Malalasekera, W. (1995) *An introduction to computational fluid dynamics: the finite volume method*. Harlow: Longman Scientific & Technical.
- Visser, PS.; Krosnick, JA.; Marquette, J.; Curtin M. (1996). Mail surveys for election forecasting? An evaluation of the Columbus Dispatch poll. In: *Public Opin. Q.* 60:181.227
- Wagner, A.; Gossauer, E.; Moosmann, C.; Gropp, Th.; Leonhart, R. (2007) Thermal comfort and workplace occupant satisfaction—Results of field studies in German low energy office buildings, In: *Energy and Buildings*, 39, pp. 758-769
- Wall, M. (2006). Energy-efficient terrace houses in Sweden - Simulations and measurements, In: *Energy and Buildings*, 38 (6): JUN 627-634

- Wang, L.; Gwilliam, J.; Jones, P. (2009) Case study of zero energy house design in UK, In: *Energy and Buildings*, 41 (11): NOV 1215-1222
- Wojdyga, K. (2009). An investigation into the heat consumption in a low-energy building, In: *Renewable energy*, 34 (12): DEC 2935-2939
- Zhu, L.; Hurt, R.; Correa, D.; Boehm, R. (2009a). Comprehensive energy and economic analyses on a zero energy house versus a conventional house, In: *Energy*, 34 (9): SEP 1043-1053
- Zhu, L.; Hurt, R.; Correia, D.; Boehm, R. (2009b). Detailed energy saving performance analyses on thermal mass walls demonstrated in a zero energy house, In: *Energy and Buildings*, 41 (3): MAR 303-310
- Zimmermann, M.; Althaus, H.; Haas, A. (2005). Benchmarks for sustainable construction - A contribution to develop a standard, In: *Energy and Buildings*, 37 (11): NOV 1147-1157

IntechOpen

IntechOpen

IntechOpen

Energy Efficiency

Edited by Jenny Palm

ISBN 978-953-307-137-4

Hard cover, 180 pages

Publisher Sciyo

Published online 17, August, 2010

Published in print edition August, 2010

Global warming resulting from the use of fossil fuels is threatening the environment and energy efficiency is one of the most important ways to reduce this threat. Industry, transport and buildings are all high energy-using sectors in the world and even in the most technologically optimistic perspectives energy use is projected to increase in the next 50 years. How and when energy is used determines society's ability to create long-term sustainable energy systems. This is why this book, focusing on energy efficiency in these sectors and from different perspectives, is sharp and also important for keeping a well-founded discussion on the subject.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Patrik Rohdin, Wiktora Glad, and Jenny Palm (2010). Low-Energy Buildings – Scientific Trends and Developments, Energy Efficiency, Jenny Palm (Ed.), ISBN: 978-953-307-137-4, InTech, Available from: <http://www.intechopen.com/books/energy-efficiency/low-energy-buildings-scientific-trends-and-developments>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2010 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](https://creativecommons.org/licenses/by-nc-sa/3.0/), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen