

Determining the Economic Effects of using Building Physics tools during the Building Process

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Department of Building Physics



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Licentiate thesis

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*This report is dedicated to my grandfather Delphis Landry-
A builder of many things.*

Preface

There are many people I would like to thank over the course of time, which has lead to this project and this report. First I would like to thank my wife Gunilla, who is responsible for bringing me to Sweden and encouraged me to apply for the position at LTH. Professors Jesper Arfvidsson and Arne Elmroth and everyone else in the department for helping me dive into the area of building physics. Lilian, thanks for the figures and minimizing the damage word does when trying to convert documents into PDF files. Of course I would like to thank my parents for supporting my education, both emotionally and financially.

I have to say thanks to Charlie Kehoe who taught me how to build houses. While not apparent at the time, this experience proved to be more valuable than I could have imagined.

This Licentiate thesis represents what has been done during the first half of my project. The work is being carried out at the department of Building Physics in Lund Institute of Technology, Lund University. I would like to thank the financers of this project, FORMAS (The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning) and SSF (the Swedish Foundation for Strategic Research). This project is also a part of Competitive Building, Sweden's national research and development programme for the construction sector. I would also like to thank everyone in Competitive Building; I look forward to working with everyone over the next half of the project.

Stephen Burke

October 16, 2003
Lund.

Abstract

Since the basic concepts in the area of building physics are usually ignored, preventable failures are continuing to occur in modern buildings. The aim of this project is to evaluate the economic effects of different building physics aspects during the different stages in the building process and show the importance of applying building physics to designs. The hypothesis of this project is that economic benefits can be gained by mastering the economic effects related to building physics aspects in the building process, especially during the design and construction phases. The methods used for this report included a literature review, a case study, interviews and a study of archived data. The literature study showed that there is a need and a potential future market in using building physics during the design phase of a construction project. It also revealed that there is not much information on the economic effects of using building physics. The case study showed that in regards to ventilation systems, the system with lowest initial cost is not the best value for money over the long-term perspective. After 50 years, it was calculated to be the same cost as the more expensive supply-exhaust system with heat recovery. Interviews with engineering consultants showed that computer based tools are not used because they are too expensive, too difficult to use, require long learning times, require too much time to execute. It also appears that the education of the consultant plays a larger role in their ability with respect to building physics when compared to their level of experience. A study of data from SSN (National Organisation for Aid to Owners of Private Small Houses) showed the costs of repairing damages that can occur from using a crawlspace foundation are on average 33% of the market value of the house.

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1 Introduction

Building failures related to moisture, ventilation and energy issues could be avoided if there were fewer misunderstandings between the different actors involved in the building process over the importance of building physics. Ignoring these principles during the design and construction phases can lead to a number of problems during the operation phase such as increased energy usage, health problems, physical building damage and a host of other problems related to these (Wardhana & Hadipriono, 2003). These problems are mirrored in the amount of mass-media attention that problematic buildings are receiving; even to the point of being scandalous to the companies involved in all phases of the project (Luthander, 2001; Jelvefors, 2002; Samuelson and Wånggren, 2002).

Not surprisingly, companies and clients spend huge amounts of money each year to rectify these problems (Josephson & Hammarlund, 1999). For example in 2001, Canada's national housing corporation reported that premature building failures (all types) cost Canadian's about \$225 to \$375 million CND annually (CMHC, 2001).

1.1 Statement of the problem

Since the basic concepts in the area of building physics are usually ignored (Becker, 1999), preventable failures are continuing to occur in modern buildings. The problem is that the industry is not easily convinced to change their methods and prefer to continue working in the same manor as before using 'tried and proven' constructions without thinking of the implications (Landin, 2000 pp. 47) or seeking feedback on the used solutions.

Unfortunately the tried and proven methods are not always the best methods, particularly when new technology is used in combination with these methods. It is important to remember that each new building is essentially a prototype and what worked 100 years ago, may not work today. For example, crawlspaces worked very well in the past, however they do not function very well today because the combination of advances in material technology and design, specifically of the floor. In the past, the crawlspace was a heated space because of the lack of insulation in the floors. Today's houses are much more energy efficient, with plenty of insulation under the floors yet crawlspaces are still ventilated with outdoor air. This results in a low temperature and high level of humidity under the floor, which are ideal conditions for mould growth. This is thought to be one of the causes of sick building syndrome (Willers et

al., 1996; Apte et al., 2000; Wargoeki et al., 2000). In addition to mould growth, the tightness of a building also seems to be a contributing factor to poor indoor air quality.

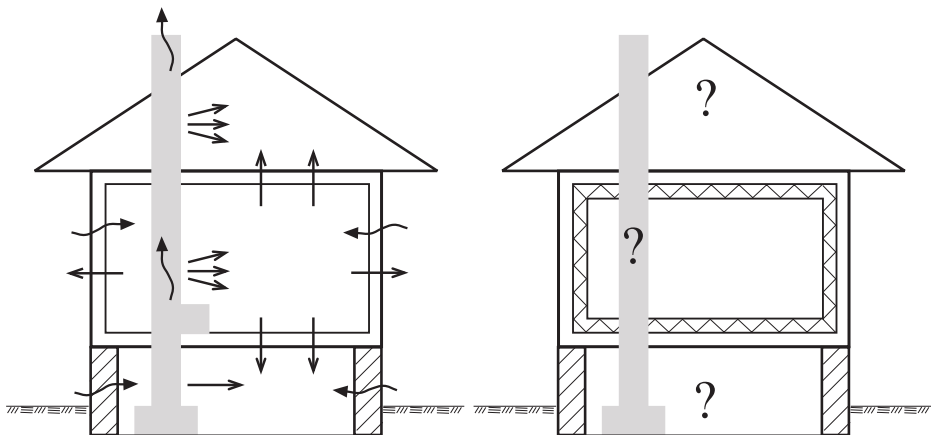


Figure 1: Heat (straight arrows) and airflows (wavy arrows) in an older house in comparison to a new house. In the old house, little insulation and no wind barrier resulted in air flowing freely into the house via cracks. Heat was released into the attic and crawlspace/cellar via the chimney or through the floor. In a modern building these flows vary due to the addition of wind barriers, insulation, the combination of materials and the various types of heating systems in use.

It is thought that buildings in the past did not have this problem because the construction was so leaky that old buildings actually had very good ventilation. Figure 1 shows the difference between a past and a modern design. In the past, heat and air flowed quite freely between the various components. Heat from the fireplace and chimney warmed the main living area, the crawlspace and the attic. This warm air did not have a high relative humidity so there was no condensation and very little to no mould growth. Now, buildings are well insulated and are virtually airtight. There is very little to no heat and airflows through the building's envelope, to the crawlspace and attic. Additionally, the moisture that is released into the air from cooking, bathing, washing, and people has no way to escape the house. The result is that the relative humidity can increase very quickly causing condensation on the inside of the windows and in the walls. The solution to this was to control the airflow from the outdoors using a ventilation system that can reuse some of the expelled heat energy. However, if the ventilation system is not designed correctly or fails, the quality of the indoor air quickly deteriorates. (Sundell, 2000 pp. 32)

One method to help the industry take notice of particularly bad designs is to show that they are not economically viable to the customer. Over the long term, choosing one design over another can have the same end result as far as PC (Production Cost), but one design can cost the owner much more money over the long-term perspective when looking at the LCC (Life Cycle Cost) of the building. Unfortunately, there is no readily available information regarding this topic to customers. (See 5.2 Phase II.) This study will show why building physics should be taken into account during the design and construction process touching on some of the economic repercussions of a past design that, for the most part, is still being used without any significant modifications.

1.2 Aim and objectives

The aim of this project is to evaluate the economic effects of different building physics aspects during the different stages in the building process and show the importance of applying building physics to designs. It will do this by using economic and building physics based tools as a means to persuade the construction industry or clients to utilize the available information thus actively preventing, or reducing the risks of failures in buildings.

The aim of this report is to provide background information for the project by showing what has been done so far in this topic area, show reasons why tools of this nature are needed in the industry and show the economic costs associated with a crawlspace design. This report will also show an example of a simple to use tool currently being developed for industry and describe the theory behind it.

1.3 Limitations

Building physics, and the economic relationship with it, is a broad subject area. This project will be limited to the economic costs from damages that could have been prevented by using building physics theory. Examples of these damages include moisture damage from various sources (not to be mistaken with water damage from leaks or rain), and thermal damage (freezing action).

This project was limited to these damages. There is work ongoing in the areas of Life Cycle Cost (LCC) in respect to ventilation systems (Johansson, 2002; Vik, 2003; Wachenfeldt, 2003; Ståhl, 2002b), and energy usage in buildings (Öberg, 2002a; Ståhl, 2002a; Hens et al., 2002; Adalberth, 1997).

Other costs were not included in this project because they are uncertain costs based on subjectivity. For example, health costs due to mould and allergies were not investigated in this project even though it can be argued that they are costs that can be traced back to building physics issues, usually moisture problems. Additionally, social costs such as the costs of lost labour, medical costs and drugs were also not considered.

1.4 Hypothesis

The hypothesis behind this project is that economic benefits can be gained by mastering the economic effects related to building physics aspects in the building process, especially during the design and construction phases.

2 State of the Art

2.1 Building physics Theory

Building physics is the science of how energy interacts with the materials within a building envelope. It encompasses the fields of heat transfer, moisture transfer and air flows. This means that building physics can include other areas such as energy efficiency, indoor air quality, mould in buildings, ventilation systems etc. As seen in Figure 2, some countries include acoustics and fire protection, however in this report the Swedish definition is used. For a more detailed description of the various topics below, please refer to Appendix I, Paper I.

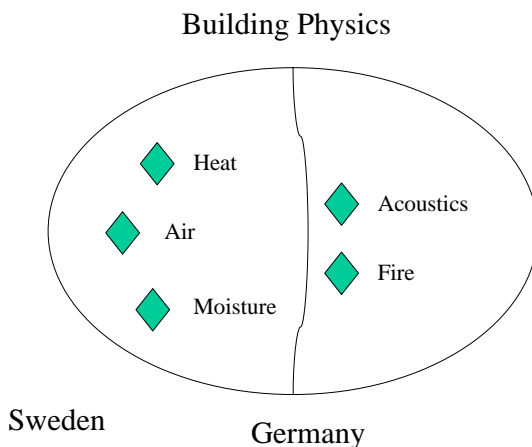


Figure 2: Building physics in Sweden is defined differently than in other countries, for example Germany includes acoustics and fire studies in their definition of building physics and Sweden does not.

2.1.1 Heat

One aspect that building physics covers is the study of heat transfer through a building's envelope. Energy efficient buildings would not be as advanced as they are today if it were not for this area of science. The idea with energy efficient homes is to increase the amount of insulation within the walls so that less energy is required to maintain a constant temperature inside the building. This theory applies for both warm and cool climates. This increases the level

of comfort in the building since people are very sensitive to even small changes in temperature. A poorly insulated building or a building with a low thermal mass can be an uncomfortable building (Öberg, 2002b pp. 64). However, thermal comfort is not determined only by the temperature difference; for example moisture levels, air pressures, air movement and material choices are other factors that play a role with the thermal comfort of the indoor environment.

Currently, energy use in the building sector accounts for 40% of the total energy used within the EU (Sjöström, 2000). The majority of this is related to the operational phase of a building project. The interest in energy conservation during all phases of a construction project have stemmed from the implications regarding the environment and economics. The easiest methods to reduce the energy use in a building are to add insulation and upgrade the windows to three panes of glass.

Unfortunately, energy efficient buildings have negative aspects that are not so clear-cut. Since the walls must be thickened and tightened, this can cause problems in the areas of ventilation and moisture control. If a building is not designed properly, the risk for moisture and ventilation problems increases as the energy efficiency increases (Thörn, 1999). The building also becomes more sensitive for what were considered smaller issues and it becomes very important to treat all three variables - heat, air and moisture, at the same time. For example, in energy efficient homes the building envelope is virtually airtight to minimise heat loss via escaping airflows, windows are upgraded and the insulation is thickened. Thermal bridging that is considered negligible in a conventional house can provide a means of significant heat loss and the ventilation system become more vital to control the indoor air quality and indoor moisture levels. Only an understanding of heat and moisture transfer theories along with knowledge of the material properties in the construction can counter these effects.

Calculating the temperatures of different layers in a wall is fairly straightforward today. Increasingly, researchers and industry are combining thermal calculations with moisture calculations since the two are linked. The theories behind these calculations are essentially the same. However there is one small factor that increases the difficulty of calculating the moisture levels, and that is that the moisture properties are very sensitive to changes in the moisture and temperature state. When calculating temperatures, one assumes constant moisture content. One cannot assume a constant temperature when

dealing with moisture flows. In addition, there are other variables such as the material's properties and air velocity that can have effects on the flows.

Computer software is readily available for calculating heat flows in buildings (See 2.3 Tools). Most of these are designed to calculate the heat flow in various components such as attics, walls, crawlspaces, etc. Some can simulate the heat flow in a one, two or three-dimensional state. The refining of these types of programs has led to software that is specialized to calculate energy loss. These programs can be very complex and can take into account the position of the building (to calculate solar gains or the amount of shading from other buildings or trees), the types of materials used, the type of ventilation system, the amount and type of heating required, the physical dimensions of the building, the effect of the local climate on the energy usage, etc.

2.1.2 Air

Ventilation, whether it is natural or mechanical, provides air from the outdoors into buildings. Poor ventilation can lead to indoor air quality problems that can, in turn, lead to health problems for some people (Seppänen & Fisk, 2002). Poorly designed ventilation systems can also be energy consuming and give a poor indoor environment. If the ventilation system is not balanced properly, condensation can occur in the walls, on the windows and odours can be detected from neighbouring apartments. This can lead to other problems like mould growth and high dust levels.

If these problems continue without remediation, health problems may surface in the occupants of the building. Asthma is one of the serious problems, which in the US, seems to be increasing despite the fact that ambient air pollution is decreasing. (Brugge et al., 2000)

Engdahl (1998) showed that these problems are more prevalent than one may believe. In his study, it was found that, on average, only about 33% of all multi-family buildings, schools and offices in Sweden conformed to the regulations that were valid when the system was brought into operation. In other words, 67% of these buildings were not up to the standards of when they were installed.

2.1.3 Moisture

Moisture problems are one of the main topics today in building physics. It is a complex problem requiring a multidisciplinary approach in order to grasp the true effects of this problem. To gain an appreciation of the scope of the

problems generated by excess moisture in a building, we must look to medical doctors, researchers, microbiologists, environmental scientists, biologists, physicists, chemists and engineers for their input and experiences.

Moisture can occur in a building through a number of different paths. There are three methods of transportation that allow the water to come into contact with the materials, convection, diffusion and capillary action. Convection occurs when air moves the water particles. Diffusion is the phenomena of where the water concentration wants to be at equilibrium. Capillary action mostly occurs underground where the water travels into materials with small pore spaces.

Which ever method the water takes, there is a risk during the entire construction process that materials will become wet. Before the physical construction work begins, materials can be delivered wet. They can become wet after delivery because of improper storage, or stored on the ground. It is important to protect your materials during every phase of construction. Wet materials during the construction phase can lead to problems later (Samuelson & Nielsen, 2002).

After the building is finished, it is still at risk from both the indoor and outdoor environments. Appendix 1, Paper I, shows some of the damages that can still occur at various moisture levels. A majority of the moisture problems occur once the moisture level of the environment reaches 75%. Ventilation control becomes even more important in removing excess moisture in the air, moisture that is attributed to people by sweating, showering, cooking foods, etc. Some industries must also deal with high moisture levels by having adequate ventilation systems. These include paper mills, swimming halls, and other facilities that have a large quantity of open water (Ebbehøj et al., 2002).

The largest risk from the outdoor environment comes from the weather. Depending on geographic location, some places have a high humidity level all year round, such as coastal cities. However, all locations are at risk from rain and snow.

2.2 Economics

Building physics is not usually associated directly with economics. Most work looks at some areas of building physics, usually under the term indoor air quality and relates economic factors to SBS (Sick Building Syndrome), or BRS (Building Related Symptoms). For example, a research project in Uttar Pradesh, a state in India, looked at the economic burden caused by respiratory

illness. In this project the author looked at the direct costs, indirect costs and opportunity costs of dealing with this illness. Poor indoor air quality due to the combustion of bio-fuels was suggested as one of the main causes and the total economic burden was found to be between 73 billion to 167 billion Rupees (€1.3 to 3 billion) per month (Parikh & Biswas, 2002). In the US, the direct and indirect costs of treating asthma caused by poor indoor air quality were reported to be about \$13 billion US (€11 billion) (Weiss & Sullivan, 2001). Fisk (2000) reports that the potential annual savings and productivity gains are; US\$6-14 billion (€5 – 12 billion) from reduced respiratory disease; US\$2-4 billion (€1.7 – 3.4 billion) from reduced allergies and asthma; US\$10-30 billion (€8.4 – 25 billion) from reduced SBS; and US\$20-160 billion (€17 – 136 billion) from direct improvements in worker performance that are unrelated to health issues. In 2002, approximately 6,3% of Sweden's BNP, or SEK 147 Billion (€16 billion) were invested in the building sector (Sveriges Byggindustrier, 2003 pp. 6). Tolstoy (1994) states that in Sweden, roughly SEK 6 billion (€665 million) per year is spent on repairs and maintenance of buildings and of that, approximately half goes to damages attributed to moisture damage.

The Object's Life Cycle

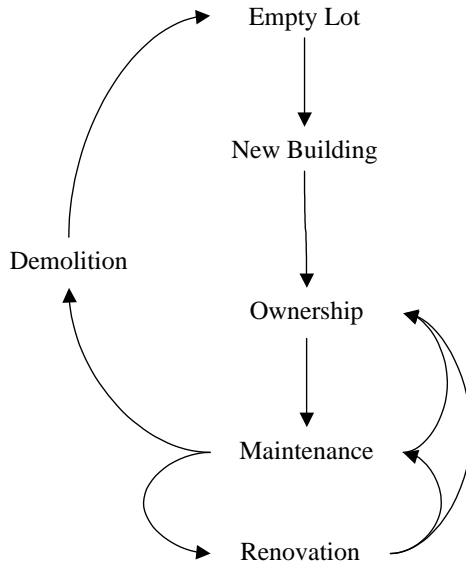


Figure 3: The life cycle of a building from a systems perspective, focusing on the costs for the building. During a building's lifetime, it may undergo little or many periods of maintenance and or renovations and it may change owners a number of times before the destruction phase.

Figure 3 shows the very simplified life cycle of a building focusing on the main costs for the client. First the client must purchase an empty lot. Next the builder constructs a building on the lot. Ownership of this building is transferred or changed depending on if the construction company owns the building or not. Over the course of time, the owner will spend money on maintenance and may eventually renovate the building. The owner may then choose to sell the building to another owner and the cycle repeats. Eventually the current owner may decide to demolish the building leaving an available lot.

Taking into account the above costs during the lifetime of the building will give an accurate view of the costs due to damage and renovation of the building. In order to determine the LCC of a building, operation costs must be considered. This would include heating, electricity, water, waste-water, and all other expenses. The latter can be accurately simulated on available software in order to determine the cost difference if a building's component is modified.

There is no available software that can simulate the costs due to maintenance and repairs based on the building's components.

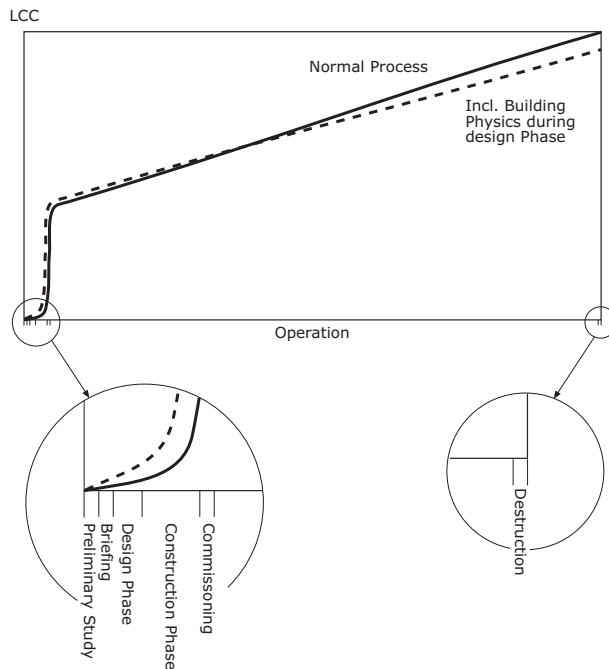


Figure 4: The total LCC of a building over its lifetime. The construction process only covers a small amount of time in relation to the lifetime of a building.

Figure 4 shows the LCC of a building over its lifetime. Design, material selection, and quality all affect the performance of the building in the future. By using building physics tools during the design phase, it is possible to reduce the LCC of the building even if the construction costs increase slightly.

2.3 Tools

According to various studies (Augenbroe, 2002; Boyer et al., 1998; Ellis & Mathews, 2001; Hien et al., 2000; Paper IV), it appears that designers of buildings do not use the tools that are available today because of a number of reasons. Ease of use was a significant factor, i.e. the tools that are available today are too complex or they are not user friendly and are time consuming to use. Tools also require a high level of knowledge to both input the required

data and interpret the results. In addition, some of the initial data required to run the simulations may not be decided upon yet and can lead to problems with the input data.

Boyer et al., (1998) points out that researchers are the ones responsible for the construction of these tools for the designers and policy makers. The authors also state that the models should be a simplification of reality that uses recent theories that are adequately supported by the scientific community. Unfortunately what the researcher thinks of as simple, the other groups may find redundant hence leading to the problems above that discourage the use of these tools.

Augenbroe (2002) has a similar point of view regarding the difficulty of using current tools, however argues that experts should make programs that run over the Internet for other experts. This is because the current trend “recognizes that the irreplaceable knowledge of domain experts and their advanced tool sets is very hard to match by ‘in-house’ use of ‘dumbed down’ designer friendly variants” (Augenbroe, 2002 pp. 891). In other words, the industry should employ experts that are able to run and understand the latest programs and theories. (Hien et al., 2000 pp. 727) agrees with this stating, “...such software (software that analyses acoustics, ventilation and indoor air quality) should only be used by the specialists”.

Bellia (2003 pp. 457) contradicts this by stating, “that the application of more complex calculation methods, in most cases, should result impracticable, especially by design professionals”. In other words, tools should be made for the typical designers, not for a few specialists.

3 Structure of the Project

3.1 Project Phases

This project is divided into six phases. Phase one was the Identification Phase and the objective of this phase was to identify areas where knowledge of building physics increased the foundation on which decisions during the building process were made and to formulate a number of questions for a problem based starting point.

Phase 2 was called the Literature Survey and this phase is ongoing throughout the entire project. The objective of this phase was and is to scan the available literature for documents relating building physics and economics directly. This phase is also important to understand the background to why this link is relevant today and why this project is important.

Phase 3 is called the Adaptation and Verification Phase. The project is currently in this phase that is using the economic data found in Phase 2 and building a tool, in this case software, that will allow designers to simulate various designs for different parameters related to building physics. The tools will be adjusted to work together and they will be tested and verified later.

Phase 4 is called Case Studies. This phase involves testing the tool in various companies and gathering feedback.

Phase 5, the Evaluation Phase, analyse the results from Phase 4 and modify the tools as per recommendations from industry.

Phase 6 is the Information Phase. In this phase the results of the entire project are released, the software is finalized and released on the Internet along with an instruction manual.

3.2 Building Physics and Economic Tools

The principles of the tools are based on the theories of building physics and economics described in section 2 State of the Art. Figure 5 shows a simple diagram of the tool concept being used in this project. In the centre lies the Interface program developed at the Department of Building Physics at Lund University. This interface program will connect various programs that are specialised in the different areas shown. The primary idea behind this toolbox is to collect existing freeware that is available into one package. Designers

would have a collection of tools available in one software package, available over the Internet. This reduces the need for a number of different software packages. For example, programs from the Department of Building Physics will be incorporated into this package as well as some external programs. Contact has been made with the Danish Technical University in Copenhagen regarding a window simulation program. Whilst it is unknown if this program will be included, it shows that there are other tools available for free, thereby reducing the cost factor for designers.

The software could also be connected to a database. This database could be local or on the Internet and could provide material databases, economic information, and the risks associated with specific designs.

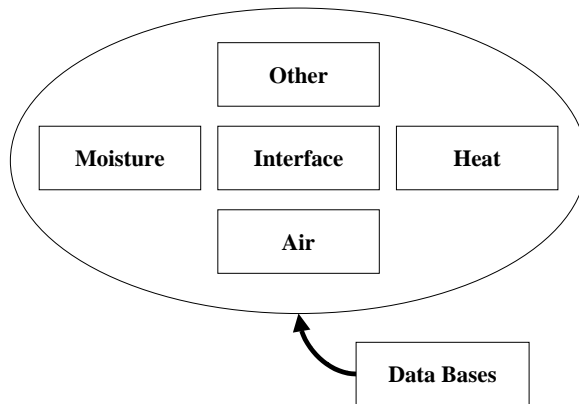


Figure 5: The toolbox developed in this project will include freeware programs that can simulate various aspects of building physics. Databases will provide material and economic data for the toolbox and all the subprograms included in it.

One of the tools for the toolbox that is currently being developed simulates the temperature of the soil under a foundation. Figure 6 shows the file structure of the program.

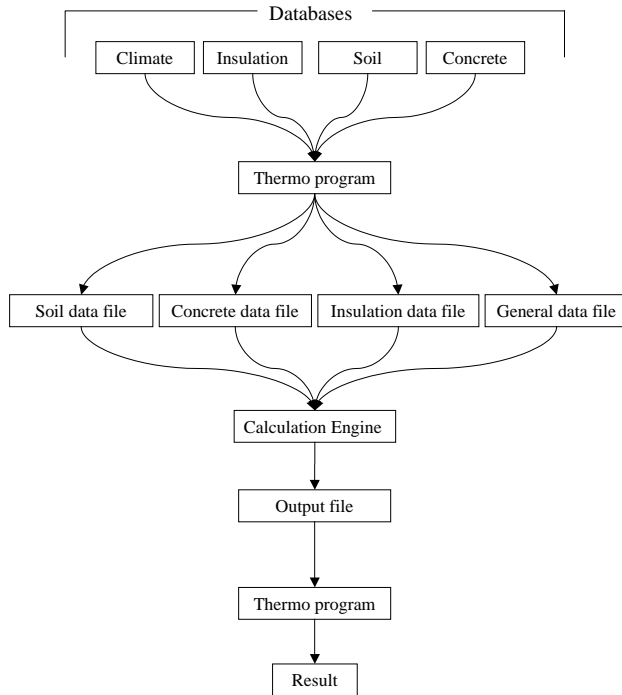


Figure 6: The file to software relationship for one of the tools under development. A number of databases will supply the material data to the program. The dimensions will be entered into the program as well as a number of options available for each design type. The program will generate data files for each component that will be processed by the calculation engine. The calculation engine will simulate the desired conditions and create an output file that will be converted into an image by the main program.

The program will have predetermined design templates for foundations that the user can choose from. The user will enter the dimensions for the design, choose the types of materials from the databases and run the simulation. The Thermo program will create four data files that will be run by the calculation engine. The calculation engine will create an output file that will be interpreted to graphical results by the Thermo program. This program will be unique in that it is a simple interface program that is more realistic than any available program for simulating temperatures under a building's foundation. It is more realistic because it takes into account the material's properties during three phases; when frozen, during melting (heat of fusion), and unfrozen.

The databases are external so that they can be updated individually. The output text files can also be edited manually, although it is advised not to modify these without working knowledge of the calculation engine.

This program will also incorporate a number of different designs and options for those designs. Information will also be incorporated in the program on the long-term problems associated with the design, the historical costs (damage) and tips on how to improve the design from a building physical standpoint so that there is a decreased risk of common problems occurring. In the future, the program will also display LCC information in the form of the difference in values between a bad and good design. This information will also be stored in a database.

4 Methods

4.1 Literature Review

A number of methods have been applied to this project. As stated above, the first method, which will be applied throughout the entire project, is the literature study (initial results in Paper I). The literature study was performed to answer the questions:

- What aspect of building physics should be focused on in respect to the economic questions?
- What is potentially the most expensive failure that can be solved using building physics? Can this failure be studied within the specified time period? What are the alternative failures that can be studied?
- Has there been any work done previously relating economic issues to building physics aspects? Where? What were the results of the study?
- What tools are available to industry today? What are the properties of these tools? Does industry use these tools? Why or why not?

4.2 Case Study - Svedala

Papers II (a very short version of Paper III formatted for the Sustainable Building Conference in Oslo, Norway) and III used a case study in order to determine if current software could improve the design with minimal affect to the cost. Svedala was selected as the case study. This project had economic studies done in the past (Persson, 1999) and was praised for its high quality for low cost.

Drawings were acquired in order to study the technical details of the building from a building physics standpoint. Field tests consisted of temperature measurements using an infrared spot thermometer, temperature profiling using a thermal imaging system, and air leakage tests using air pressurization/depressurization. Of particular interest are the thermal bridges, the air tightness and ventilation rate. In every calculation and simulation, the real indoor and outdoor temperatures were used.

Energy use data (heating and hot water energy) and climate data for the previous year were obtained and the drawings were analysed using VIP+, ENORM, and HEAT2. VIP+ and ENORM simulations were run using the same specifications as the buildings and this data was compared to the real values. HEAT2 simulations were compared to thermal images. Once the simulation programs were fine-tuned, a number of parameters were changed in order to determine the energy savings that could have occurred. For a more detailed description of the method, see Paper III.

4.3 Interviews

Interviews with eight Engineering Consultants from various companies have been used during this project to answer some of the questions above that were not answerable using the literature studies (results in Paper IV). The interviews were designed around the following two themes using (Taylor & Bogdan, 1998) as a guide:

- Their perception of the building process.
- Their level of comfort and experience in working with building physics issues.

The methods used in the design of the interviews were based on a combination of open and closed (yes, no, specific alternatives) questions (Appendix II). The open questions were used for assessing key issues of the interviewees unbeknownst to them. For example, a respondent can be assessed on his or her familiarity with the latest information and technology without directly asking. Closed questions were used to categorise the different interviewees into predetermined categories.

In total eight consultants were interviewed in a time span of two weeks. Only a couple of consultants declined to be interviewed because they were too busy but were positive to the interviews and some even recommended alternative people to call. The majority of the people approached accepted the request. All the consultants answered all of our questions to our satisfaction.

After the 5th or 6th interview, answers were being repeated, resulting in almost no new information. It was decided after the eighth interview that it was not necessary to conduct any more interviews.

All interviews were recorded for further analysis and notes were taken during the interviews. Later, the minidisk recordings were transcribed to paper. The interviews ran from one to two hours depending on the respondent.

4.4 Archives

Paper V consisted of a review of archived documents from SSN (Småhusskadenämnden or National Organisation for Aid to Owners of Private Small Houses) located at the Department of Building Physics that were used in a previous study done by (Svensson, 1999). Of the total archived documents, there was sufficient data to review 188 different cases from all over Sweden. The information consisted of applications made for funding for moisture-damaged homes with crawlspace foundations. This study involved looking at the cost to repair the home to a satisfactory state and this cost was based on the lowest bid submitted by various construction companies. This cost was compared to the age of the house and its market value in a repaired state i.e. the price that the owner could sell the house for after the repairs were completed.

4.5 Future Methods

The hypothesis will be shown to be true or false in the remainder of the project by designing a toolbox for industry and then applying it in industry. This toolbox will contain a simple tool and a database of information. The participating companies will give feedback on the tool, and will also be asked to keep track of the money spent on using the software (i.e. the man-hours per project), the money saved from the project (i.e. less materials) and details around the impact of using the tool on each design it is applied to (i.e. was the design modified or changed in any way as a result of using the tool). The results of this will be analysed to determine if the hypotheses was true or false. In addition, the tool will be modified as per the industries recommendations.

5 Results and Discussion

5.1 Phase I

As seen in section 3 Structure of the Project, this entire project is divided into six phases. The first phase, the Identification Phase, began the project by identifying areas where building physics effects increased the foundation on which decisions during the building process were made. Since most of the building physics theories are related to the design phase, it was decided to focus this project on the design phase of the building. This also appears to be in agreement with the research community since almost all the tools based on building physics are for the design phase.

The next area that needed to be identified was what kinds of tools are currently on the market? What is the user profile? There are a lot of tools available. The problem is that the user profile is typically researchers and the software reflects this by having a steep learning curve. Basically, only researchers can operate this software, hence not a lot of programs are sold. To recoup some of the economic loss, the price of the program is set very high. These are deterrents for most small to mid-sized companies who neither have the funds, or personnel to use this software nor develop their own in-house software.

Taking this into account, it was decided that one method of determining the economic effects that building physics has on a building project is to build a useful, low-cost toolbox for consultants/architects and study the economic effect it has on the design and the company that decides to test it.

5.2 Phase II

The second phase, which will continue throughout the entire project, is the literature study. Papers I, III, IV and V reflect most of the progress in this area. The results of this phase so far are that there is not much information on the economic repercussions of building physics in regards to moisture damage, however there is some. This information is available through different sources such as SSN, SWECO and the various county environmental offices. There are a few other organisations that collect moisture damage data, however they do not have any costs documented. Appendix III (in Swedish) provides a more in-depth view of the available information in Sweden. The main problem with the

above organisations is that their data is not on computer. It requires many man-hours of work to search through all the paper files and transfer them to computer.

Paper I shows why it is important to consider building physics during the construction process. While there is not much literature directly relating building physics to economics, there is clearly a relationship when reading Paper I. Applying building physics theory in combination with today's knowledge of building materials can solve many of the health problems and prevent physical damages caused by mould in buildings already at the design phase of the project. One obvious question is: With all the documentation showing the problems caused by certain designs, why does the construction industry continue to produce these problematic buildings?

Paper IV provides insight into some of the possible answers. An interview with engineering consultants explored the question above and found that new knowledge is not being incorporated into the building process. Tools are not being used by the industry because they are too expensive, too difficult to use, require long learning times, and require too much time to execute. Some companies employ building physics experts, whose sole job is to keep up to date on the latest research and apply it to new designs. One problem is that most companies do not have these experts and instead rely on their civil engineers working on the project. These engineers admitted that they do not have the time to keep up to date with the progress in the field. One can see that there is a lack of a feedback loop in the system. That is, the consultants are not able to learn from experience. They are not usually informed if past solutions failed or functioned.

This was accentuated when analysing the interviews. It appears that the education of the consultant plays a larger role in their ability with respect to building physics when compared to their level of experience. Additionally, the person's confidence level when dealing with building physics issues was inversely related to their education level. In other words, the consultants with the lowest education level were confident that they knew how to deal with moisture problems, while the highly educated consultants were prone to consult with colleagues and, preferably, experts in the field before proposing their solution.

Papers II and III look at two apartments in Svedala. The results of this study show that these buildings function well from a building physics standpoint with the exception of the ventilation system. The system installed was an exhaust system and without increasing the LCC after 50 years, a supply and

exhaust system could have been installed. This would have solved the problems with the air quality and the draughts. Another possible effect could be a decreased use in the heating energy (the indoor temperatures were raised to compensate for the draughts),

Perhaps the largest limitation with this project lies with the economic data related to the type of building. When various companies were approached, (See Appendix III), many of the larger companies admitted to having information on what designs were problematic, however this information was deemed as confidential and could not be seen by anyone outside of the organisation. Other organisations had details on the types of damages, and the appropriate remediation needed, but they lacked any economic figures.

Many companies do not have any responsibility to the project after the typical two-year warranty is over. Health related issues are difficult to prove and quantify cost-wise, so it was decided to quantify the cost of repairing the physical damage to the structure. This is the cost that is usually paid by the client or owner of the building and this damage can occur well into the future during the operation phase of the building.

Paper V used data from one of the previously mentioned organisations. SSN is a Swedish organisation that was started in 1986 in order to assist people who have homes that are damaged by mould or moisture damage. SSN keeps every case documented in their archives and has done so since they began. The documentation includes the application for assistance, a technical review by a consultant, various bids from construction companies to repair the structure, the amount of money that the home owner is responsible to pay and the decision of SSN with regards to financial support for the repair costs. However, the data was very limited because of the limitations set by SSN as to what projects are eligible for assistance (Paper V).

The preliminary results from Paper V showed that the typical costs of repairs that occur from using a crawl-space design for a foundation is approximately 33% of the houses market value. There have been many studies in the past (Matilainen & Pasanen, 2002; Elmroth et al., 2002; Svensson, 2001) showing why the crawl-space design is a high-risk solution. One of the reasons why it is still used is that it is a cheap solution that allows easy access to the underneath of the structure.

5.3 Phase III

As mentioned in the Methods section, the project is currently in Phase III. This phase builds on the first two phases making use of the economic data collected thus far and incorporating it into one building physics tool. The tool being developed was requested by industry and it will be a basic tool that can calculate the temperature under the ground of various foundation types for different types of soils and climates. The reason for using this tool would be to optimise the amount of insulation under a building so that both frost damage can be avoided in the long term, and the floor can be as energy efficient as possible.

The concept of energy efficiency ideally wants as much insulation as possible under the foundation. However, the problem with this is that there needs to be a minimal amount of energy escaping under the building to prevent the water in the ground underneath the building from freezing. If it freezes, structural damage to the foundation can occur. The tool will also include a database informing the user of the potential problems with using the specified design; some estimated costs associated with future repairs and tips for preventing moisture problems for various designs.

6 Conclusions

There are economic incentives for the use of building physics for both builders and customers. However, the literature review showed that there is not a lot of data available relating economics and building physics. (Paper I) A study later revealed that some companies claim to have this type of information, however they are unwilling to release it for research purposes. (Appendix III)

Industry continues to produce problematic buildings, possibly because of the lack of a feedback loop in the building process. It can also be contributed to the client not willing to pay the extra amount to have this work done or the client assumes that this type of work is included in the price, not being informed otherwise by the consultant. (Paper IV)

One example of choosing the cheaper alternative was in regards to the type of ventilation system selected for apartments in Svedala. The cheaper system was installed in the apartments and the result has been unsatisfied tenants who complain of, amongst other things, cold drafts. An LCC analyses showed that after 50 years of operation, the more expensive system would have cost the same amount as the cheap system, and would have prevented the cold drafts, amongst other things. (Paper II; Paper III)

The interviews conducted during this project have confirmed that the situation regarding the use of computer based design tools in Sweden is no different than in other parts of the world. There are lots of tools available, i.e. energy simulations and thermal transfer programs, that are not used because they are too expensive, too difficult to use with long learning curves, and require too much time to use. This indicates the need for simplified, low cost and fast tools in the industry that take into account building physics and economics. (Paper IV)

7 Future research

In the next half of the project, more economic data for the database/LCC model will be collected from numerous sources. The computer tool currently under development will be completed and trial runs with a number of companies will be undertaken. Data from the trial runs (See section 4.0 Methods) will be collected and analysed in order to determine the economic load and whether or not the tool influenced the design. This will be compared to the potential damage that may have incurred if the design was not modified.

A future development for the tool is the addition of moisture calculations. This will allow designers to quickly simulate if their design is sound from a moisture transfer dimension.

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9.1 Paper I

Burke, S. (2003). Reducing the Risk of Failure in Performance within Buildings. In: ed. Atkin, B., Borgbrant, J., Josephson, P-E., *Construction Process Improvement*, Oxford: Blackwell Science

Reducing the Risk of Failure in Performance within Buildings

Stephen Burke

Introduction

Building failures occur daily because of misunderstandings over the importance of building physics, especially among the different actors in the construction process, each of whom may have a different appreciation of causes and effects. Legislation, which has been passed to ensure the health and safety of the occupants, has addressed some of the larger performance issues such as thermal comfort, energy usage and, to some extent, indoor air quality. However, other types of building failure continue to be ignored. These are the longer-term soft issues such as high moisture content in a building, high-energy costs and the overall sustainability of the building.

These types of building failures are believed to be linked to health problems and are largely preventable with today's knowledge of building physics. This chapter looks at current building failures directly attributable to the neglect of building physics principles, and why it is important to include these factors actively in design decision-making.

State-of-the-art review

Building physics is comprised of many various components. This section will look at these components, the role that economics plays and the effects that building failures have on people's health.

Building physics

Building physics is the science of how matter and energy interact within a building system. More specifically, this field encompasses the areas of heat, air (ventilation), moisture flows and the energy interactions between all of them.

It is important to note that the Swedish context of building physics does not include acoustics and fire protection as in other countries (Sandin 1990). This area of science exists to ensure that people have an area to live in that provides thermal comfort and does not cause health problems. Many health issues arise when fundamental physical principles are overlooked or ignored and this can translate into higher costs for society as a whole.

The literature related to economic aspects of building physics is negligible. Jóhannesson & Levin (1998) attempted to examine these two areas concurrently in their paper by looking at the relationship between design that neglects common theories of building physics and the consequent environmental and economic cost. In their paper, a typical Swedish single-family dwelling was examined under two scenarios: one without any special environmentally friendly materials or features, and the other incorporating materials that are considered to be environmentally friendly by

current standards. The authors focused on the performance of available environmentally superior materials when considered in a life cycle cost (LCC) context and found many to be inferior. Using more environmentally friendly materials did yield lower energy use and costs for construction. Over the operational life, the difference in performance between the two buildings was great enough for the environmentally friendlier building to be more energy-intensive over its life than the standard building. The weakness in this paper, as declared by the authors, is that it does not look at the economic repercussions of either including or excluding building physics issues in themselves; but it is able to give an idea of the result of ignoring building physics principles.

It appears that most of the literature that is related to building physics looks at building physics in its various components and does not bring economic factors into view. The literature generally considers potential problems that a building can have from a health perspective and tries to attribute the problem to one or two faulty components in the building and their possible remedy.

Heat flows

Heat flow principles are the backbone of modern, energy-efficient buildings. In order to make a building use less energy for heating and cooling, walls are insulated with materials that minimise the heat flow between the inside and outside of a building. Another benefit of an energy-efficient building is the level of thermal comfort that people feel in the building. People are very sensitive to temperature changes and even a small heat loss is detectable. Thermal comfort is not, however, determined by temperature difference alone; moisture levels and air pressure can also have an effect on people's thermal comfort.

With energy-efficient buildings come new problems in the areas of moisture and ventilation. While heat flows are in themselves largely understood, the repercussions of energy-efficient buildings on moisture levels and health are not. As a building's energy efficiency increases, so does its potential for moisture and ventilation problems if it is not designed properly (Thörn 1999). The design, construction, materials and workmanship of the smaller components of a building become more important and can make a significant difference in building performance. For example, reducing the thermal bridging in a typical Canadian timber-framed wall by applying an exterior insulated sheathing yields a 12% gain in efficiency (Ministry of Housing 1990).

Europe is currently trying to find away of encouraging people to build more energy-efficient homes. One means of accomplishing this is by creating an 'energy certification ...[offering] advice for new and existing buildings and a public display of certificates in certain cases' (ECCP 2001).

In addition to this, new and newly renovated buildings will have to meet a minimum standard of energy performance, and this will be measured by a standardised measuring system. This should force designers and construction companies to increase their level of performance, resulting in higher quality buildings than we have today.

The United States has also initiated a similar programme called High-Performance Commercial Buildings: A Technology Roadmap. 'The fundamental goal is to optimise the building's performance in terms of comfort, functionality, energy efficiency, resource efficiency, economic return, and life-cycle value' (Swartz 2001).

This plan will be executed over the next 20 years and will involve the US Department of Energy (DOE) and its partners in both the public and private sectors.

It is becoming more common today for researchers to combine heat and moisture flows in their research areas and attempt to answer the questions of what effects heat flows in buildings have on moisture flows and ventilation requirements (Samuelson 1998). The theory behind moisture and heat flows are very similar, but there is one important factor that makes moisture calculations much more complex than heat flows. The difference is that when heat flows are calculated, the materials are assumed to be dry and the effects of thermal conductivity are negligible. Calculations are therefore based on a constant temperature and moisture state. Yet, moisture properties are very sensitive to changes in both temperature (the vapour permeability is temperature dependent) and moisture state. One cannot assume a constant temperature or moisture state when calculating moisture flows. In addition, other factors such as the material's properties and air velocity can have effects on the flows. A careful balancing act is required to obtain buildings that are both energy - efficient and healthy for its occupants (Sandin 1990).

Computer software is available for calculating heat flows in buildings. Most of these are specific programs designed to calculate the heat flows of various components like attics, crawl spaces and walls. Some of the software such as *MOIST*, *HEAT2* and *HEAT3* look at the one, two and three-dimensional steady state of a design respectively. The user is able to improve the heat resistance of the design by changing both the design and materials used in the simulation in order to decrease the amount of heat energy lost from the building. The main concern with current software that is available today is that it is difficult to use (Blomberg 2000; Burch & Chi 1997).

There are also many computer programs available for calculating the energy usage of a building. These programs usually take into account the weather, type of windows, type of walls, and other specific details of a building. Each program usually has a feature that sets it apart from others. For example, *ENERGY-10* can include passive solar heating, glazing and thermal mass in the design phase (*EREC* 2000). *NHER Evaluator* also calculates energy usage; however, it has the option of calculating surface condensation and the effects of cold snaps (*NES* 2000). Using software of this sort enables users to test alternative materials and designs in order to optimise their building's energy usage.

Air flows

Ventilation is the link between the indoor air and outdoor air of a building. With proper ventilation, a building has a readily available supply of fresh air that keeps the interior thermal environment comfortable and moisture levels under control. As buildings become more energy-efficient, they are required to be more airtight. This places more importance on a properly designed and balanced ventilation system. Without properly designed ventilation systems, buildings can rapidly become odorous and unhealthy to the occupants, because of a build-up of chemicals, moisture and organic compounds. In recent years there have been many studies looking at the relationship between indoor air quality and ventilation rates. The consensus is that, up to a certain point, the lower the ventilation rate, the worse the indoor air quality (Fisk 2000; Sundell 2000; Wargocki *et al.* 2000; Apte *et al.* 2000; Milton *et al.* 2000). For a more detailed examination of the importance of ventilation systems, see Chapter 5 (*A life cycle cost approach to optimising in door climate systems*).

Moisture flows

Moisture and its effects on a building is a common topic of discussion within the building physics field today (Luthander 2001; Samuelsson 2001). The topic is, however, very complex and covers many areas of science.

If we want to understand fully the problems caused by moisture we must look to various disciplines in the scientific community. They include medical doctors and researchers, microbiologists, biologists, physicists, chemists and engineers. By taking a multidisciplinary approach, we can begin to understand the nature of the problems associated with moisture in buildings and how to prevent them (Wolkoff *et al.* 1997; Sundell 2000).

Three methods of transportation that enable moisture to come into contact with materials are convection, diffusion and capillary action. Convection processes involve moving air that picks up and deposits moisture on the surface of materials. Diffusion of moisture through the air contributes less moisture to a material than convection, due to the volume of moist air that is exposed to the surface of the materials. Capillary action mostly takes place underground, when groundwater is drawn into the materials (Sundell 2000; Nevander & Elmarsson 1994).

There are many different paths for moisture to enter a building and these can appear during any of the different stages in the construction process. Before the construction phase, some of the materials can be shipped wet to the job site. For whatever reason, these materials are not allowed to dry properly or they are exposed to water in storage or during transportation. Even if materials are shipped dry, they sometimes become wet at the job site due to improper storage. If materials are stored properly, i.e. stored indoors or covered up, the risk of a building becoming damaged due to moisture can be significantly reduced (Sundell 2000; Nevander & Elmarsson 1994).

After the building is complete, there is still a risk of damage from both the indoor and outdoor environments. Figure 7.1 shows some of the possible damages that can occur when different materials are exposed to various levels of moisture. The majority of moisture damage begins once the relative humidity has reached a level of around 75%. This shows the importance of proper ventilation and indoor climate control. Indoors, people contribute to the moisture level by physically sweating, cooking food, taking showers etc. In other buildings such as paper mills, swimming pools, and other facilities that use a lot of water, there is a very high risk of moisture damage due to condensation (Sundell 2000; Nevander & Elmarsson 1994).

The greatest outdoor risk to a completed building is the weather. Rain, snow and humid air can result in exposed materials becoming very moist. In addition, leaks in the vapour barrier and in the roof can allow moisture to come into contact and contaminate various materials.

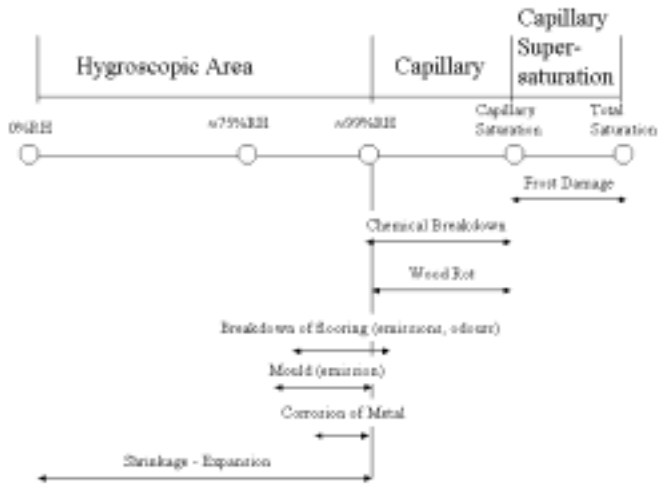


Fig. 7.1 The effects of Relative Humidity (RH) on different building components (based on ideas, contributed during a discussion, by Professor Göran Fagerlund, Lund Institute of Technology, Lund, Sweden).

Despite the availability of this knowledge, the same problems continue to occur. A recent, large-scale housing project (Hammarby Sjöstad in Stockholm) that was designed according to environmentally friendly principles became a focus for the mass media when moisture problems developed in some near finished apartments. The problem was attributed -though not proven -to an unusually moist summer during the on-site production phase. The materials were not protected adequately from the moisture and in turn became wet. Not long after the heating system was activated, mould began to grow on the materials, contaminating a number of the apartments (Luthander 2001). Problems of this nature are not limited to Sweden; Denmark, the UK and many other countries are seeing an increase in moisture-related problems. These projects illustrate that even well designed, environmentally friendly buildings can have moisture problems due to a combination of weather, materials and, increasingly, the on-site production process.

Computer programs that attempt to predict the likelihood of moisture penetration are increasing in number. However, they are few in comparison to heat modelling programs due to the complexity of moisture flow. In order to develop a reliable moisture model, an accurate temperature model must be used. Some software exists today: *WUFI* from Germany is able to calculate both heat and moisture flows in a one- or two-dimensional scale using different materials (Gertis 2000). *RISK1* from Sweden is a one-dimensional program that calculates the risk of moisture damage to a building depending on its geographic location (Harderup 1999); and *MOIST* from the US is a one-dimensional heat and moisture calculation program (Burch & Chi 1997).

Economic aspects

Failure in the performance of buildings results directly in financial loss for owners, occupants and other stakeholders each year. According to Fisk (2000), in the US, the estimated potential annual savings and productivity gains are US\$ 6-14 billion from reduced respiratory disease, US\$ 2-4 billion from reduced allergies and asthma, US\$10-30 billion from reduced sick building syndrome symptoms, and US\$ 20-160 billion from direct improvements in worker performance that are unrelated to health. In Sweden, about SEK 6 billion (€665 million) per year is spent on repairs and maintenance. Of that, roughly half goes to damages attributed to moisture damage (Tolstoy 1994).

Today, the average Swedish household can expect to pay SEK 200 000 - 300 000 (€22 000-33 000) to repair its moisture-damaged home. These costs do not include health care costs associated with asthma, multiple chemical sensitivity, sick building syndrome and reduced productivity, all of which can be caused by a building with poor performance. While it is debatable whether some of these illnesses can be attributed to physical or psychological causes, it remains the case that people suffer from symptoms caused by inadequate buildings (Willers *et al.* 1996; Wolkoff *et al.* 1997; Arnetz 1999; Terr 2000; Apte *et al.* 2000; Milton *et al.* 2000; Wargo *et al.* 2000).

It is rare for construction companies -house builders in particular- to calculate and show their customers the long-term operating costs and likely problems associated with a specific design. Barrett & Stanley (1999) touch on the issue of customer empowerment, arguing that the construction sector should empower its customers and should enable them to become more acutely aware of the details of their project (or home). This could be interpreted as arguing the case for greater awareness on the part of customers. If customers are insufficiently experienced to address certain issues of the construction process, the sector should provide information to enable them to fulfil their role as informed (or intelligent) clients. This information could be in the form of possible and known design issues, estimated operating costs such as energy usage over the lifetime of the building, maintenance costs or the overall sustainability of the building (Barrett & Stanley 1999).

When a building is found to malfunction, the materials of its composition are among the first items to be investigated. The decision to use one material over another is usually more of an economic issue than one of performance. An exception to this is if a more expensive material is chosen for its environmental properties. However, this does not mean that the material is superior physically. Usually, greater emphasis is placed upon materials that are cheap and that will perform to the minimum performance required by legislation and building codes. This helps to keep the cost of the building down, which is an advantage to both the construction sector as well as the economy.

Recognising that the lowest bid does not always represent the most economically advantageous solution is a widely held view. Some countries have adopted other methods such as eliminating the highest and lowest bids and accepting the bid closest to the average (Hatush & Skitmore 1998). While this method can help to reduce short-term building failures by allowing companies with better quality control over workmanship to be awarded contracts, this does not guarantee that long-term building failures will be avoided. The operating costs of a high-quality building can still be high due to inadequate measures regarding energy use. However, companies

can reduce the risk of both short and long-term problems and energy costs by addressing aspects of building physics early in the construction process.

Research project

Project description and objectives

The aim of this project is to determine and develop tools that could be used to include aspects of building physics in the design stage of buildings, by highlighting some of the economic benefits. This project will entail the identification of building physics areas having the largest potential impact on the decision-making process, the design of a tools package for use in the sector, the testing of this package by companies and the analysis of results. The main objective of this project is complementary to other projects discussed in this book. The concept behind this particular project is that by improving the quality of new buildings, the construction sector will gain techniques and knowledge that will make it more competitive on both the national and international level.

Research methodology

This project makes use of qualitative and quantitative methods. In the early days of this project, a literature study was conducted in order to determine the areas where the building physics tools package would have the most beneficial impact on the construction sector. This will be continued during the entire project. A problem with literature surveys is that they do not indicate the kinds of tools the sector might be interested in deploying.

Interviews and surveys are methods of enquiry that could be used to help in defining such tools. These methods would be more reliable than a literature study; however, such methods can be problematic, not least because of the difficulty of establishing a representative sample. That said, it is recognised that commercial exploitation of the results of the research would most probably require sampling of the population.

Participant observation is an alternative method that could be used to record a construction company's activities and enable a tools package to be designed to fit those activities. However, this was not considered to be an appropriate method, because of the amount of time required to conduct observations.

Once a tool is designed and developed, a few methods are available for analysis and verification. The primary method under consideration is a detailed case study of one company to determine what effects the tool has had on the company's decision-making process when planning a building. An alternative is to use the tool with a number of different companies and create examples that are less detailed, but perhaps more representative of the construction sector than a single case study. A later phase in the research may, therefore, include a set of case studies in which specific experiences of using the tools package might be investigated.

Research results and industrial impact

Quantification of results

In this project, we expect to see that the cost of actively incorporating building physics principles into the design phase of a building is demonstrably less than the potential consequences of not including them. Up to now, the literature suggests that there are large potential cost savings from integrating building physics principles into design decision-making. The literature also suggests that these savings should come primarily from reduced renovation costs, increased energy efficiency of the building during occupation, increased performance from workers and decreased sick leave/health care costs.

Implementation and exploitation

Discussions will take place with related projects under *Competitive Building*, with a view to having the resultant tool utilised in practice -see also Chapter 6. The aim will be to help designers achieve greater energy efficiency and avoid, or at least reduce substantially, moisture problems. A tools package of this nature could also increase the competitiveness level of Swedish construction companies on both the national and international level.

The incentive for utilising the tools package in routine design is to cut ownership costs for the customer (and taxpayers) by reducing the amount of repairs arising from moisture problems and health problems associated with the occupation of buildings. If customers were made aware of the tools available to designers and construction companies, they might force their use through demands for better information. There is also the health dimension. Operatives who feel healthier are more productive; even a small increase in productivity can translate into worthwhile profits for a company. In addition, by ensuring a high level of healthiness, the amount of health care resources needed may be reduced.

Conclusions

Today, a considerable amount of money is being spent on repairing buildings damaged by moisture, treating people who have become ill in their home or work environment and paying unnecessarily high energy bills. For the most part, technology exists to reduce these costs dramatically; however, the construction sector is generally not motivated to utilise the available information.

Building physics has the potential for builders to generate and for customers to save large sums of money each year. Easy-to-use tools for the sector are needed to highlight the economic benefit of key decision-making during design. This would help to create a smoother transition to designing better buildings than the present state of affairs.

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9.2 Paper II

Paper II

Burke, S., Johansson, D. & Öberg, M. (2002). Decreasing a Buildings Operational Energy Costs through the Application of Building Physics Principles During the Design Phase. In: Sustainable Building Conference Proceedings, 2002,Oslo, Norway

Decreasing a Buildings Operational Energy Costs through the Application of Building Physics Principles During the Design Phase

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1. INTRODUCTION

Energy use in the building sector represents approximately 40% of the total energy use within the EU (Sjöström, 2000). The predominant part of this is related to the operational phase of a building project. The implications regarding the environment in addition to the economy, have led to an increased interest for energy conservation in buildings during all phases of their lives.

Building physics plays a key role in the design of energy efficient buildings. It is not always considered during the design of a building, yet it influences the energy use and thermal climate of a building over its entire life. Disregarding these principles can result in superfluous operational costs and environmental impacts.

This paper reports on an examination of a multi-family dwelling, built in 1998, located in Svedala, southern Sweden regarding building physics, indoor climate and energy performance. The objectives are to point out potential improvements and the resulting economic issues for this specific building and report the actual energy data and software for energy balance calculations.

2. METHOD

A modern, multi-family dwelling, layout shown in Fig. 1, was selected for this study. There is no basement or attic, no internal staircase or common heated areas in this building. The simplicity of this design was thought to make the energy calculations more precise by decreasing the uncertainty and the number of parameters. It is one of nine identical buildings located in the same area of Svedala. The typical outdoor temperature varies between -1 and 16 °C on average during the year and the difference between day-time and night-time is about 6 °C.

The construction consists of a traditional slab block frame of concrete cast *in situ* on prefabricated floor slabs with a brick clad, wooden joist curtain wall façade. The roof is a light structure of gypsum boards and mineral wool carried by timber trusses. The window area is 80%

on one length, 20% on the other with no windows on the gables. The particular building analysed in this paper has its 80% window area facing the north. The heat and hot tap water are supplied by way of hot water radiators. One exhaust condensing natural gas boiler located centrally in the building heats the water. A mechanical exhaust ventilation system removes air from the kitchens and washrooms. The intake is a simple slot in the wall located above each window. Each building contains eight apartments comprising a total of 520 m².

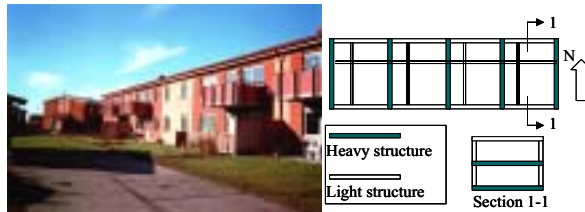


Figure 1 Multi-dwelling building Erlandsdal 1B in Svedala. Exterior (Facade), principal plan and section

Two apartments in the examined building were chosen for thermal imaging, air tightness testing and air flow rate metering. Apartment one is located on the second floor close to the outdoor roof and the gable of the building. Apartment two is located on the bottom floor in the centre of the building. The specific apartments were chosen due to the availability of the inhabitants during the time of the measurements.

The air tightness of the apartments was measured according to the Swedish standard SS 02 15 51 (SIS, Swedish Standards Institution) using a Minneapolis Blower Door, Model 3 outfitted with a C-Ring. The ventilation rates were measured according to the manufacturer's instructions for the Mätstos funnel and VelociCalc model 8355 air velocity meter apparatus. The thermal imaging was conducted using an Agema Thermovision 900, liquid nitrogen cooled thermal camera coupled to an Agema computer system. A Raytek Raynger MX4 advanced infrared thermometer was used to measure additional surface temperatures during the period the measurements were being taken. Glaser calculations were completed as outlined in Harderup (2000, 36-38) and the software package Heat2 (Blomberg, 2000) was used to analyse specific details of the drawings to determine the theoretical indoor wall surface temperatures, the effects of thermal bridging, and other possible design problems. The input boundaries for Heat2 were based on the outdoor and indoor temperatures measured on the day that the measurements were taken.

The actual use of energy for space heating and hot tap water as well as the electricity used for common areas over two one-year periods (2000 and 2001) were collected from the owner of the building, AB Svedalahem. Household electricity use for the year 2000 was obtained from the supplier, Sydkraft AB. The electricity readings were for the entire year, however the natural gas readings were available for each month. When the building was simulated, the different kinds of energy needed to be known.

Energy balance calculations were performed with two different software packages. They were 'VIP+' (Skanska IT-Solutions, 1996) and 'ENORM' (Svensk Byggtjänst). The advantages with VIP+ are one-hour time step simulations, modeling of air infiltration, solar gains and the influence of thermal capacity. The advantages with ENORM are its simplicity and that it is commonly used in Sweden. Input data regarding the technical characteristics were gathered from the construction documents and from field measurements. Data on internal gains from people and indoor temperature were estimated on the basis of the number of inhabitants. Internal gain from electricity was adjusted to the electricity bought by the households.

Parametric studies on the consequences concerning energy use and indoor climate were related to alternative designs concerning ventilation systems, the thermal capacity, air tightness, windows and the direction of the building. These simulations were performed with the energy balance programmes VIP+ and ENORM. Related impacts regarding life cycle economy were examined with Life Cycle Cost calculations where the present value method was used.

3. RESULTS AND DISCUSSION

3.1 Ventilation system

The results from a survey completed earlier indicated that the ventilation system was a weak point in these buildings. With regards to perceived indoor air quality and health related issues, the building and its services appear to be functioning well. However, cold air from the intakes above the windows generates dissatisfaction with the thermal comfort, especially during the winter. In several cases, the tenants have blocked the air intakes to counter this effect. This may result in creating a vacuum effect in the apartments, which in-turn explains why smells from the neighbours cooking are noticeable.

The ventilation rates were measured in the kitchen and washroom of both apartments. The initial flows set by Svedalahem for the kitchen and washroom were 10 L/s and 15 L/s respectively. These rates also conform to the minimum rates required for these rooms as set in the Swedish building regulations (Boverket, 1998). In apartment one, the measured flows were 6.3 L/s and 12.2 L/s for the kitchen and washroom respectively. In apartment two they were 9.3 L/s and 9.0 L/s respectively. These measurements follow Engdahl (1997), which shows that most ventilation systems in flats are quickly thrown out of calibration shortly after installation. In both instances, the flow rates are lower than the minimum required by law.

A parametric study was completed to show the influence in the Life cycle cost (LCC) if the system were a supply and exhaust system with a heat recovery unit. The initial cost would be three times the real cost, the maintenance cost would be higher but the energy use would be lower resulting in an equal LCC after 50 years. The LCC would be about 2040 SEK/m². The real rate of interest was 2% for energy and 3% for the rest. The heating cost was 0.46 SEK/kWh and the electricity cost was 0.65 SEK/kWh. Despite equal LCC, the indoor climate would be better.

3.2 Apartment air tightness

The air tightness in apartment one was measured to be 0.39 l/(s·m²) and apartment two was 0.22 l/(s·m²). Swedish building regulations require that the air leakage from a building must be under

0.8 l/(s·m²) therefore both flats are good in regards to air tightness. Apartment one seems to be normal however apartment two seems to have a very low number. This could be attributed to the fact that apartment one is located on the top floor and has a wood-framed ceiling, two wood-framed external walls and two concrete walls, only one of which is an exterior wall, and a concrete floor that has a heated flat under it. Apartment two, which is on the bottom floor, consists of only two wood-framed external walls, concrete walls towards neighbouring flats, a concrete ceiling and a concrete floor (insulated slab on ground).

If the tightness were increased, the energy balance with an exhaust system would not be affected as air leaks only substitute air through air intakes. With a supply and exhaust system with a heat recovery unit, a completely tight building would decrease the annual energy use with 3.5 kWh/m² compared to the average measured tightness and 6.2 kWh/m² compared to the regulated value.

3.3 Surface temperature aspects

With Heat2, the wood framed wall including the foundation and soil under the building was simulated in a steady-state environment using the actual temperature readings obtained in the field. This simulation showed the theoretical temperatures based entirely on the design of the walls, while the thermal camera showed the real temperature profiles. In this case the calculated values were accurate to within +3°C of the measured values. This difference can be attributed to workmanship since the computer software calculates based on a perfect fitting structure.

3.4 Actual energy use versus calculated

Electricity bought by the eight households totalled 13914 kWh, which corresponds to 26.7 kWh/m². The gain of energy from the 16 people living in the building was calculated by assuming 80 W per person of released energy and that half of their time is spent inside the apartment, which gives 1.23 W/m². Common electricity used for the block corresponds to 2.5 kWh/m² and does not contribute to the energy balance as the related heat is released outside of the climate shell. Ventilation rates used in the calculations were 25 l/(s·flat) based on the final inspection rate. Figure 2 shows the annual energy use for the building.

Actual energy use for space heating and tap water heating in the actual building for 2000 and 2001 was 145 kWh/m² and 151 kWh/m². This is a bit higher than the average energy use 140 kWh/m², for new multi-dwelling buildings according to 'Miljövärdsberedningen' (2000). The use of electricity, 26.7 + 2.5 = 29.3 kWh/m² is a bit lower than the average 35 kWh/m² (Ibid). The energy use for space heating and tap water heating for the neighbouring houses were lower eventually because of a lower demand for hot tap water. The year 2001 had 12% more degree hours than 2000, which explains the difference in radiator heating need between the measured building and the calculated building.

If the need for radiator heating in the summer is zero, all the energy for June, July and August must go to heating the tap water. With that assumption, the tap water energy demand for year 2000 should be 95 kWh/m² and for 2001, 77 kWh/m², which are high values. The Trelleborg project (Johansson and Johansson, 1999) indicated 36 kWh/m² and the ENORM default value gives 46 kWh/m². More research is needed to find the reasons behind the high summer energy use. Possible ways could be to compare cold-water use for the different houses or to make gas

readings every hour and check the night consumption to point out possible leaks and extraordinary behaviour.

The calculated energy use depends a lot on the need for hot tap water. In this case, the energy need for hot water was unknown. Therefore, the agreement between the actual readings and the calculations do not coincide. If the energy need for hot water was changed to the actual summer values, the calculations would agree better with the actual readings. The energy use for different kinds of energy is shown in Fig. 2 for the actual house as well as the calculated alternatives.

VIP+ is a more detailed software than ENORM thus also requiring some more input data. ENORM gives valid results for dwellings if the input data are plausible but any modelling of building physical aspects such as solar gains, thermal mass and air tightness is not possible.

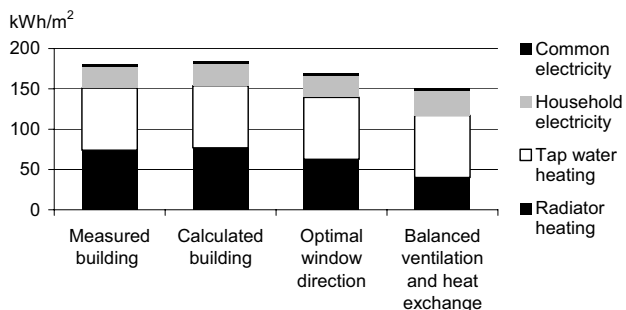


Figure 2 Total energy use 2001 for the examined building in Svedala. The tap water heating is estimated from the summer energy use for the actual measured building. The measured value of 2000 was used for household electricity as the value for 2001 could not be obtained.

3.5 Orientation of the building – solar gains – thermal capacity

The orientation of the windows of the original building is 80% to the North and 20% to the South. If the building is rotated 180° the required space heating is reduced by 13.4 kWh/m². The original building can be defined as a semi heavy structure with regard to active heat capacity. Parametric studies were conducted for also for a light and a heavy type of structure. With the original orientation of windows the annual difference between light and heavy structure is 2.8 kWh/m² and with the opposite orientation with more free excess energy from solar radiation the difference is 4.7 kWh/m² corresponding to 1.3 and 2.2 SEK/m², year.

Parametric studies on thermal mass, air tightness and orientation of windows indicate effects on annual energy cost of 1-6 SEK/m². These differences are rather small looking at the total annual costs but in the life cycle perspective they correspond to a present value of 30-170 SEK/m² and should thus be taken into account by the choice of design solutions.

4. CONCLUSIONS

The project in the case study in Svedala functions well except for the ventilation system that could have been a supply and extract system without increasing the life cycle cost. This would have benefited the energy use, the life cycle cost and the indoor thermal comfort. The problems with air quality and draught spotted in the questionnaire could have been solved by a supply and exhaust ventilation system. Maybe the indoor temperature could have been decreased with less heating need as a result. The air tightness of the building shell influences the energy use in buildings with balanced ventilation but not with mechanical exhaust ventilation. The building is tight compared to the regulations.

The building physics tools used in this study correlated well with each other and the simulation software indicated where there could be potential problems. A couple of measurements matched those of the calculated values, however most measured values fell a couple of degrees below the theoretical values. The tools also gave indications of areas that could be improved such as the ventilation air intake, and the effect of different ventilation systems on the life cycle cost however, the life cycle cost was not significantly reduced with a more complex system.

One problem with examining a house is the lack of models for user behaviour and a lack of measurements to split different energies and grounds for energy use. Measurements also need to be made with a smaller time interval.

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9.3 Paper III

Paper III

Burke, S., Johansson, D. & Öberg, M. (2002). Examination of operational energy use and physical function by utilizing building physics tools. In: Energi- och resurshushållning I bebyggelse, Department of Building Physics, Lund University, Report #TVBH-7721

EXAMINATION OF OPERATIONAL ENERGY USE AND PHYSICAL FUNCTION BY UTILIZING BUILDING PHYSICS TOOLS

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INTRODUCTION

The building sector represents approximately 40% of the total energy use within the EU (Sjöström, 2000). The predominant part of this is related to the operational phase of construction projects. The implications regarding the environment, as well as the economy, have led to increased interest for energy conservation in buildings during all phases over the lifetime of the building.

Building physics can be defined as the physics for a building or the built environment regarding energy, moisture and ventilation. It is a key factor regarding energy use and energy efficiency, however it is not always adequately considered in the design of conventional buildings. This results in superfluous operational costs and environmental impacts. Furthermore, building physics aspects are of particular importance in the areas of indoor climate and thermal comfort, which are the underlying issues in this project.

This paper reports on an examination of a multi family dwelling built 1998 located in Svedala in southern Sweden. The goal with calculating the energy use for a building during the design phase is to predict the actual values for after the house is built. To be able to make good predictions, it must be possible to categorise the different kinds of energy used as well as different household behaviour and their influences on the total energy use. The energy use for this building was measured and compared to simulations conducted with two different software packages, thermal imaging, ventilation flow rates and air tightness measurements.

The thermal indoor climate was examined to explore the indoor climate problems that occur to the people living in the houses. People, especially in colder climates, spend a great deal of time indoors, thus making a good indoor climate very important. It is economically and environmentally desirable to have a good indoor climate that is correlated to lower energy use and lower environmental impact. The thermal environment can be affected in a couple of ways during the building process. One way is by an inferior design. A design with a lot of thermal bridging or drafts can be cold, and will not be comfortable to the occupants. Equally

important is the quality or craftsmanship of the construction workers. This factor can turn a good design into a poor building. In theory, a building's best performance is limited by its design; a building's actual performance is limited by its construction crew.

Aim of the study

The aim of this study is to indicate areas where the design of the building could be improved from the building physical perspective and to evaluate the impact concerning the risk of moisture damage, energy use, indoor climate and whole life cost. This paper also compares two of the available software packages and examines the applicability regarding different aspects of building physics.

METHOD

Using a case study, current building technology is analysed with regards to building physics, indoor climate and energy performance. Potential improvements and their economic and environmental consequences are examined using parametric studies. The studied building is located in Svedala in South Sweden (N55°31'14", E13°13'31").

Description of the case — the building and its services

A modern multi-family dwelling, layout shown in Fig. 1, was selected for the study. There is no basement or attic and no internal staircases or other common heated areas. The simplicity of the design should make it easier to perform energy calculations and decrease the uncertainty and number of unknown parameters. The building was completed in 1998 and is one of nine identical buildings located in the same area in Svedala. It has a traditional slab block frame of cast *in situ* concrete on prefabricated floor slabs with a brick clad wooden joist curtain wall façade. The roof is a light structure of gypsum board and mineral wool carried by timber trusses. The window area is distributed with 80% to one of the long sides and 20% to the other and no windows on the gables. The particular building analysed has the 'window side', shown in Fig. 1, facing north. Hot water radiators are used to supply space heating from one natural gas boiler, which also furnishes hot tap water and is located centrally in each building. The gas boiler is exhaust condensing with an efficiency level well above 100% based on the lower heat value, but the efficiency is estimated to 100% due to losses in the distribution system. A mechanical exhaust ventilation system (F-system) evacuates air from kitchens and bathrooms and provides fresh air via simple air intakes above the windows. Each building contains eight apartments comprising a total of 520 m². The building and the alternative technical solutions covered by the parametric study are described in detail in Appendix A.

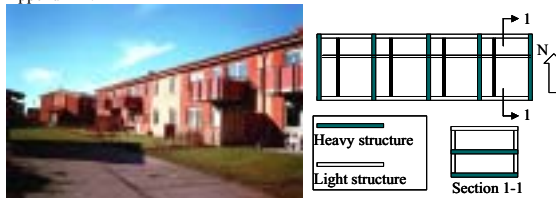


Figure 1: Multi-dwelling building Erlandsdal 1B in Svedala. Exterior (Facade), principle plan and section.

The typical frequency of the temperature in Svedala is shown in Fig 2. Temperature measurements for the years 2000 and 2001, which are the years of the measured energy use, were used in the software calculations. The temperature data were measured in Lund, which is 20 km north-west from Svedala, but the climate is estimated to be the same.

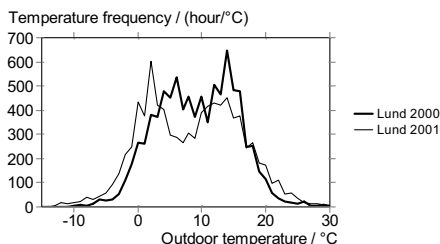


Figure 2: The temperature frequency for Lund in 2000 and 2001, which is representative of Svedala (SMHI, 2002). The average outdoor temperature (8.4 °C) for 2001 is almost the same as the average temperature for the period of 1991 to 2001. Older data from 1973 to 1990 show lower average temperatures (7.1 °C) for Sturup, (Harderup, 1995) which is close to Svedala and Lund but appears to have a slightly colder climate.

Description of the neighbouring buildings

Of the other eight buildings identical to the studied building, monthly gas readings were available for the two closest to the examined building. The only difference is the direction of the facades of the buildings. These two buildings are labelled Neighbouring house 1 with the majority of the windows directed towards the Northwest and Neighbouring house 2 with the majority of the windows directed towards the West. The energy use for these two buildings was compared to the software calculations and the studied building.

Analyses methods used

The normal indoor temperature as well as perceived indoor climate was derived from a standard questionnaire; 'Stockholmsenkäten' (Engvall and Norrby, 1992) that was handed out and analysed during spring 2001. Any problems indicated by the questionnaire were, if possible, explained through the analysis of the building and the technical service systems. The result of the questionnaire was presented as profiles of complaints covering the indoor temperature, ventilation, acoustics, light and health. The reference is a survey of 14235 households in Stockholm.

The technical details regarding building physics were explored by studying the construction drawings and conducting field tests consisting of temperature measurements using an infrared spot thermometer, temperature profiling using a thermal imaging system and the rate of air leakage using air pressurisation tests. Of particular interest are the occurrence of heat bridges, the air tightness and the ventilation rate. The results of this analysis are the consequence of the design as well as the buildings production. In every calculation or simulation the actual temperature according to the questionnaire (22 °C) was used.

Two apartments in the examined building were chosen for thermal imaging, air tightness testing and flow rate metering. Apartment one is located on the second floor close to the outdoor roof and the gable of the building. Apartment two is located on the bottom floor in the centre of the building. The specific apartments were chosen due to the availability of the inhabitants during the time of the measurements and not because of the level of complaints from the residents in these apartments.

The air tightness of the apartments was measured according to the Swedish standard SS 02 15 51 (SIS, Swedish Standards Institution) using a Minneapolis Blower Door, Model 3 outfitted with a C-Ring. The ventilation rate was measured according to the manufacturer's instructions for the Mätstos funnel and VelociCalc model 8355 air velocity meter apparatus. It should be noted that in apartment 2, the washroom ventilation outlet could not be measured using our funnel system because a clothes dryer closet was bolted to the wall directly under it and could not be moved. In this case, the air velocity was measured with our instrument and the area was measured. This allowed us to calculate the airflow in the washroom.

The thermal imaging was conducted using an Agema Thermovision 900, liquid nitrogen cooled thermal camera coupled to an Agema computer system. A Raytek Raynger MX4 advanced infrared thermometer was used to measure additional surface temperatures during the period the measurements were being taken. The Glaser calculations were completed as outlined in Harderup (2000, 36-38).

The software package Heat2 (Blomberg 2000) was used to analyse specific details of the drawings to determine the theoretical indoor wall surface temperatures, the effects of thermal bridging, and other possible design problems. The input boundaries for Heat2 were based on the outdoor and indoor temperatures measured on the day that the measurements were taken. If a more exact simulation is required, a program called Heat3 could give results for a three-dimensional model, however it was not available.

The Glaser method is a simple method of determining the risk of condensation in a wall based on the indoor temperature, outdoor temperature, indoor relative humidity, outdoor relative humidity and the materials used in the wall. This method can also give an indication of the risk associated with mould growth. Unfortunately, this method has many limitations, the largest one being that the calculation is not dynamic and cannot calculate weather variations, or seasons. It is also very time consuming to do by hand.

Energy use

The actual use of energy for space heating and hot tap water as well as the electricity used for common areas over two one-year periods (2000 and 2001) was collected from the owner of the building, AB Svedalahem. Household electricity use for the year 2000 was obtained from the supplier, Sydkraft AB. The electricity readings were for the entire year, however the natural gas readings were available for each month. When the building was simulated, the different kinds of energy needed to be known. The need for space heating, the need for heating tap water, the need for household electricity and the need for household electricity must be separated.

The electricity for the household use excludes outdoor lighting and service buildings. Therefore, it was assumed that all the electricity could provide heat to the indoor environment.

The hot tap water flow was not measured. An estimation of the hot tap water consumption can be done in several ways though the only accurate method is to measure the flow and the temperature. In the summer where the need for space heating should be zero, the gas consumption should show the energy used for tap water heating and this energy can be assumed to be constant all year. A small increase in the energy use during the wintertime is normal (Johansson and Johansson 1999) depending on the temperature of the colder inlet tap water. The tap water use during the summertime was compared to the figures from an investigation in Trelleborg, South Sweden, (Johansson and Johansson, 1999) and the default value in the software package ENORM. The Trelleborg study was also based on the summertime gas consumption. Key figures describing the hot water usage component of the total tap water use could give the energy demand for tap water heating if the cold tap water usage were available for the study building. This method was not used because it does not take the heating system into consideration.

Energy balance calculations

Two different software packages were used to calculate the energy balance, and the first step was to correlate the actual recorded annual energy use with the programs then compare the programs. The programs used were 'VIP+' (Skanska IT-Solutions, 1996) and 'ENORM' (Svensk Byggtjänst).

Input data regarding the technical characteristics were gathered from the construction documents and from field measurements. Data on internal gains from people and indoor temperature were estimated on the basis of the number of inhabitants, which was determined by the questionnaire. Internal gain from electricity was adjusted to the electricity bought by the households. The use of energy for hot tap water was estimated by use of the default value of ENORM since the statistic data for this default value should be more rigid than rough estimations.

VIP+ is a dynamic program that can assess the impact of thermal inertia and air leaks. The program manages energy supply from space heating, solar radiation, internal gains (people, appliances) heat recovery from ventilation and the energy released by transmission, ventilation, air leaks, hot water production and cooling. There are two specially designed calculation modules, one for the calculation of air flows through ventilation and air leaks according to Nylund (1980) and one for the heat capacity according to Johannesson (1981).

ENORM was developed to compare a building with the minimum level of performance dictated by the Swedish building regulations, BBR (Boverket, 1998). ENORM is one of the most used software for energy calculations in dwellings in Sweden. ENORM uses a temperature function based on day values to calculate the energy demand. Thermal storage is considered according to EN 832 where a general correction is made depending on the thermal capacity. The lowest outdoor temperature, which should dimension the maximum power of the installations, is influenced by the thermal capacity according to BBR. In general, ENORM cannot calculate the maximum required power and a detailed consideration of the thermal storage is not presented.

ENORM handles air infiltration according to BBR. It assumes that the infiltration flow is constantly 4% of the test flow at 50 Pa. According to BBR, all areas that face an area with a significantly different temperature than the indoor temperature have leaks. With an extraction system, the under pressure results in a much smaller air leakage because it does not matter if

the flow comes through the leaks or through the air intake devices, at least within a reasonable amount of infiltration. This is not considered in ENORM. In cases other than extraction ventilation, ENORM under estimates the influence from air leakage (Larsson and Svensson, 2000). VIP+ models the leaking flow by using wind data from the actual location and the leakage data for each wall.

Parametric studies

Parametric studies on the consequences concerning energy use and indoor climate were related to alternative designs concerning ventilation systems, the thermal capacity and air tightness. These simulations were performed with the energy balance programmes VIP+ and ENORM. Related impacts regarding life cycle economy were examined with Life Cycle Cost calculations where the present value method was used.

It is impossible to recover heat from the exhaust air with the exhaust ventilation system in the study building because it does not have a heat pump. The supply air temperature is almost equal to the outdoor temperature, which can cause draught problems when the outdoor temperature is low. The advantage with F-ventilation is the low installation cost. The alternative system is a balanced supply and extract system (FTX) with a heat recovery unit with a plausible temperature efficiency of 75%. This leads to higher installation costs but lower energy costs though the electricity cost increases with two fans and the pressure drop of the heat recovery unit. The software VIP was used to calculate the heating need for both F and FTX ventilation since VIP handles air leakage better than ENORM especially for the extract system. The fan electricity can be calculated with ENORM. The climate data used for this calculation is from an average year in Norrköping to get a more generalised result than Svedala 2000 or 2001.

In a new and not restricted area, the direction of the facades can be altered, sometimes without costs. A parametric study is done with VIP+ to see the LCC gain when the direction is altered from the actual case.

RESULTS AND DISCUSSION

Indoor climate survey

The indoor climate survey comprised the entire set of nine, excluding orientation, identical buildings with a total of 64 flats. A final response rate of 88% was achieved (56 of 64 households). The following aspects were perceived significantly (95% CI) better than the reference from 10000 households in the Stockholm area; odours in general, light, acoustics and sick building symptoms. The following aspects were reported worse; cooking smells from neighbours and the indoor temperature during winter. The perception of temperature during summer, air quality and humidity did not deviate significantly from the reference. Besides the 45 specific questions within the questionnaire, the respondents were invited to state any other comments. A recurring remark deals with cold draughts during winter. A thermometer was distributed along with the questionnaires and the average indoor temperature recorded was close to 22°C. This temperature was used for the energy balance calculations.

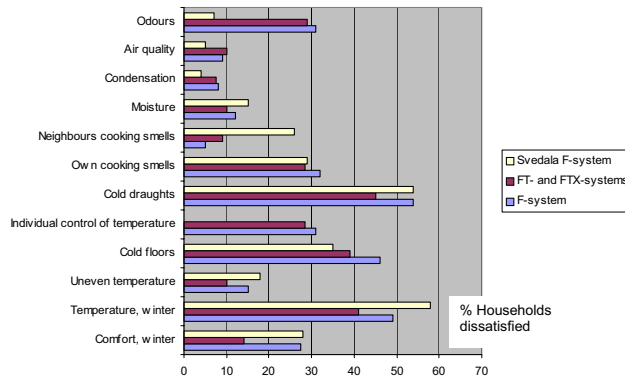


Figure 3. Indoor climate complaint profile Erlandsdal 1b and references according to survey by Engvall and Norrby, (1992)

The survey indicates that the ventilation system is a weak spot. With regards to perceived indoor air quality and health related issues the building and its service systems appear to be functioning well. However, cold air from the intakes above windows generates dissatisfaction with the thermal comfort, especially during winter. In several cases the tenants have blocked the air intakes to counter this. This may result in opposite air streams through the system, which in-turn explains why odours from the neighbours cooking are noticeable.

Ventilation Rates

The ventilation rates were measured in the kitchens and washrooms of both apartments. A report from Svedalahem showed that the ventilation systems were initially set for the kitchens and washrooms at 10 l/s and 15 l/s respectively. These rates conform to the minimum ventilation rates for these rooms set by the Swedish building regulations: BBR, Boverkets Byggregler (Boverket, 1998).

In apartment one, the measured airflow in the kitchen was 6.3 l/s and in the washroom 12.2 l/s. In apartment two, downstairs, the measured rates were 9.3 l/s and 9.0 l/s for the kitchen and washroom respectively. In both instances, the flow rates are lower than the minimum flow rates required by BBR. Additionally, these measurements follow Engdahl 1997, which shows that most ventilation systems in apartments are quickly thrown out of calibration shortly after installation.

