Energy efficient and healthy buildings

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Abstract
Indoor environment has become an important subject matter in Scandinavia since increasingly many buildings demonstrate poor indoor air quality, problems with mould and other sick building syndromes.

There are worries that the malignity is derived from tighter constructions and more sparse ventilation since problems have been escalating contemporary to better energy efficiency in the building stock.

Based on this possible linkage, Sweden has decided to include also indoor environment aspects in the implementation of the directive on energy declaration of buildings. By the same token, a co-operation between the Swedish Energy Agency (STEM) and the National Board of Housing, Building and Planning is underway where more than 100 schools are investigated regarding their energy usage patterns as well as their indoor environment status. Results from this inventory will be elaborated in this paper.

The hypothesis for the investigation is that it is quite possible to demonstrate energy efficient and healthy buildings, and therefore results will give no significant statistical linkage between poor indoor quality and low specific energy use. Preliminary findings underpin this assumption. The paper will discuss the factors and their statistical interaction in more detail, and a discussion will be held on what other reasons there can be behind the sick buildings.

Introduction

MOTIVATION
The Swedish goal for energy demand in buildings is a decrease with 20 % by 2020 and 50 % by 2050. Given these goals and efficiency opportunities in the building sector a thorough knowledge of its characteristics is essential for the governments development of incentives. However measures have to be carried out in a careful way in order to avoid indoor health hazards.

Sweden investigated its buildings in 1990 from an energy and indoor health aspect, the STIL and ELIB projects. However only the domestic sector was investigated from an indoor health perspective (the ELIB project). A follow up to these studies has been planned for some years not least as a support for the implementation of the Building performance directive and the Energy services directive. In 2005 office buildings were investigated once again, but only from an energy viewpoint. The paper "A key to success: Improved statistics on energy end use in buildings", deals with these results. Last year the Swedish Energy Agency joined its energy investigation for schools with an indoor health investigation financed and organised by the National Board of Housing, Building and Planning.

There are two main ways to conserve energy, to optimise the function of the system in question or to question the system all together. This paper deals with the former: can energy consumption be lowered without degrading the environmental performance of the climatic envelope that our buildings provide. When striving to conserve energy usage it is important to keep in mind the physical parameters maintained by installations in the building. The integration of energy and indoor environment issues meets the growing needs to assess buildings as an entirety and not only as an energy-consuming device.

OTHER RELEVANT STUDIES

Before launching the STIL2 programme the most recent available Swedish energy-statistics for non-domestic buildings were compiled in 1990, in a project called STIL ("Statistik i lokaler", "Non-domestic buildings statistics"). Apart from delivering up to date energy statistics, the STIL2 programme also enables comparisons between energy end-use in buildings between 1990 and energy end use of today.

ELIB was conducted in the early nineties by the Swedish Institute for Building Research (SIB) in co-operation with the Department of Occupational and environmental Medicine in Örebro and the Swedish Radiation Protection Institute. The project had three main areas of interest, Indoor environment, Technical characteristics of the housing stock and Energy savings potential. The project was nations wide study of Swedish dwellings and the first such to include indoor environment.

Quality assurance in O&M- Energy and environment (An O&M tool for certification of energy performance and indoor environment) Ulf Rengholt et. al. 2005)

The project by LFF (Supply of Premises Administration) in the city of Gothenburg has developed an O&M tool where energy use and indoor environment quality are integrated issues. The tool comprises techniques to measure and assess thermal-, air-, lightning-, and sound quality, and methods to determine energy use by quantity and fuel.

The result is an O&M tool capable to create combined energy-indoor environment certificates in line with the EPBD, including measures to improve energy performance and indoor environment. Using such methodology will lead to increased sustainability in the energy context ant to healthier and more comfortable environments.

SAMPLING

The investigated population consist of certain kinds of schools according to Swedish categorisation of enterprises (*Företagarregistret*): primary schools (*Förskolor, SNI 80101*), schools (*Grundskolor, SNI 80102*), high school *(Gymnasieskolor, SNI 80210)* and vocational high schools *(Gymnasiala yrkesutbildningar, SNI 80211).* Furthermore, restrictions are set considering the sensibleness of energy audits:

- The area shall preferably be larger than 200 m^2.
- School activities shall conform at least 80 % of the investigated area.
- One full year of complete energy statistics shall be available, and in the case of schools with electric heating, monthly values are required.
- School activities shall have been ongoing in the concerned building(s) for at least one year, and shall continue throughout the period of investigation.
- Schools forwarding energy to other end-users shall be avoided.

The sample has been derived in two steps, 1) a sample of municipalities (21 of the total 290), and within these 2) a sample of schools, aiming at a total number of 130. Municipalities are stratified by climate and population density. Moreover, a larger probability where given to large population centres. For practical reasons further, sites close to the auditors home-office where prioritised before those at large distance. A gross-sample of 433 schools in the 21 municipalities prepared the ground for the final set of 130 chools. A third sampling weight derives from the fact that for a few schools, the inventoried area does not exactly equal the actual full area of the concerned school. Each school covered by this investigation thus has a weight for scaling up results to the national context. The scaling up has however not been made in this article, the focus has been on comparing energy and environment parameters for individual schools.

Inventories

ENERGY USE INVENTORY

Method

Focus for the energy inventory has been to quantify electricity requirements by purpose other than heating in the school sector. However, knowledge of the overall energy balance is a prerequisite for proper allocation of electric energy into categories.

Inventories of energy end use patterns in the 130 schools have been made in two major steps. First, contacts were established with the official school caretaker, commonly responsible for several schools in a municipality. They can provide drawings, recent energy statistics and other relevant information about the usage of the school building. In addition to contacting the caretaker, the project has in many cases contacted the energy service provider(s) in order to complement or verify energy statistics for the concerned schools. The entire school, including all buildings has been included.

Secondly, an energy-auditor visits the school. The total recorded electricity use is allocated to different end-user categories. Besides observations in each room, observations in installations control room and server rooms if any, a dialogue with responsible staff is paramount. School staff knows how equipment is used. The project has relied on around ten auditors, trained in a common methodology for estimating, specifying and compiling data. Further to this, two specialists have had the quality assurance role, including revisiting around 10% of the buildings for a control-audit.

Parameters related to energy-use referred to in this article are determined as follows:

Area [m^2]: The inventoried area measured from drawings. Overall Internal Dimension (OIDt)(temperate) is used. OIDt is defined as the total area within outer walls, excluding non-heated area (< 10 °C).

No. of children/students: A Figure derived from the schools' own statistics.

Energy use MWh per year: Based on records kept for a period of at least twelve months within the latest eighteen months.

Specific energy use kWh/m^2, year: For each school its energy use is divided by its area.