Apartment tightness

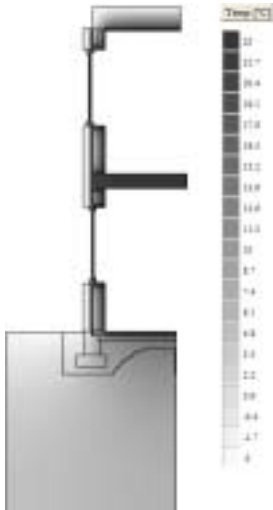


Figure 4: Temperature profile simulation of the wood framed wall, foundation and soil of the study building.

The air tightness in apartment one was measured to be 0.39 l/s-m^2 and apartment two was 0.22 l/s-m^2 . Boverket requires that the air leakage from a building must be under 0.8 l/s-m^2 therefore both flats are good in regards to air tightness. Apartment one seems to be normal however apartment two seems to have a very low number. This could be attributed to the fact that apartment one is located on the top floor (second) and has a wood-framed ceiling, two wood-framed external walls and two concrete walls, only one of which is an exterior wall, and a concrete floor that has a heated flat under it. Apartment two, which is on the bottom floor, consists of only two wood-framed external walls, two concrete internal walls, a concrete ceiling and a concrete floor (insulated slab on the ground).

Basic moisture dimensioning

Using the Glaser method (Harderup 1995) for calculating the temperature and moisture profile in a wall, the risk of condensation and mould growth was analysed for one year. Using this method, it was determined that there is very little risk of condensation inside the wall at anytime during the year. It also shows us, however, that there is a small risk for mould growth in the wood studs, dependant on weather during the summer months. It is important to note that the accuracy of this risk assessment is low because the Glaser method cannot take into account diurnal effects, varying humidity levels or temperatures both indoors and

outdoors. There are some programs available such as WUFI (http://www.wufi.de/index_e.html) or MOIST (<http://www.bfrl.nist.gov/863/moist.html>) that are able to calculate the temperature and moisture profile of materials, however they were either not available or not valid for Sweden's geography and climate.

Analysing the drawings

With Heat2, the wood framed wall including the foundation and soil under the building was simulated in a steady-state environment using the actual temperature readings obtained in the field. This simulation showed the theoretical temperatures based entirely on the design of the walls. Figure 4 shows the results of the simulation run by Heat2. It is important to note the approximate temperatures at the roof corner, windows, the concrete floors, and the soil under

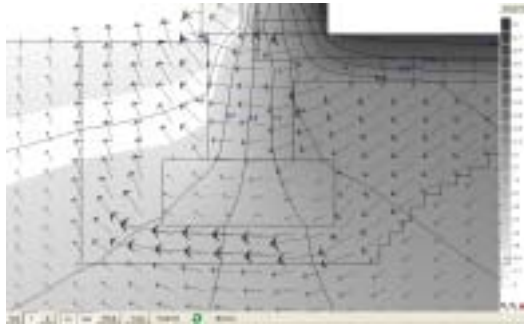


Figure 5: Temperature profile and heat flow through the foundation simulated by Heat2.

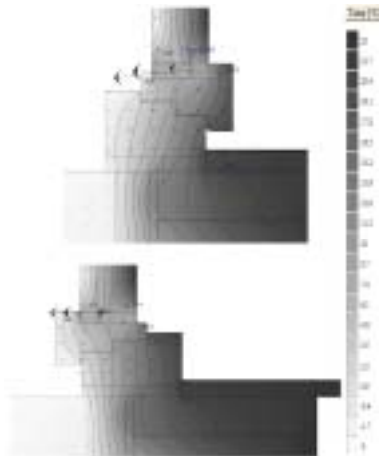


Figure 6: Temperature profile and heat flow through the two types of windows used in the building. The top drawing represents the windows used on the top floors that open inward, and the bottom drawing represents the windows on the bottom floor that open out.

the building. This simulation was done using an indoor temperature of 23°C and an outdoor temperature of -3°C, which were the conditions during the measurements. Looking at Fig. 5 gives good temperature and heat flow profiles of the foundation and soil under the building. The white space indicates the 0°C zone if the ground is theoretically exposed to a long-term outdoor temperature of -3°C. From this diagram, it is possible to see that there is no risk of frost damage to the foundation. Another simulation that was run using -15°C showed that the foundation was at a high risk of being damaged because the freezing zone travelled straight down through the foundation and under it. If there is water in the soil under the foundation, it could expand causing the footer to crack, and possibly sink after the ground thaws. However, this problem is unlikely to happen in southern Sweden due to the high average winter temperature of -0.5°C.

Specific details of the lower and upper level windows can be seen in Figure 6. In this figure, the top image shows the design of the windows for the top floor apartment and the bottom image shows the ground floor apartment. The simulation showed that although the frames were made of the same materials and dimensions, a difference in heat flow can occur just by flipping the design, in this case the design was a mirror image through the y-axis. The temperature difference between these two designs is about 1 to 3°C difference where the inside glass meets the wood frame, with the top floor windows being of superior design.

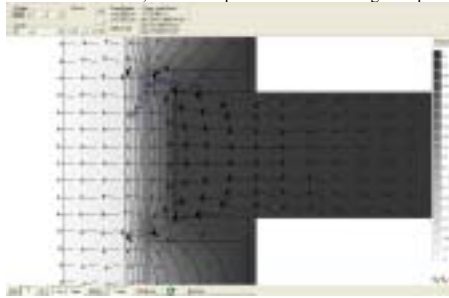


Figure 7: Heat flow and temperature profile through the concrete slab and the wall.

One of the areas of concern was the concrete floor between the ground and the 1st floor. Figure 7 shows the direction of the heat flow, indicated by the arrows, as well as the temperature profile. The concrete slab has wood above and below it, and about 50mm of insulation to the left of it. This component could have been designed in a better way so that there was less heat loss through this route due to the fact that it the walls are not supporting this floor, that is being done by steel beams which are specifically used to support the floor.

Thermal Imaging Results

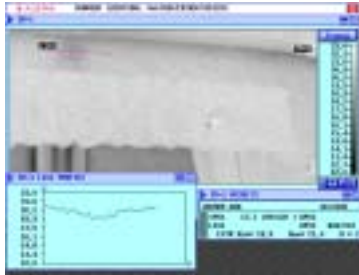


Figure 8: Thermal image of the north wall of flat 1 located on the top floor.

Thermal imaging enables the temperature profile to be viewed on the surface of an object. This is very useful when analysing the quality of a wall, floor or ceiling in a building. Figure 8 shows the corner of a wall connected to the roof of the building. The camera reports that the temperature is around 20°C. With Heat2 it was determined that the theoretical temperature for this area was around 18°C. This indicates that the quality of this wall along this seam is quite good without any air infiltration. Figure 9 shows the temperature in the northeast corner of the upper apartment where the walls meet the roof. In this corner there is a low temperature reading of about 14 to 15°C. This is quite low, but not unexpected. This point is typically one of the weaker points in a building due to pressure differences and the general temperature profile in the wall.



Figure 9: The temperature in the northeast corner of the upper flat where the walls meet the roof

Figure 10 explains why the occupants were complaining about a cold draft when sitting at their kitchen tables. This image shows the air intake location for the ventilation system. It is basically a hole in the wall that allows outdoor air to enter the apartment. It is also located in



Figure 10: Ventilation intake over the kitchen window.

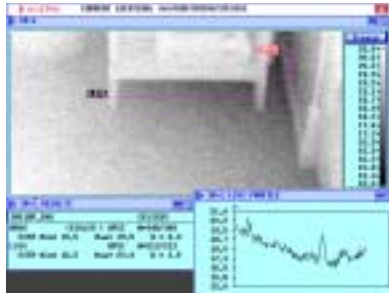


Figure 11: Bedroom with a cold floor.

an inconvenient position because the cold air that enters the apartment has only one flow path, which is down along the window and then it is directed out over the kitchen table when it meets the warm air from the radiator. This draft effect is also magnified when the stoves fan is turned on due to an increased flow of outdoor air. To combat the draft effect, the occupants closed the air intakes and this lead to other problems by creating a high negative pressure in the house. By doing this, the air is sucked in through the weaknesses in the walls. One such weakness was discovered under the kitchen window where air was entering between the window ledge and the wall. A better solution would have been to put the intake behind or just above the radiator so that it could heat up the intake air quickly.

Figure 11 shows a floor that is located on the south side of the building in the second apartment. This apartment was located on the ground floor and this image was from a bedroom with two external walls. The wall on the right is approximately 1 meter long and the

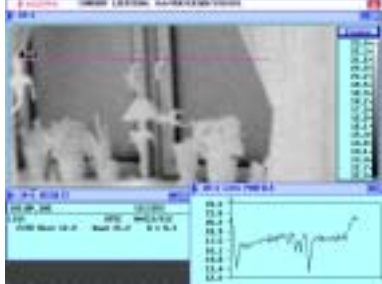


Figure 12: Thermal image of the kitchen windows.

temperature at about 0.5m is approximately 15.5°C. This seems unusually low for an insulated concrete slab on the ground and it is not yet known why this occurs. Further investigation showed that this phenomenon occurred in another apartment in the same location. This has led us to believe that there is chance that there is a fault in the design, or there is no insulation in this area. The explanation for why the temperature seems to curve back to the wall near the top of the image is that there is a radiator located on the wall just above this area.

Windows are always a major source of energy loss and a cause of thermal discomfort. Figure 12 is of the windows on the top floor. The graph shows the temperature profile across the line. The spikes going down to 13°C seem low, but the simulation run in Heat2 (see Figure 6) confirms this temperature, which occurs due to the aluminium or steel strip between the glass panes. An interesting thing is that the wood area between the windows is around 16 to 19°C. This also corresponds with the simulations from Heat2.

Actual energy use

The electricity use was collected from 2000. Electricity bought by the eight households totalled 13914 kWh, which corresponds to 26.7 kWh/m². Gain of energy from the 16 people living in the building was calculated by assuming 80 W/person of released energy and that half of their time is spent inside the apartment, which gives 1.23 W/m². Common electricity used for the block corresponds to 2.5 kWh/m² and does not contribute to the energy balance as the related heat is released outside of the climate shell. Ventilation rates used in the calculations were 25 l/(s·flat) based on the final inspection rate.

Actual energy use for space heating and tap water heating in the actual building for 2000 was 145 kWh/m². This is a bit higher than the average energy use for new multi-dwelling buildings, 140 kWh/m² according to 'Miljövärdsberedningen' (2000). The use of electricity, 26.7 + 2.5 = 29.3 kWh/m² is a bit lower than the average 35 kWh/m², according to the same

reference. The energy use for space heating and tap water heating for the neighbouring houses one and two were collected for comparison since the houses are or should be exactly the same except the direction of the facades. Figures 13 and 14 show the monthly energy use for the three buildings for 2000 and 2001 respectively.

If the need for radiator heating in the summer is zero, all the energy for June, July and August goes to heating the tap water. With that approach, the tap water energy demand for year 2000 should be 95 kWh/m² and for 2001 77 kWh/m², which is high. The Trelleborg project (Johansson and Johansson, 1999) indicated 36 kWh/m² and the ENORM default value gives 46 kWh/m².

To find out why the summer energy use for heating is so high, the other two equal neighbouring buildings in the area were examined. Here, the summer months indicate an annual tap water energy use of 79 and 64 kWh/m² respectively for 2000. The same figures for 2001 are 56 and 47 kWh/m² for the neighbouring buildings respectively. The summer of 2000 had a low average temperature in July and August, which can explain the difference between the years for all compared buildings. Perhaps the radiator system was turned on in the summer of 2000, however the 77 kWh/m² used in the actual study building is still high. The number of people living in the neighbouring buildings was not examined. More research is needed to find the answers of the high summer energy use. Possible ways could be to compare cold-water use for the different houses or to make gas readings every hour and check the night consumptions to point out leaks and extraordinary behaviour.

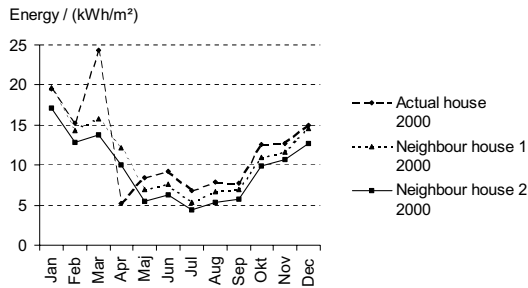


Figure 13: Monthly energy use for tap water heating and space heating for the three equally sized buildings with just the direction of the facades differing. Building 1 is the study building. The year is 2000 and the sums are 145, 132 and 114 kWh/m² respectively for the actual study house, the neighbouring house one and the neighbouring house two. The March reading for the actual building was wrong and influences the April reading but the sum is correct.

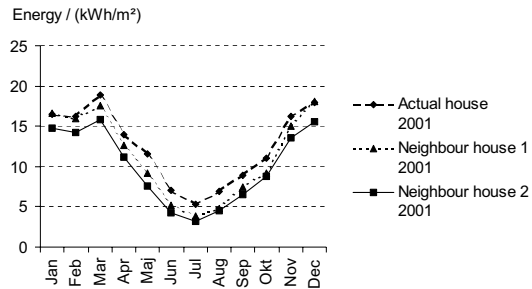


Figure 14: Monthly energy use for tap water heating and space heating for the three buildings. The year is 2001 and the sums are 151, 136 and 120 kWh/m² respectively for the actual study house, the neighbouring house one and the neighbouring house two.

Figure 15 shows the use of bought energy split into different kinds of energy. The split between space heating and tap water heating is estimated as in the calculations. The total number is around 180 kWh/m², which is rather high. Maybe the hot water production is the main answer to this.

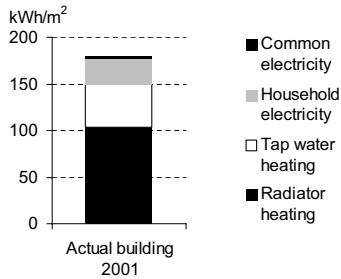


Figure 15: Total energy use 2001 for the examined building in Svedala. The tap water heating is estimated according to ENORM's default value.

Energy balance calculation versus actual energy use

The annual energy use for the actual building was calculated with VIP+ and ENORM with input data according to the method section. The results from the calculation of the building are shown in Table 1.

Table 1: Energy balance calculation according to VIP+ and ENORM (kWh/m², year). Climate data has been taken from Lund.

	Energy demand					Energy supply			
	Trans- mission	*Air leakage	Ventila- tion	Hot water	**Cooling	Solar gains	Heat exchange	Internal gains	Heating need
VIP+	70.8	0	56.8	45.7	1.7	27.9	0	37.5	110
ENORM	57.8	3.1	56.7	45.7	-	22.9	0	-	95.4

* With mechanical exhaust ventilation leakage has no significance for energy use as the infiltration only substitutes fresh air through the air intakes. ENORM does not consider that. It may however disturb the thermal comfort and give unbalances of air exchange rates.

** A maximum temperature of 28°C was given as it is deemed that the tenants will open windows at that level. Otherwise an unrealistic amount of energy will be stored within the building. The figure reflects the amount of energy that needs to be ventilated and can thus be used to express thermal discomfort.

The difference between the actual energy use for space heating, 145 kWh/m², and the calculated with ENORM, 95 kWh/m², is 34%. There is also a difference between VIP+ and ENORM. There are several aspects that contribute to this difference such as

- No detailed examination of the influence from thermal bridges has been done. The default value of VIP+ has been used for both software packages. Therefore, it does not explain the difference between VIP+ and ENORM.
- The climate data is from Lund and not from Svedala. Since Svedala is located some kilometres longer from the coast, the average outdoor temperature can be a little bit lower, but the difference is not explained.
- The energy need for hot water could have a large influence on the result.

Generally, the figures from the calculations are lower than the measured values, but if the tap water heating power is estimated to the power during summertime, the need for space heating for the actual house during 2000 would be (145-95) kWh/m² = 50 kWh/m². This should correspond to the Heating need minus the Hot water in Table 1. That is 64 kWh/m² for VIP+ and 50 kWh/m² for ENORM. For ENORM it corresponds well, but for VIP+ the simulated space heating need is overestimated, compare Table 2. For 2001 the results according to VIP+ are very close to the measured value. The cold summer of 2000, explained by lower hot water energy need for 2001 compared to 2000 for the buildings, can explain the difference. The difference between VIP+ and ENORM depends on different parts of the energy and it is difficult to predict which program gives best results. Table 2 gives the total heating energy values for different years.

Table 2: Annual heating energy need.

	Measured value	VIP	ENORM
Total heating energy 2000 Svedala (Lund) / (kWh/m ²)	145	110	95.4
Total heating energy 2001 Svedala (Lund) / (kWh/m ²)	150	122	105.4
Total heating with hot water heating power corrected to the whole summer heating power 2000 (kWh/m ²)	145	159	125
Total heating with hot water heating power corrected to the whole summer heating power 2001 (kWh/m ²)	150	153	136.7

Even though the results do not conform exactly to the actual energy use the programme is regarded accurate enough for parametric studies. It also seems like if the measured values of tap water were available, the energy use calculations would correspond better. The high heat consumption in the study building can also be caused by unknown problems in the system or water leakage.

It is shown that there is a large influence of behaviour on the real energy use values. The indoor temperatures are set in the simulations but vary in reality and the tap water consumption, as well as the household electricity, influences the results. Both ENORM and VIP+ also compare the actual calculated building with the demands of BBR (Boverket, 1998). This building did not pass the demand according to ENORM. The average U-value is good enough but the need for heating is too high due to higher internal heat loads in the BBR reference building. Here, the ENORM default value for tap water heating is used, but BBR does not consider tap water use. According to VIP+ the outcome is similar as the BBR referring to the higher internal heat loads according to BBR.

With the VIP+ programme it is also possible to estimate the effect of window orientation and thermal capacity with regard to solar radiation. The orientation of the windows of the original building is 80% to the North and 20% to the South. If the building is rotated 180°, the required space heating is reduced by 13.4 kWh/m². The original building can be defined as a semi heavy structure with regard to active heat capacity. Parametric studies were conducted for also for a light and a heavy type of structure. With the original orientation of windows the annual difference between light and heavy structure is 2.8 kWh/m² and with the opposite orientation with more free excess energy from solar radiation the difference is 4.7 kWh/m². The feature of considering thermal storage in VIP can also be used to study the effect if indoor temperature set point was decreased during night time, or of high temperatures in the building during the summer time.

Parametric studies

The parametric studies were done by altering the stated parameters for the actual building. The parametric studies comprised of thermal storage, air tightness and type of ventilation system using the matrix displayed in Table 3. It is shown that the influence of thermal storage between the heavy and the light building frame is about 3% irrespective of the ventilation system and air-tightness. There are several aspects to consider within this context. The effect is larger in a building with a more neutral or south oriented proportion of windows. The excess energy from people and appliances varies over the day, which increases the effect. On the other hand there are furniture and fittings in the flats irrespective of building structure that also contribute to the thermal storage and thus evens out the difference between the types of structures.

The air-tightness contributes to a variation of up to 10% with the values on tightness of building shell that were used by the simulation. Note that value 1.6 m³/(m²h) at 50 Pa was the average of the two flats that were measured in the field tests. The figure 2.9 m³/(m²h) at 50 Pa is the tightness corresponding to the Swedish building norm and 0.8 was chosen to reflect what is deemed possible to achieve when great care is taken by design and execution with regard to connections and choice of materials.

Table 3: Parametric study on energy use. Relative required energy for space heating

Type of building frame	Mechanical exhaust ventilation	Balanced ventilation with heat exchange		
		Air tightness 0.8*	Air tightness 1.6*	Air tightness 2.9*
Semi-heavy	1 (original)	0.96	1 (reference)	1.06
Heavy	0.99	0.95	0.99	1.06
Light	1.02	0.98	1.02	1.08

* $m^3/(m^2 \cdot h)$ at 50 Pa pressure difference over the climate shell except slab on ground. The value used in BBR is in $l/(m^2 \cdot s)$ and the corresponding figures are 0.152, 0.304 and 0.8.

The thermal storage also influences indoor temperatures and thus the thermal comfort. To assess the contribution of this the number of weeks with indoor temperatures above 28°C can be considered. Comparing the original structure with the heavy and the light, we find that 6, 4 and 10 weeks respectively have more than 20 hours of indoor temperature exceeding 28°C. The difference would be even larger with more windows facing the south.

The simulated impact on energy use and indoor temperature during the summertime with regard to the orientation of the building and its windows is presented in Table 4. The distribution of exterior wall area in the original building is 189,6 m² to the North and South and 48 m² to the East and West. Total effective window glass area is 44,8 m² that is 80% to the North and 11 m² and 20% to the South.

Table 4: Impact on energy use and indoor temperature of the buildings and windows orientation.

Orientation	Energy use (kWh/m ²)	Relative energy use	Number of weeks with more than 20 hours indoor temperature exceeding 28°C
North	110	1,00	6
East	108	0,98	16
South	98	0,90	20
West	107	0,98	17

* Direction for façade with 80% windows. Original building: North.

The life cycle cost consequences related to changes in energy use of the magnitude discussed above; 1, 3, 5 or 10% are presented in Table 5. It is deemed reasonable to expect an increased energy cost of between 1 to 3% above inflation. The calculation horizon selected was 50 years and the real interest rate 3%, which is plausible in the long-term perspective (Johansson, C., Öberg, M. 2001). The figures should be seen in relation to the cost differences of design alternatives that influence the energy use. According to Persson (1999) the cost for the chosen concrete frame was 85 SEK/m² more than a timber frame. Energy cost is only one of many parameters by the choice of materials and systems for the building frame and climate shell; acoustics, robustness, flexibility, maintenance to mention a few others. A life cycle cost calculation of energy however shows that even relatively small differences looking at the annual energy cost are of significance in the life cycle perspective.

Table 5: Present value (SEK/m²) related to change of energy use and developments of energy prices for a period of 50 years. Reference is the Svedala case study energy cost in 2000, 64 SEK/m².

Increase of cost for energy above inflation	Change of energy use related to the use in 2000			
	1 %	3 %	5 %	10 %
1 %	19	59	98	196
3 %	32	94	156	313

The LCC analysis comparing F-ventilation and FTX-ventilation was based on the annual energy use calculated by VIP and ENORM shown in Table 6, where the input data for the LCC analysis and the results are presented. The energy costs are the actual. The discount interests for energy and maintenance are estimated (Johansson, 2002). For both the extraction system (F) and the supply and extraction system with a heat recovery unit (FTX), it is estimated that the entire installation costs will reoccur one time at year 25. The energy costs are the real costs for the occupants in Svedala. The installation cost for the FTX-system is supposed to be three times the cost for the F-system.

Table 6: An LCC-analysis made for the study building with extraction ventilation (F) and for a theoretical building with supply and extraction ventilation (FTX).

	F	FTX
<i>Energy need</i>		
Annual heating need / (kWh/m ²)	120,2	90,2
Annual fan electricity / (kWh/m ²)	3,2	7,5
<i>Energy costs</i>		
Heating cost (natural gas) / (SEK/kWh)	0,46	0,46
Electricity cost / (SEK/kWh)	0,65	0,65
<i>Annual costs at today's value</i>		
Annual heating cost / (SEK/m ²)	55,3	41,5
Annual electricity cost / (SEK/m ²)	2,1	4,9
Annual maintenance cost / (SEK/m ²)	3,8	5,8
<i>One time occurring cost at today's value</i>		
Refurbishment cost at year 25 / (SEK/m ²)	97,1	291,2
<i>LCC-analysis input data</i>		
Life span / year	50	50
Real discount interest for energy / %	2	2
Real discount interest for maintenance / %	3	3
<i>LCC-results</i>		
Installation cost / (SEK/m ²)	97	291
LCC - heating / (SEK/m ²)	1737	1303
LCC - electricity / (SEK/m ²)	64	153
LCC - maintenance / (SEK/m ²)	99	148
LCC - refurbishment / (SEK/m ²)	46	139
LCC - total / (SEK/m ²)	2044	2034

The analyses show that it would be about the same life cycle cost if an FTX-system were chosen although the difference is small. The higher installation cost is compensated by lower energy use. In addition, the indoor thermal climate should benefit with an FTX-system with reduced draught problems near the windows. Thereby, a decrease in average indoor

temperature can occur because the occupants would still feel comfortable. No considerations are made about the decrease of the installation cost of the radiator heating system due to the decrease in peak power demand. According to ENORM the peak power demand for heating decreases from 17.8 to 12.3 kW, which will decrease the installation, cost of the radiator system by about 5 % (Johansson, 2002)]. ENORM is not a good program for peak power calculations but the magnitudes should be valid. When the FTX-system is used, it is important to decrease the air infiltration since there is no heat recovery from the leaking air. VIP does model that but ENORM does not.

CONCLUSIONS

The project in the case study in Svedala functions well with the exception of the ventilation system that could have been a supply and extract system without increasing the life cycle cost. This would have benefited the energy use, probably the environmental impact, the life cycle cost and the indoor thermal comfort. The problems with air quality and draught spotted in the questionnaire could have been solved by a supply and exhaust ventilation system. Maybe the indoor temperature could have been decreased with less heating need as result. Air tightness of the building shell influences the energy use in buildings with balanced ventilation but not with mechanical exhaust ventilation. The building is tight compared to the regulations.

Thermal storage in dwelling buildings has little effect on the annual energy cost but in the life cycle perspective it should be taken into account by the choice of design solutions. The impact of thermal storage is significant for the thermal comfort in summer time. VIP+ is a more detailed software than ENORM and therefore needs more input data. Still ENORM gives valid figures for dwellings if the input data are plausible.

The building physics tools used in this paper correlated well with each other and the simulation software gave an indication of where there could be potential problems. A couple of measurements matched those of the calculated values, however most measured values fell a couple of degrees below the theoretical values. The tools also gave indications of areas that could be improved such as the ventilation air intake, and the effect of different ventilation systems on the life cycle cost however, the life cycle cost was not significantly reduced with a more complex system.

One problem with examining a house is lack of models for user behaviour and a lack of measurements to split different energies and grounds for energy use. Measurements also need to be made with a smaller time interval.

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Appendix A. Description of the building.

	U-value W/m ² °C	Frame type		
		A Original	B Heavy	C Light
Exterior Walls		Area m ²		
<i>North</i>				
Heavy	0.224		125.5	
Light	0.224	125.5		125.5
<i>East</i>				
Heavy	0.224	24	48	
Light	0.224	24		48
<i>South</i>				
Heavy	0.224		157	
Light	0.224	157		157
<i>West</i>				
Heavy	0.224	24	48	
Light	0.224	24		48
Interior Walls				
Heavy		98	248	
Light		150		248
Interior Floors				
Heavy		260	260	
Light				260
Roof				
Heavy	0.147		260	
Light	0.147	260		260
Slab on ground				
	0.234	224.4	224.4	224.4
	0.36	36	36	36
Windows and doors		North	South	Glass %
Windows	1.5	47.2	15.7	70
Doors	1.5		16.9	
Window-door	1.5	16.9		70
Ventilation type				
F		Mechanical exhaust ventilation		
FTX		Balanced ventilation with heat recovery unit		
Air leakage		(cold surfaces except slab on ground)		
08	0.8 m ³ /m ² .h at 50 bars			
16			1.6 m ³ /m ² .h at 50 bars	
29			2.9 m ³ /m ² .h at 50 bars	

9.4 Paper IV

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Paper IV

A Swedish perspective on the prevention of moisture problems during the building's design phase

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Abstract. *Moisture problems in buildings are increasingly being reported in the mass media in Sweden, often leading to some controversial stories about companies and their building processes. Using building physics and building performance principles during the design stage can often prevent most problems from occurring. One of the big questions is, with all the available knowledge about designing a building, how can these problems still be occurring in expensive, new buildings? This paper explores this question by interviewing some engineering consultants on how they evaluate the performance of a building, and to what extent knowledge about building physics theory is being used during the design process to prevent moisture problems from occurring. It was found that building physics is not used extensively in the building industry due to many reasons. The lack of good tools and the fact that clients do not request it are two main reasons. However, it was revealed that clients do not request it because they either have no vested interest in spending the extra money for a better design, or they do not know it is optional and just assume everything is taken account of in the final design. Furthermore, the consultants do not advise them on the available options applicable for their particular design. Due to the method used to analyse the interviews, an unexpected relationship between education level and their perceived level of awareness of building performance issues emerged. It appears that the higher the level of education of the consultant, the more they are aware of the impact of performance issues in a building's design. Their experience level does not appear significant in this relationship, however this cannot be proven and will require more studies to verify.*

Keywords: *building physics, building performance, interviews, tools, consultants, education, economics.*

1 Introduction

Building physics in Sweden is defined as the study of the transport of heat, moisture, and air through a building's envelope in relation to both the indoor and outdoor climate (Hagentoft, 2001). It is a key area in the development of energy efficient, healthy and durable buildings. It is important to note that the Swedish

definition of building physics does not include lighting and acoustics, as in most other countries around the world.

In many countries, architects are responsible for the design and dimensioning of a building. In the Swedish construction industry it is common that the architects are only responsible for the form and shape of a building and engineering consultants are responsible for the technical specifications. Recently, Sweden has seen an increase in the amount of mass-media attention that problematic buildings are getting; even to the point of being scandalous for the companies involved in all phases of the construction (Luthander, 2001; Jelvefors, 2002; Samuelson and Wånggren, 2002). One of the big questions is, with all the available knowledge about designing a building, how can these problems still be occurring in expensive, new buildings? This paper explores this question by interviewing some engineering consultants on how they evaluate the performance of a building, and to what extent knowledge about building physics theory is being used during the design process to prevent moisture problems from occurring.

Background

Behind this study are two research projects that are closely related to each other.

One project, *Performance indicators as a tool for decisions in the building process*, deals with the problem of developing a tool that will increase the application of building physics in the early stages of design. Issues that have to be discussed and handled properly in order to create supporting knowledge for making sound decisions about a building's design. Performance indicators can assist in this decision-making and help to avoid failures that would otherwise reduce service life. Even though knowledge about designing a building is widely available, incorrect decisions are all-too common. Consequences include a reduction in service life arising from conditions such as mould growth, rot and corrosion. These conditions can be avoided, but not without the application of robust knowledge based on the principles of building physics. However, this requires more than knowledge; it demands tools that designers can understand and use. It is important, therefore, to have a clear picture of what is required of any decision support tool, which is why the interview study is important in the further development of the tool.

The second project, *Tools for determining the economical effects of building physics aspects during the building process*, investigates, studies and quantifies the economical benefits in using the knowledge from building physics as a design and decision tool in the building process. Problems in the building process related to building physics will be identified in co-operation with the building industry. Existing calculation programs, data bases, statistical inquires will be compiled into useful, easy to use tool packages especially designed to give adequate information about the costs and risks associated with different designs. These interviews were necessary to gain insight into what extent building physics is utilised in the construction industry, and what types of

applications designers want that would enable them to apply building physics theories more easily to designs.

Method

As mentioned in the previous section, the two projects behind this paper are developing tools to be used during the design phase in the construction industry. Information and insight was needed about the design process in the Swedish industry as well as the types of tools that designers would want to use.

Since the tools are to be designed for the designers during the design phase of a project, we focused our information gathering on the designers who will potentially have use for our tools.

Questionnaires were first considered as the method of gathering information, however they have the disadvantage of being too linear. In addition, the information generated could not be anticipated, so it was not considered appropriate to gather the information by questionnaires. Interviews were more appropriate by allowing us to be dynamic, with the ability to probe interesting information to a much deeper level than is possible by questionnaires.

The questions for the interviews were formulated around two themes. One was to get a picture of the consultants' conditions used to evaluate the performance of a building, and the second was to determine what extent building physics issues are taken into account during the construction process.

To ensure that all interviews yielded comparable results, they were based on five key questions with additional supplemental questions based on each key question:

- 1 - How would you describe the design process of a building?
- 2 - What are the most important performance requirements when designing a building?
- 3 - How do you evaluate the performance of a building?
- 4 - What influences do economical aspects, such as market conditions and market trends have on the design of a building?
- 5 - Do you and your co-workers feel comfortable working with building physics issues, i.e. heat, air and moisture issues?

Interviews were conducted with eight different building consultants in the Swedish construction industry. All but one, the building physics professional, were chosen at random with no information about them prior to the interviews. It was decided to stop conducting interviews at eight because very little new information was yielded after the fifth interview.

Table 1: Profiles of those interviewed

Category	Education	Experience
A	PhD in building physics	20 years
	Civil engineer + extra education building physics	15 years
B	Civil engineer	30 years
	Civil engineer	15 years
	Civil engineer	15 years
	Civil engineer	7 years
C	2-year engineering diploma	6 years
	High school	40 years

The results were analysed based on the grounded theory approach, which “is a method for discovering theories, concepts, hypotheses, and propositions directly from data rather than from a priori assumptions, other research, or existing theoretical frameworks” (Taylor and Bogdan, 1998, p. 137).

2 Relationships

Some of the consultants indicated that experience is very important in the industry when dealing with the performance of a building. However, this was not apparent when analysing the interviews. When looking at the experience level compared to the perceived level of awareness, i.e. the whole picture of the design process combined with a comprehension of complex performance issues and an awareness of the current levels of technology base, there did not appear to be any pattern. However, the level of education appeared to be related to their level of awareness. Figure 1 shows how we perceived the level of awareness for each person interviewed.

It is important to remember that the engineers in category C, and part of category B, did not have access to an expert. This could affect the results in this study since a lot of education flows internally from the experts in the companies. Other companies with experts and category C employees working together may have a totally different level of awareness due to the expert’s influence. More in-depth studies would be needed to investigate this relationship further.

There also seemed to be different attitudes towards the required time directed to handle moisture control issues during design. Those within category A said that they would like to have some more time whereas those in category C did not even allocate time especially for these issues. This was stated despite that they stated earlier that these issues are highly prioritised. They did however motivate it by using safe and well-known designs, referring to their own experience. However, their experience on well-known designs can be questioned as the consultants rarely have the time or the opportunity to return to, or follow-up projects that were finished 10 years ago or more. In practice, the long-term design for engineers is 2 years, according to one of the interviewed engineers.

When asked who is responsible for most of the performance problems experienced in buildings today, the consultants in categories A and part of B were also including themselves when asked. This was the opposite of the others (categories C and part of B), who blamed anyone else but themselves.

One of the key questions dealt with how comfortable the consultant feels if they must work alone on problems dealing with building physics. In most cases the answer to this question was related to whether or not they have access to an expert in building physics. If the consultant had access to an expert, they were usually not comfortable working with these issues and usually sought advice from their expert before finalising a design. The consultants in this category acknowledged that since the media attention began, they have felt even less comfortable with these issues and rely heavily on their experts. Those without an expert in-house were more prone to saying that they felt very comfortable with building physics issues.

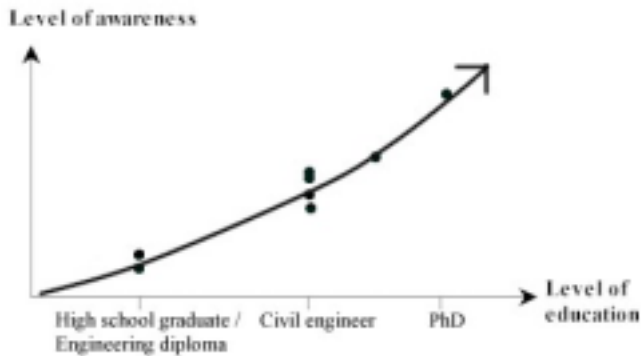


Figure 1: Perceived correlation between level of education and awareness

The group within the profession that has lower education level relies mainly on their experience (category C=High school graduate, engineering diploma). But if professionals rely mainly on experience, how do they know when there are gaps in their knowledge or whether some of their standard rules are no longer applicable (Barrett & Stanley, 1999)? Decisions made without knowledge of their consequences can have dire effect (Ellis & Mathews, 2001).

One might easily draw the conclusion that people with less knowledge would suffer from insecurity more so than those with expert background. This was not the case during the interviews. Members of group C, showed a great deal of confidence and no worries about the complexity of building physics. Confidence is the strength of a person's belief that a specific statement is the best or most accurate response (Peterson & Pitz, 1988). So far, no study has been performed that examines if there is any correlation between mistakes in design and the level of building physics knowledge of the designer. However, there is a great deal of research, which indicates that people are often more confident than they are correct (Blanton *et al*, 2001). Blanton et al. (2001) states that educators may meet obstacles from people's overconfidence about their knowledge when trying to educate them. As the individual with the PhD said, "People *think* they can moisture proof a building, but they can't and I have to correct the problems later, which takes a lot of time."

3 Trends

Moisture design appears to be a growing trend in Sweden. This can be explained by the attention from mass media that various projects around Sweden have been getting. Specifically these projects involving mould in buildings and moisture damage in newly constructed buildings, largely multi-family dwellings (Jelvefors, 2002; Luthander, 2001). This trend is increasing because the media has brought it to the attention of the public that the consultants do not perform a moisture analysis on a building's design during the design phase. The clients, who are not always familiar with what a moisture analysis is, are beginning to request these because the media reports that mould and moisture problems can be solved using these methods. However, the consultants still think that the clients are not willing to pay extra for such expertise work since the clients often believe that it is included in the normal design work. Not long ago, two of the companies tried to promote special units handling building physical issues. Those units do not exist today because of the lack of interest from the clients to pay for such services. It was believed that the clients do not have a long-term perspective and that is why it is difficult for the designers to motivate it.

Has the number of experts increased in practical design work? In another civil engineering area, geotechnics, a trend is the growing number of experts (post doctoral) joining conventional firms instead of making a career within the university (Goodings & Ketcham, 2001). This trend helps bring existing research into practice where it is most needed. Augenbroe (2002, p. 891) agrees with the idea of making more use of experts in the industry stating, "The latter

trend recognizes that the irreplaceable knowledge of domain experts and their advanced tool sets is very hard to match by ‘in-house’ use of ‘dumbed down’ designer friendly variants”. This difference between having a tool, versus having an expert in the company is significant, and this was reflected in the results of the interviews. All consultants who had access to an expert made use of them constantly, and all stated that they would be uncomfortable working with moisture control problems if they did not have access to their expert. They much prefer having the expert than using a simplified tool.

4 Consultant or Engineer and their Liability

Noting that moisture analysis requests began increasing after the media reported moisture problems, we began to wonder what the role of a consultant is in the Swedish construction industry and what their liabilities are. One tool used is called ABK 96 (Byggandets kontraktsskommitté, 1996). It is a standard contract that explains in detail how engineering and architectural consultants should conduct themselves. It also describes the limitations of liability that a consultant has. Most consultant companies use this voluntary contract to guide the consultants and also the client – consultant relationship. Each party is informed of what is expected of them by the other.

Despite this, there also appears to be some confusion around the labels of consultant and engineer for consulting companies, even though it is not spoken of. A consultant is defined as “an expert who gives advice.” (Princeton, 1997a) An engineer is defined as “a person who uses scientific knowledge to solve practical problems.” (Princeton, 1997b) Paragraph four (Byggandets kontraktsskommitté, 1996, p. 5) states that the consultant must be competent, professional and have adequate knowledge to consult in the areas of their field. However, overconfidence and lack of awareness in building physics on the part of some consultants, can cloud the issue of a consultant having adequate knowledge for building physics issues.

From the interviews, it was obvious that many consultants expect to be told what to do by the clients without informing the clients of what is available. In this way some of the consultants take on the role of engineer. This change in attitude is reflective of the traditional methods of building design consulting when a lot of information was unknown and the designs were simpler. An example was one consultant disclosed technical solutions to example problems during the interviews that are proven to lead to mould and moisture problems in houses.

If a client is an experienced buyer or an expert client, they will have predetermined tasks and technical solutions available for the consultant since they are usually aware of all the major problems and their solutions. However, not all clients are fully informed, almost all have some weakness, for instance the science of building physics is not known by a typical client. A statement

during one of the interviews, “Clients don’t know enough (about building physics-issues) to have any requirements” supports this idea.

There are occasions where poor decisions have been made that have led to a failure in performance. This was exemplified during the interviews where one described how she strongly advised the client not to follow the architects’ direction of having the outside wall continue into the ground without a base. Two years later the predicted problems arose and the plaster closest to the ground fell off due to frost erosion. Clearly this was a case where the client was not used to handling these issues, lacked the experience to make a correct decision and the consultant failed to present the information. The reasons are considered to be due largely to the inability of design engineers to encode and present the consequences of a decision. By improving the quality of information during the design process, the client is better equipped to understand the different issues implicated in the project (Barrett and Stanley, 1999). The consultant above admitted that by having real life cases to show, including a cost of the consequence, the outcome of this case might have been different.

The consultant in this case was not liable for the damages that incurred later because the consultant, firstly, recognised the problem and secondly, recorded their disagreement with the client in the protocol during the design phase. The consultant would have been liable for the damages if they did not inform the client of the problem, either voluntarily or unknowingly, i.e. was not aware of the consequences of a particular design feature. This case was not typical in that the consultant did a moisture analysis to determine the consequences.

The client usually assumes that the consultants they hired will solve all the known problems. The reality is that most consultants, not all, are actually operating like engineering firms, in that they do not analyse a building from a building physical point of view unless asked specifically. Their reasoning being that changing the design requires more time, hence more money that clients are unwilling to pay. The result of this is that the minimum amount of work is done when analysing a building’s design and the clients get very upset when problems occur.

One fact that they are neglecting to consider is that the cost of the building might actually decrease if the design is optimised using building physics. This could be in the way of material substitution, removing unnecessary components, or utilising a quicker construction method. In the U.K., quantity surveyors are able to calculate the cost difference of various designs. This position does not exist in Sweden so it is very difficult for the engineering consultants to motivate changing the design based on building physics theory to the clients because it is very difficult to calculate the savings or extra costs that will result.

5 Tools

When asked what building physics tools were used when conducting the evaluation of a building, most replied that they did use some very basic ones. Two people, including the expert, built their own tools from Delphi Pascal or Excel spreadsheets. Only the expert had a 'wish list' for what was desired in future tools. The others said they did not know since either their local expert uses the tools, or they did not use any.

When those who replied that they did not use any tools were asked why, they replied that they were too costly to buy, too difficult to learn, required too much time to run the simulations, and not enough time was allocated to evaluate a building's design properly. These results follow Hien *et al.* (2000, p. 727) who found that "Most firms view the use of simulation tools as involving extra costs and effort but with little recognition and appreciation from the clients."

The most desired features of any tool according to the consultants, were that they had to be easy to use in terms of low level of input and output data. These are statements that contradict with what is typically produced by researchers. Researchers have too often failed to deliver numerical models and tools that are user friendly and that take into account the education and expertise of the likely user (Goodings & Ketcham, 2001). Hien *et al.* (2000) reveals that designers regard current tools as user unfriendly with very steep learning curves; moreover, the output generated could be extremely difficult to interpret and utilise for design decision-making. Ellis & Mathews, (2001, p. 1011) also confirm this and have identified that tools of today are:

- Complicated (not user friendly)
- Time consuming (too much input)
- Require a high level of theoretical knowledge (to make the input and to interpret the results)
- Information needed is not available during preliminary design.

Regarding the wish list of the tools the answers can be categorised after what level of education the respondents have. Those within category C had no wish list. Category B directed their interest to simplify computer programs in order to make use of such programs, whereas category A people had a bigger picture and directed the use of wish tools that could be used to persuade the clients for better performance. Examples of these are tools that can show the consequences of a chosen design in terms of reduced service life due to mould, rot or corrosion and cost analysis programs. Energy calculation, heat flow and airflow programs were not mentioned by any of the interviewees despite the fact that these areas all fall under the area of building physics.

Building industry related journals were also mentioned as being a tool that provides them with useful information. However, the interviewee did not state what specific types of journals they referred to.

6 The Bigger Picture

Despite advances and knowledge in the construction industry in the past decades, it appears that this knowledge is not generally implemented until it becomes a requirement. This was explained by Becker (1999, p. 526) who states, “incorporation of new concepts into an existing professional activity field can be accomplished only if the right infra-structure, composed of some basic conditions, is present:

- the acting parties recognize the significance of these concepts and their contribution to improving the results of their work,
- clear routines and friendly working tools for smooth incorporation of the new concepts are available, and
- young new professionals are educated to regard the new concepts as an integral part of the profession.”

These statements can be seen in the Swedish construction industry today. From the interviews, we saw that some recognise the significance of the concepts of building physics and building performance. Most indicated that there were no good tools available for designing a performance building. Some did not even know that there were tools available on the market today.

With the third point, compliance and company tradition will quickly change the young professionals into operating like the other members of a company. Even if they want to make changes according to what was learned in school, a higher power can quickly overrule any decisions that they feel are unnecessary. The younger workers learn quickly not to make these decisions again in the future.

7 Conclusions

The interviews conducted with the engineering consultants in the Swedish construction industry suggest that experience might not necessarily be important when it comes to consultants and the topic of building physics performance. In addition, the higher educated consultants felt less comfortable and showed less confidence when working with these issues than their less educated counterparts. Their comfort and confidence levels were also inversely related to their amount of access to an expert in building physics, i.e. the more access they had, the less confident they were in working with these issues. The consultants with no expert support felt very confident and comfortable in working with these issues, however the quality of their work could be questionable due to a lack of feedback loops in the system. Awareness, education, and a view of the bigger picture are all needed to effectively deal with performance problems in the current construction industry. However, even if they possess all of these traits, there are many obstacles out of their control that can prevent an effective analysis of a building’s design. Some of these obstacles include having to make do with the amount of time allocated to the analysis phase of a building, meeting

the client's demands, the architect's demands, the level of competence of the consultant, whether or not they have access to an expert in building physics, and the types of tools they have at their disposal.

The interviews indicate that problems are still occurring in new buildings today because either clients do not request the correct design options, the designers do not include these options in their designs due to the extra time it takes, or the constructors disregard some basic issues which lead to problems during the construction phase. Sometimes clients do not request extra design work because they believe it increases the total cost and they will not be personally affected by the improvements, for example clients who build public housing, or apartments.

Mass media has had an interesting effect in Sweden in that people are beginning to ask for moisture design during the design phase even if they do not know what it is. This could indicate some sort of failure on the consultant's part since it is the job of the consultant to advise the client of what their available options are when designing a building. During the course of these interviews it is apparent that some consultant companies are used to having knowledgeable clients who know what they want out of the design phase. When a less enlightened client comes along, the consultants expect to be told what to do and the clients assume that every problem is accounted for in the design phase. Perhaps those companies should reassess their company to determine if their service is in fact a consultant or an engineering based service since there appears to be a great deal of confusion both for the clients and with-in the industry themselves.

Building physics is not used very much in the industry overall, however some companies use it often, even employing a full-time professional in the field. It is used a lot after damages occur instead as a preventative measure. There are many reasons for this, mostly due to the amount of influence that short-term economics contributes and the fact that most clients do not have to live with the consequences of bad designs. In the area of building performance, almost all of the efforts go into the structural aspects of a building. Very little effort is put into moisture design, tightening the building envelope, or maximising the energy efficiency of the building.

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9.5 Paper V

Burke, S. (2003). The renovation costs of crawlspaces due to moisture damage. In: Construction Economics and Organization - Proceedings of the 3rd Nordic Conference on Construction Economics and Organization, (111-7) April 23-24, Lund, Sweden

Paper V

The Renovation Costs of Crawlspace due to Moisture Damage

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Abstract

Moisture problems can take up to 10 years to reveal themselves in buildings. They are quite prevalent in Sweden today, potentially costing the economy a lot of money in repair costs. Moisture design is a method used by building physicists to determine the risk of a building developing moisture problems in the future if it is utilized during the design phase of the construction process. One design that is known to be problematic is buildings with crawl spaces. These buildings are one of the highest risk buildings of developing moisture problems, which can lead to indoor air quality problems. This report looks at the economic costs of repairing homes built with crawl spaces.

Introduction

Crawlspace have been around for a long time all over the world. In the past, houses were built above the ground on stonewalls. As man learned about insulation, they began to seal off this space in order to keep the heat in their buildings. They were also used to store food during the winter, as they were the ideal storage room, dark, moist and cold. It is these very same properties that cause problems for the structure of the buildings and this problem is one found throughout the world (Figley and Sieber 2002) (Matilainen and Pasanen 2002) (Hellström, L. 2002) (Arnstad, L. 2002) (Hinks and Cook 1999). Crawlspace are also one cause of mould problems in homes, which can be a serious health issue for the occupants causing allergies and sicknesses (Sundell 2000) (Haverinen et al. 2001b) (Haverinen et al. 2001a).

In Sweden, crawlspace were popular before the 1940's and again in the mid 1960's and 1980's (Tolstoy et al. 1984) (SCB 1972) (SCB 1980) (SCB 1988). From 1982 to 1991, 250000 houses, 25%, were built in Sweden with crawlspace (Elmroth et al. 2002). Crawlspace are a cheap method of building a foundation for a house, however if they are not constructed correctly, the reparation costs can easily exceed the money that is initially saved.

Crawlspace have the advantage of allowing people to access the area of a building that might otherwise be inaccessible. This can be useful for low cost repairs, easy access to, for example water leaks, floor insulation etc. Lately, crawlspace are becoming the cause of moisture problems that lead to health issues and costly renovation costs. Part of the problem can be attributed to the lack of knowledge in the area of building physics.

This paper looks at the potential economic repercussions of choosing a crawlspace as a foundation type, and is part of a larger project that looks at the economic effects of using building physics during the design phase.

Method

Småhusskadenämnden (SSN) is a Swedish organisation that was started in 1986 in order to assist people who have homes that are damaged by mould or moisture damage. SSN keeps every case documented in their archives and has done so since they began. The documentation includes the application for assistance, a technical review by a consultant, bids from construction companies to repair specific problems and the resulting decision, which includes the cost to renovate the building, the amount of deductible that the home owner is responsible for and the value of the house after the renovation is complete.

The economic data for this report was gathered from some of these archived documents. These documents cover applications submitted between 1986 and 1996. The documents used for this paper are currently located in the Department of Building Physics at Lund University.

Limitations

The houses looked at for the purpose of this paper had moisture-related damage that received money from SSN. This data does not take into account buildings that were not eligible for funding. There are limitations on the part of SSN for which houses are funded and for which are not. "SSN will only fund projects that are:

- Younger than 25 years old (if it is not renovated or expanded), before 1993 the limit was 30 years old
- Built before 1989
- Constructed for permanent use
- Serious damage at the time of application
- A one- or two-family house.

SSN will not fund projects if:

- The applicant does not own the house
- The damage is already repaired
- The damage is repaired through a court order or similar
- The building is classified as a summer cottage
- The damage is covered by insurance or warranty
- The damage was known to the owner at the time of purchase (under certain conditions funding can be approved)." (Svensson 1999, 3)

The author does not break down the costs for each case. Only the total reparation costs were used and the specific types of problems were not reported. All costs are in the monetary value of the year of payment. The costs have not been converted to today's value.

Crawlspaces

A crawlspace foundation comprises of a footer that supports concrete walls. The top of this space usually comprises of an insulated floor and the bottom is usually gravel or earth. These spaces are usually ventilated with outdoor air; however, some designs have no ventilation at all.

Some designs have a plastic layer lying on top of the gravel or earth. Usually today the layer is gravel so that the drainage is much better. This was changed because the earth bottoms were prone to collecting moisture.

Some of the newer solutions for a crawlspace is to turn it into another heated section of the house, complete with the same level of ventilation found throughout the house. This component is well insulated and is approximately the same temperature as the indoor environment (Elmroth et al. 2002).

Theory behind moisture design – building physics

Moisture design is a method of designing buildings taking into account moisture flows and levels (Airosto and Graad 1999) (Harderup 1998). This is based on the theories of moisture flow, air flow and heat flow in a building's envelope. A crawlspace with outside air ventilation has more risk of developing mould problems because of water condensing on the floor joists, concrete walls, insulation and floor surface. Mould begins growing when the moisture level is at a relative humidity of about 80%. During the summer it is not uncommon for the relative humidity to be at 100% in the crawlspace (Nevander and Elmarsson 1994, 293).

The temperature of the ground beneath a house changes temperature slowly during the seasons. In the winter there is very little chance of mould or moisture problems developing because the air entering the crawlspace contains very little water. The crawlspace is warmer than the outdoor air due to energy losses through the floor. In this case the relative humidity will decrease because of the outdoor air and the temperature in the crawlspace. In the summer the air entering is warmer and contains much more water than the air in the crawlspace can hold, the excess water is condensed out.

Understanding the complete system of temperature changes, energy loss from the building, saturation levels and mould have allowed researchers to simulate the crawlspace environment in order to determine the risk of mould growth (Harderup 2000) (Svensson 2001). This risk can also be indirectly used to predict the risk that a specific design will require renovations/repairs in the future.

Economic analysis of the cases

A total of 188 cases were examined from the archives of SSN. The information obtained included; the year of construction, the location, the crawlspace area (m²), the total cost to repair the building (SEK), and the market value of the house after completion of the repairs. Of these, 142 cases had all the information available. The remaining cases were usually missing one of the following components; the year of construction, the crawlspace area or the market value, however all of the data was used because all the cases contained the cost of remediation.

Looking at Figures 1 and 2, it is not possible to see an obvious trend in the data. However, it seems like the data indicates that cheaper houses are generally more problematic and are more expensive per m² to repair than larger houses.

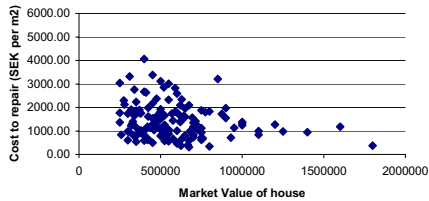


Figure 1: A graph of the market value of the houses compared to the cost to repair the damage (SEK) due to mould and/or moisture damage per m² of crawspace area.

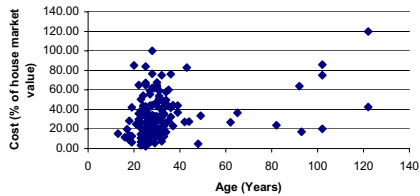


Figure 2: The relationship between the current age of the building and the cost to repair the damage expressed as the percentage of its market value.

In the cases studied, the average cost to repair a house with mould and/or moisture damage is 163000 SEK with a standard deviation of ± 81593 SEK. In relation to the value of the house, the average damage cost 33%, with a standard deviation of $\pm 21\%$, of the market value of the house to repair. Most of these repairs occurred when the houses were about 20 years of age.

The average year of the buildings examined was 1970. This agrees with the time frame for the data as seen in the limitations section. However, some buildings were over 100 years old. They were included because they had a section that met the requirements for funding.

In one case, the repair cost was equal to 120% of the market value (i.e. it cost more to repair the house than to build a new one of equal design). In this case the house was demolished, as economically it was not worth repairing the house.

Discussion

While it would be dangerous to draw any significant conclusions from the data in this paper, it is interesting to see the potential costs associated with a specific design. These are costs that are not advertised with the purchase of a building, however they are legitimate costs. It is interesting to look at it from the perspective of the building owner. If the owner borrows 1 million SEK to build a house, and the loan is paid back over 40 years, (assuming the loan is paid back in equal instalments on the principle loan) a repair cost after 20 years can result in the owner owing close to or more than the amount that they originally purchased the house for.

One defence against this situation happening to a homebuyer may be for the homebuyer to hire a competent engineering consultant that has a good history and knowledge of applying building physics. The homebuyer must trust their consultant and allow them to be involved as the client's representative during the design phase. In this way, the consultant can be instructed to look out for the homeowner's best interests and address small problems and issues that can be fixed quickly and cheaply during the design phase that could have a large impact in the future. Paying a little more for their services in the present can save a lot of money in the future (Yverås 2002).

Conclusions

If building physics principles are used one way or another during the design phase, the risk of damage of this magnitude occurring should decrease. The average cost to the homeowner to repair the damage has been about 33% of the house's market value. While it is not secure to draw any significant conclusions from the data used due to the spread of values, it is interesting to see the amount of money that is required after 20 years in order to maintain the indoor air quality of the building because of the problems caused by crawlspaces.

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10 Appendix II – Interview Questions

Key Question: How would you describe the design process of a building?

Design Process

- 1) How much time is spent evaluating buildings? (Moisture, lifetime calculations, energy use, thermal comfort, IAQ, ventilation etc...) key: to determine the level of importance of these issues.
- 2) How much time would you like to spend? Key: are they even aware of the issues or are they restricted in some way?
- 3) Hindrances? Key: Describing the restrictions.
- 4) How are the various aspects integrated to get the whole picture? Key: determine if there is any form of co-operation between the different consultant groups.
- 5) If you had more money on a project for the evaluation phase, where would you spend it? Why? (Get them to elaborate on the answers.) Key: To see if they are aware of the bp aspects. Do they really think it is important?

Key Question: What are the most important performance requirements when designing a building?

Performance Requirements

- 1) What performance requirements do you have and how do you check that they are evaluated? Key: Shows if they use the performance concepts at all.
- 2) Do the customers have specific requirements? Key: Shows the level of knowledge of the clients.
- 3) Are most clients experienced the construction industry? Key: Do the clients experienced with the construction industry skip over the consultants?
- 4) Does the consultant ask the clients about other requirements (above the minimum required by law)? Key: Shows if they understand performance concepts.
- 5) Has the clients ever suggested any other solutions that the consultants disagreed with? Key: How have they dealt with such clients? How do they show client's their mistakes in the design of the building? Do they even point out flaws if the client has approved/designed the design?
- 6) Do you ever educate your clients on the importance of evaluating a building's long-term performance? Key: Empowering the client, is it done?

Appendix II

- 7) Do the clients assume it's the job of the consultants to evaluate the building? Key: What is expected of a consultant?
- 8) Is it possible that, because some of the clients are not going to be the end-users of the buildings they commission that they do not care about the building's long-term performance?
- 9) Have you ever made recommendations that would improve a building only to have them dismissed by the client because of cost/other reasons? (Examples)

Key Question: How do you evaluate the performance of a building?

Tools (#1 Performance Decision Tools #2 BP & economic decision tools.)

- 1) Hypothetically speaking, what types of decision tools would be useful to you if there were some available? Key: Recognise holes in the market.
 - 2) What specific feature would you want in these tools? Key: Defining the tools needed.
(If not natural, steer towards performance and BP based tools and note reaction.)
 - 3) What are the benefits to your company in using these tools? Why not? Key: Identify obstacles for the implementation phase of our projects.
 - If pos. – Do you currently use any tools? Key: ID the 'good' software on the market.
- Yes – Which ones do you use? Describe their strengths and weaknesses. Key: Use this information to improve our own tools.
- No – Is there a reason to not use the tools ex. Are they too difficult to use, do they take too much time to use? Are the results from the current tools worthless? Key: Use this information to improve our own tools.

Key Questions: What influences do economical aspects, such as market conditions and market trends have on the design of a building?

Economical Aspects

- 1) What are the current market conditions (generally)? Key: Historical background
- 2) What are the current trends in regards to a) customer demands and b) industry demands? Key: Historical background

3) What do you have to gain by using performance and BP based tools? Key: Identify obstacles for the implementation phase of our projects.

Key Question: Moisture problems are becoming more popular in the media. As you know, it is a part of BP theory. Do you feel comfortable working with BP issues (heat, ventilation and moisture issues)?

Level of Competence

- 1) Do your co-workers feel comfortable with this?
- 2) How does the industry in general feel? Nervous?

Comfortable?

- 3) What is needed to solve this problem?

11 Appendix III – Report for Bo-Verket (In Swedish)

Statistik över fukt- och mögelskador i byggnader

Rapport 2003-01-14

Jesper Arfvidsson
Stephen Burke
Arne Elmroth

Appendix III

Avdelningen för Byggnadsfysik
Lunds tekniska högskola

1

Inledning

Syftet med denna undersökning är

- att sammanställa och utvärdera befintlig statistik beträffande fukt- och mögelskador i byggnader i Sverige.
- att analysera om de befintliga statistikkällorna innehåller adekvat information
- att ge en bild över vilken statistik som finns tillgänglig och vad som saknas.

Till fukt- och mögelskador hänförs inte, i denna undersökning, frostsador, vittring eller direkta vattensador.

Arbetet är utfört på uppdrag av Boverket, (Dnr 100-2786/2002)

Metod

För att få information om olika organisationer, myndigheter och företag för statistik över fukt- och mögelskador har ett stort antal telefonintervjuer genomförts. Dessa har i flera fall kompletterats med direkta intervjuer med personer som aktivt arbetat med frågorna i resp företag. Oftast har flera personer intervjuats inom ett och samma företag/organisation för att få ett bättre och säkrare bedömningsunderlag. För intervjuerna har målsättningen varit att få med ett företag som representerar olika aktörer inom hela byggsektorn. Vi har sålunda intervjuat byggföretag, konsulter, fastighetsförvaltande bolag, försäkringsbolag, kommunala organ m.fl.

En genomgång av befintlig litteratur inom området ges inledningsvis.

Resultat från litteraturgenomgång

I det följande redovisas genomgången litteratur med korta sammanfattningar av resultat och innehåll.

Utvärdering av Småhusskadenämndens arkiv avseende kryppgrunder, Genomgång av arkivet (C. Svensson 1999) [1]

Syftet med genomgången av Småhusskadenämndens arkiv är att finna material som är lämpligt att utvärdera med hjälp av fältmätningar och datorsimuleringar samt att redovisa åtgärder avseende fukt- och mögelskadade uteluftsventilerade kryppgrunder som varit vanliga under 1990-talet. Studien har avgränsats till uteluftsventilerade kryppgrunder som varit fukt- och mögelskadade och blivit åtgärdade med stöd från Småhusskadenämnden.

Svensson konstaterar i sin studie bland annat följande:

- En stor del av husen var 10 år eller äldre vilket indikerar att problem med fukt- och mögelskador i uteluftsventilerade kryppgrunder troligtvis kommer att fortsätta uppstå i både nyare och äldre byggnader.
- Materialet är omfattande men antagligen inte representativt eftersom ex. huseta ålder, beläning på huset, taxeringsvärde och åtgärdskostnad styr självrisken för husägaren och därmed i viss mån även vilka hus som blir åtgärdade.
- Hus byggda eller renoverade under 1970-talet är överrepresenterade. Detta beror delvis på att många hus producerades under denna period samt utformningen av bidragsreglerna.
- Undertrycksventilation är den helt dominerande huvudåtgärden i materialet. I många fall fungicidbehandlades grunden. Långtidseffekterna av detta är osäkra.
- Efterkontroll av funktion hos de åtgärdade grunderna är obefintlig.

Praktisk tillämpning av fuktdimensionering, Förstudie: Utvärdering av Småhusskadenämndens arkiv avseende kryppgrunder , (Pleijel 1995) [2]

För att kunna bedöma om de tekniska utredningarna går att använda i fortsatt forskningsprojekt krävdes någon form av genomgång av nämndens arkiv. Den genomgång som denna förstudie omfattar har begränsats till småhus grundlagda med kryppgrund. Sammantaget har material från 178 fuktskadade hus grundlagda med kryppgrunder samlats in. Studier har genomförts i 105 av dessa. Av dessa har 85 accepterats som möjligt underlag till fortsatt forskning. Ett antal allmänna kommentarer avseende de studerade tekniska utredningarna redovisas, bland annat:

- Flertalet konsulter för inte ett resonemang kring klimatets påverkan på gjorda fuktmätningar. I mycket få ärenden redovisas en rimlighetsbedömning av fuktmätningarna och inte i något fall att mätningarna är kvalitetssäkrade.
- I flera fall är orsakssambanden diffusa avseende elak luft.
- I de fall elak lukt har konstaterats förekommer sällan forcerad ventilation eller förbättrad ventilation enligt anvisningar i SBN som föreslagen åtgärd.
- Den dominerande åtgärdsmetoden är undertryckshållning (57,5 av antalet ärenden). I de flesta fall i kombination med konstruktiva åtgärder.

20 Fuktskador, (Samuelsson 1977) [3]

Syftet med denna bok är att belysa omfattningen av fuktskador och visa på möjligheten att beräkna fuktförlopp för att gardera sig mot framtida fuktskador. Skadorna beskrivna här utgör ett tvärsnitt av de skador som kommit till författarens kännedom och samtliga har utretts av personal från LTH. Det är författarens uppfattning att fuktskador är mycket vanliga. En sammanställning av Konsumentverkets fastighetsreklamationer i Uppsala och Gävleborgs län 1975 redovisas samt resultat från intervjuer med ingenjörer som arbetar med skadebesiktningar. Dessa menar att 70-80% av alla skador härrör från fukt. I skriften beskrivs fuktskador i olika sammanhang:

- Fuktskadade fönsterbågar och –karmar
- Fuktskada i frysrum
- Dubbelt plåttak
- Lagerbyggnad med platta på mark
- Slagregn mot fasadtegel
- "Läckage"

- Invändigt isolerat plåttak över potatislager
- Luktproblem i småhus
- Regngennomslag genom skalmur
- Saltutslag på tegelväggar
- Regngennomslag genom träfasad
- Sprickor i papptäckning
- Betongtak
- Avvattning av låglutande tak. Isproblem
- Putsavflagningar
- Golvskada i gtegnishall
- Kondens mot oisolerat plåttak
- Tegelbalkar
- Mögel i tryckimpregnerat virke
- Kakelskada i badrum

Vidare ges i litteraturlista på 56 svenska och internationella referenser i ämnet, de flesta från 1970-talet.

Mögel i hus, Orsaker och åtgärder (Samuelsson 1985) [4]

Rapporten handlar om åtgärder mot mögel och framför allt mögellukt i bostäder. Inga medicinska aspekter tas upp utan endast byggnadstekniska och i viss mån mykologiska. Rapporten sammanfattar erfarenheter från skadeutredningar mellan 1977-1985 gjorda vid Statens provningsanstalt i Borås. Under dessa år beställdes 360 skadeutredningar och dessa redovisas utifrån:

- Uppdragsgivare - kommuner och landsting störst följt av privatpersoner.
- Skadad byggdelen - uppreglat golv dominerande.
- Byggår - flest mögelskador på hus byggda 1975.
- Tid till mögellukt - de flesta mögeldoftande hus är nya.
- Skadeorsak - markfukt och läckage dominerande.

Mögel i bjällklag. Undersökningsrutiner och skadefall (Axén, Hyppel, Moqvist 1984) [5]

Rapporten beskriver utredningsrutiner, skadeorsaker och årgärdsmetoder. Sammanlagt har 795 hus undersökts (682 med betongplatta på mark, 81 suterränghus, 32 med kryppgrund). Redovisningen ger en bra bild av svårigheterna vid utredningar av fukt- och mögelskador. Orsakssambanden är dock ofta oklara.

Effekter av åtgärder i mögelskadade hus, Erfarenheter av skadeundersökningar och skiljedom i 146 hus i V Fasseröd, Uddevalla (Elmroth och Samuelsson 1987) [6]

I ett bostadsområde i Uddevalla uppfördes på 1970-talet sammanlagt 359 hus. Redan i samband med garantibesiktningar anmäldes problem med mögellukt. Tvist uppstod mellan husägare och byggherre som 1982 ledde till skiljedom. Då hade sammanlagt 146 husägare anmält mögellukt. Skriften redovisar och beskriver undersökningar och utredningar som föregick skiljedomens beslut. Resultaten sammanfattas till rekommendationer för skadeundersökningar av fukt- och mögelskadade hus.

Fukt, En handledning i anslutning till Boverkets byggregler av Gunnar Krakenberg (Krakenberg 1996) [7]

Krakenberg konstaterar att fukt anses vara den enskilt dominerande faktorn som orsakar byggfel och dålig inomhusmiljö. Han hänvisar till i sin skrift till bl. a. följande artiklar och skrifter:

- Byggsfelsesstudier inom SVR – Slutrapport från en arbetsgrupp, sammanställd av Sven G Bergström, Väg- och Vattenbyggaren nr 7 1989 visar att ca 40-50% av byggfelen härrör från projekteringen, ca 20-30% från utförandet på byggsplatsen och ca 10-15% från undermåliga material. Felen vid projektering beror till stor del på felaktig materialanvändning, i kombination med bristande eller felaktig materialinformation från tillverkare.
- SIB, Statens institut för byggnadsforskning undersökte i början av 1980-talet skadeförekomsten i byggnader uttryckt som behovet av extraordinärt underhåll. Som exempel på skadedrabbade konstruktioner ges:
 - Låglutande papptak
 - Uteluftventilerade krypgrunder
 - Platta på mark med ovanliggande värmeisolering
 - Källarytterväggar med invändig värmeisolering
 - Fönster och dörrar av trä

Den dyraste åtgärden anges vara byte av rötskadade fönster. *Är kostnaden att åtgärda skador och fel i husbeståndet för hög? N Tolstoy, Väg och vattenbyggaren 11-12 1984.*

- Lukt och mögelskadetredningar gjorda på SP, Sveriges Provnings- och forskningsinstitut, visar att de vanligaste skadeorsakerna beror på markfukt, läckage samt byggfukt. De dominerande skadade byggdelarna är uppreplat golv, flytande golv, kryprum samt källare. *Mögel i hus – Orsaker och åtgärder.*
- Allergitredningen refererar en expertgrupp inom Världshälsorganisationen, WHO, som uppskattar risken att nya hus kan drabbas av "sjuka hus" problem till 10-30%. *Allergitredningen – Att förebygga allergi/överkänslighet, Betänkande av allergitredningen.*
- I Sveriges allmännyttiga bostadsföretags bestånd av flerbostadshus är ca 58% berört av fukt och mögelskador. *Fukt och mögel i flerbostadshus.* En klar överrepresentation av skador finns på följande byggdelar:
 - Träfönster
 - Låglutande tak
 - Fasader
 - Våtrum i byggnader från perioden 1960-1973
 - Balkongen i byggnader uppförda före 1960.
- I ca 13% av alla flerbostadshus i Stockholm relaterar de boende sina hälsoproblem till bostadens inneklimat. Som mått på hälsobesvär har man använt SBS3-index > 5 (Yrkesmedicinska kliniken i Örebro och Statens Strålskyddsinstitut) som avser den andel boende i en byggnad, eller ett bostadsområde som uppges såväl allmänna symtom, slemhinnesymtom som hudbesvär och som relaterar dessa till inomhusklimatet. För "friska" bostadsområden brukar index anta värden under 5. Senare byggda hus har en högre %-andel ned SBS3 index > 5.
 - Hus byggda före 1961, 11%
 - Hus byggda 1961 – 75, 15%

- Hus byggda 1976 – 84, 19%
 - Hus byggda 1986 och senare, 24%
 - Upplevt inomhusklimat i Stockholms bostadsbestånd.*
 - I SIB:s forskningsprogram "Elhushållning i bebyggelsen"(ELIB) uppskattas att drygt 10% av de svenska bostadshusen har grova fuktskador och att dessutom ytterligare ca 13% har mer eller mindre allvarliga problem i våtrum. *Bostadsbeståndets tekniska egenskaper.*
 - I SIB:s forskningsprogram "Elhushållning i bebyggelsen"(ELIB) uppskattades att mellan 400 000 – 500 000 människor i Sverige utsätts för inneklimat som kan påverka hälsan och välbefinnandet. Detta innebär att ca 5-7% av de boende (ca 11% i flerbostadshus, 3% i småhus) i det svenska bostadshusen uppger att de besväras av inneklimatet i så hög grad att de för minst ett SBS-symtom. (Sick Building Syndrome). *Bostadsbeståndets inneklimat.*
 - Konsortiet Byggnadsgaranti var f.o.m. 1993-07 t.o.m. 1996 försäkringsgivare till byggförsäkringar och sedan 1980-talet försäkringsgivare som den statliga bostadsfinansieringen krävde (produktionsgaranti resp. ansvarsutfästelse vid väsentliga fel). Man redovisade drygt 1000 (3%) skador för 38 000 småhus byggda 1977-95. Felen härrör sig enligt följande:
 - Konstruktion 460st / 40%
 - Material 350 st / 30%
 - Utförande 375st / 25%
- Försäkringsvillkor med höga självrisker minskar benägenheten att anmäla mindre skador. Skadefrekvensen 3% är därför för låg.

Resultat från intervjuundersökningen

I det följande redovisas den information som insamlats från respektive företag. Redovisningen sker separat för varje företag som intervjuats. En uppdelning i Konsulter, Byggföretag, Försäkringsbolag samt Stat och Kommun har gjorts. För varje företag redovisas vilken typ av information som finns vilket då i viss mån avspeglar företagets behov av information. När statistik finns redovisas omfattningen, inklusive vilka begränsningar som finns vad avser omfattningen. Slutligen redovisas om uppgifterna är åtkomliga och på vilket sätt de i så fall kan användas.

Konsulter

AK-konsult

Typ av information:

Företaget utför ett stort antal skadeutredningar med anknytning till fukt- och mögelskador. Dokumentation av alla genomförda uppdrag finns. Den innehåller typ av skada, åtgärd samt uppföljning.

Dokumentationen kan utgöra underlag för statistisk bearbetning.

Antal registreringar:

Ca 1000 uppdrag per år.

Begränsningar:

Informationen är inte direkt sökbar utan måste först bearbetas manuellt.

Tillgänglighet

Informationen kan användas under förutsättning att uppdragsgivare ger sitt tillstånd till detta.

Anticimex

Typ av information:

Företaget har omfattande verksamhet vad gäller skadebesiktningar bl.a. med inriktning mot fukt- och mögelskador. Företaget gör också många s.k. överlåtelsebesiktningar. Underlag för statistik finns i form av dokumentation av genomförda uppdrag.

Antal registreringar:

Företaget har ca 5 000 dokumenterade uppdrag per år som har anknytning till ämnesområdet

Begränsningar:

Materialet har inte bearbetats statistiskt så att typ av skada eller omfattning kan urskiljas. För att få en struktur som är möjlig att bearbeta statistiskt erfordras en total manuell genomgång av materialet. För detta åtgår omfattande tid.

Tillgänglighet:

Det är oklart om företaget är berett att upplåta sin dokumentation för statisk bearbetning och under vilka villkor

Sycon-Barab – Konsultföretag

Typ av information:

Företaget utför ett stort antal skadeutredningar med anknytning till fukt- och mögelskador. Dokumentation av alla genomförda uppdrag finns. Den innehåller typ av skada, åtgärd samt uppföljning. Dokumentationen kan utgöra underlag för statistisk bearbetning.

Antal registreringar:

Det finns ca 20 000 för åren mellan 1982 och 2002.

Begränsningar:

Dokumentationen innehåller inga uppgifter om kostnader. Utredningarna avser endast större hus. Data efter 1990 finns i digital form.

Tillgänglighet:

Materialet uppges vara tillgängligt för statistisk bearbetning, men för detta erfordras en betydande arbetsinsats. Villkoren för hur det ska ske måste tydliggöras.

Sveriges forsknings- och provningsinstitut, SP Borås

Institutet utför utredningar med anknytning till fukt- och mögelskador. Informationen finns i form av dokumentation av genomförda uppdrag. Den innehåller, beroende uppdragets typ och omfattning varierande mängd information. Dokumentationen kan utgöra underlag för statistisk bearbetning i de fall materialet inte är konfidentiellt.

Statistik finns också framtagen inom projektet ”Damp building and health (DBH)” . Den bygger på en studie av 8681 hushåll. Denna data är konfidentiell fram till publicering. Viss data har dock redan publicerats: Bornehag et al 2001 [8], Hägerhed et al 2002 [9] och Bornehag et al 2002 [10].

SWECO

Typ av information:

Företaget utför skadeutredningar med anknytning till fukt- och mögelskador. Dokumentation av genomförda uppdrag finns. Den innehåller typ av skada, åtgärd samt uppföljning i de fall företaget varit med. Dokumentationen kan utgöra underlag för statistisk bearbetning. Ett nytt datorbaserat system för fastighetsunderhåll har utarbetats och börjat användas i MKB:s fastighetsbestånd i Malmö. Detta system är batadabaserat och kommer således att vara sökbar. Se vidare information om detta under MKB.

Antal registreringar:

Uppgifter om antal registreringar saknas.

Begränsningar:

Det mesta av materialet är inte direkt sökbar utan måste först bearbetas manuellt. Det nya datorbaserade systemet kommer att vara sökbar, men innehåller för tillfället för lita data för att vara intressant ut statistisk synvinkel.

Tillgänglighet

Informationen kan användas under förutsättning att uppdragsgivare ger sitt tillstånd till detta.

WSP (tidigare J&W)

Typ av information:

Företaget utför skadeutredningar med anknytning till fukt- och mögelskador. Dokumentation av alla genomförda uppdrag finns. Den innehåller typ av skada samt åtgärd och uppföljning i de fall detta är tillämpligt.

Dokumentationen kan utgöra underlag för statistisk bearbetning men måste i så fall bearbetas manuellt.

Antal registreringar:

Ca 100 per år

Begränsningar:

Informationen kan användas under förutsättning att uppdragsgivare ger sitt tillstånd till detta.

Byggföretag

JM Byggnadsaktiebolag

Statistik om fukt- och mögelskador saknas.

NCC Byggnadsaktiebolag

Statistik om fuktskador saknas

Skanska Byggnadsaktiebolag

Arbete med att sammanställa statistik för fuktskador pågår inom företaget.

Tillgänglighet:

Informationen kommer att vara konfidentiell och får endast användas internt inom företaget.

Försäkringsbolag

IF – försäkringsbolag

Statistik om fukt- och mögelskador saknas helt.

Länsförsäkringar AB

Statistik om fuktskador saknas.

Svenska försäkringsförbundet

Svenska försäkringsförbundet samlar ihop statistik från samtliga försäkringsbolag. Statistik över vattenskador finns [11], men statistik om fukt- och mögelskador saknas.

Trygg Hansa- försäkringsbolag

Statistik om fukt- och mögelskador saknas.

Stat och kommun

Kommunala Miljöförvaltningar

Typ av information:

Kommunala miljöförvaltningar hanterar ärenden med fukt- och mögelskador som anmäls av vanligen en hyresgäst som inte fått åtgärder utförda av sin hyresvärd. Miljöförvaltningen gör nästan alltid en besiktning som dokumenteras och arkiveras. Underlag för statistik finns sålunda hos miljöförvaltningarna. Varje anmält ärende lagras för sig i sökbara databaser.

Antal registreringar:

Alla kommuners miljöförvaltningar registrerar samtliga anmälda ärenden. Antalet ärenden kan variera från något fåtal till många – givetvis beroende på kommunens storlek.

Begränsningar:

För att ett ärende skall registreras och arkiveras i en databas hos miljöförvaltningen krävs att detta först är anmält till hyresvärd men att denna lämnat anmälan utan åtgärd. Miljöförvaltningarna gör ingen statistisk bearbetning av anmälda fukt- och mögelskador. Databaserna är inte centraliserade utan information lagras lokalt i respektive kommun. Vilken information och hur den skall lagras är reglerat i lag. Det finns dock inte gemensamt databasprogram eller -format som alla kommuner använder. Programmet "ECOS" verkar vara det program som förekommer i flest kommuner. Tillverkaren av detta program "Tekis" har

meddelat att 220 kommuner använder deras program. Övriga kommuner använder program med likartade funktioner. Kommunerna utväxlar inte information med varandra.

Varje kommun har olika begränsningar för hur långt tillbaka i tiden det är möjligt att söka information. Några exempel:

I Lunds kommun finns ärenden lagrade för de senaste 10 åren, medan man i Landskrona kommun endast kan komma åt information från ärenden efter 2001. I Landskrona installerades 2001 ny programvara. Denna är inte kompatibel med deras tidigare system. Äldre ärenden finns dock kvar i form av akter på papper och sökning bland dessa är således ganska arbetsintensivt.

Tillgänglighet:

All information som är lagrad i nämnda databaser är offentlig. Databaserna är dock inte fritt åtkomliga för allmänheten utan informationen lämnas ut av resp miljöförvaltning på begäran. Det är möjligt att databaserna kan göras tillgängliga för statistisk bearbetning av fukt- och mögelskador.

MKB (Malmö kommunala bostadsaktiebolag)

Typ av information:

Företaget är en mycket stor fastighetsförvaltare i Malmö kommun. Information om skadetyper, eventuella mätresultat med anledning av skador, åtgärder, kostnader och ritningar lagras i en databas. Konsultföretaget SWECO ansvarar för all hantering av MKB:s fukt- och mögelskador. Det har utvecklats och sköter det aktuella databassystemet.

Antal registreringar:

Databassystemet har nyligen tagits i bruk, varför antalet registreringar hittills är få.

Begränsningar:

Antalet registreringar är ännu så länge litet, men torde framdeles komma att innehålla värdefull information. Det finns ännu inga rutiner för hur bearbetning av databasen kommer att ske.

Tillgänglighet:

Information i databasen är inte offentlig. Det är oklart om den kan eller får användas till officiell statistik.

SABO - de allmännyttiga bostadsföretagens centralorganisation

Statistik om fuktskador saknas

Småhusskadenämnden

Typ av information:

Småhusskadenämnden hanterar fukt- och mögelskador i vissa årgångar av småhus. Nämnden ombesörjer en utredning avseende omfattning och orsaker samt föreslår relevanta åtgärder. Det finns sålunda förhållandevis omfattande information och av god kvalitet för de skador som nämnden hanterar

Antal registreringar:

Det finns ca 14000 ärenden registrerade i nämndens arkiv

Begränsningar:

Det är en rad villkor som måste vara uppfyllda för att ett ärende ska hanteras av småhusskadenämnden. Huset skall vara:

- yngre än 25 år (om det inte är kraftigt om- eller tillbyggt)
- byggt före 1989
- uppfört för permanent bruk
- allvarligt skadat vid ansökningstillfället
- ett en- eller tvåfamiljshus.

Materialet går enbart att bearbeta manuellt. Det krävs en stor arbetsinsats för att göra materialet statistiskt bearbetbart. Nämnden gör ingen egen statistisk bearbetning av skadefallen.

Tillgänglighet:

Småhusskadenämndens arkiv är offentligt och all dokumentation. är tillgängligt för ytterligare bearbetning.

Statistiska centralbyrån

Statistik om fuktskador saknas.

Sammanfattning av intervjuresultaten

Resultatet från undersökningen visar att befintlig statistik över fukt och mögelskador i Sverige är ytterst begränsad. Systematiskt bearbetad information som är offentligt tillgänglig tycks inte finnas. Försäkringsbolag har väl samlad statistik om direkta vattenskador, vilka normalt omfattas av försäkring. Motsvarande saknas för byggregulerade fukt- och mögelskador. Byggtreprenadföretagen har endast i undantagsfall samlad information om sådana skador och i den mån uppgifter finns är de tillgängliga endast för företagets interna bruk.

Det syns som om förvaltningsbolag börjat samla information i databaser som sannolikt avses kunna användas för företagets underhållsplanering. Denna information torde inte heller på ett enkelt sätt var tillgänglig annat än i undantagsfall. Det finns flera konsultföretag som utför skadeutredningar vilka är väl dokumenterade i företagets arkiv. I åtminstone något fall har det meddelats att denna information skulle kunna få utgöra underlag för statistisk bearbetning. Det innebär emellertid ett omfattande arbete. Småhusskadenämnden har utförlig information om skador, men urvalet hus som ingår är väl avgränsat till vissa årgångar av småhus och särskilda villkor för stöd måste vara uppfyllda. För denna grupp av hus kan intressant information erhållas genom att göra –sannolikt en arbetskrävande – genomgång av arkivet som är offentligt tillgängligt.

SP deltar för närvarande i en mycket stort forskningsprojekt som gäller att studera samband mellan barns hälsa och förekomst av bl.a. fuktskador i hus. Undersökningen är begränsad till Värmland och har inledningsvis startats med en enkätundersökning. I nu pågående etapp har ett större antal hus besiktigats och barnen hälsoundersökts. Resultat finns ännu inte publicerade, men de kan förväntas innehålla intressanta uppgifter om förekomst av fukt- och mögelskador. Information från denna studie bör kunna utnyttjas för planering av hur statistik kan läggas upp.

Den källa till information som är offentlig och som skulle kunna bearbetas finns hos kommunernas miljöförvaltningar. Här finns ett stort antal sökbara databaser tillgängliga. Dessa innehåller en stor mängd information som skulle kunna samlas in centralt och bearbetas. En mall för vilken information som krävs för att skapa en adekvat upplösning i olika typer av fuktskador bör utformas. Många ärenden kommer emellertid inte till miljöförvaltningarna eftersom de endast hanterar sådana ärenden som inte lösts direkt mellan hyresvärd och hyresgäst.

Förslag till åtgärder

Det synes som om kommunernas miljöförvaltningar har de bäst utvecklade tillgängliga databaserna som kan utnyttjas för att få statistik om fukt- och mögelskador. Problemet är bl.a. att det endast är ärenden som inte lösts mellan hyresvärd och hyresgäst som finns dokumenterade. En statistik blir därmed klart underskattad vad gäller förekomst av skador och behöver kompletteras på annat sätt. Miljöförvaltningarnas dokumentation skulle behöva studeras ytterligare och man bör närmare undersöka förutsättningarna för att kunna ta fram statistiskt bearbetad information. En möjlig väg som synes föreligga är att ta fram en mall för

hur information ska samlas in och vilka uppgifter som denna mall lämpligen bör innehålla. Det bör närmare utredas hur representativa uppgifter som med rimlig arbetsinsats kan erhållas.

Det synes också vara möjligt att göra en närmare genomgång av den dokumentation som finns dels hos några konsulter dels hos några större förvaltningsbolag för att kunna erhålla en bättre bild av förekomst, typ och omfattning av fukt- och mögelskador i byggnader. Det är möjligt att information från dessa företag skulle kunna utgöra underlag för statistik över fukt- och mögelskador i byggnader.

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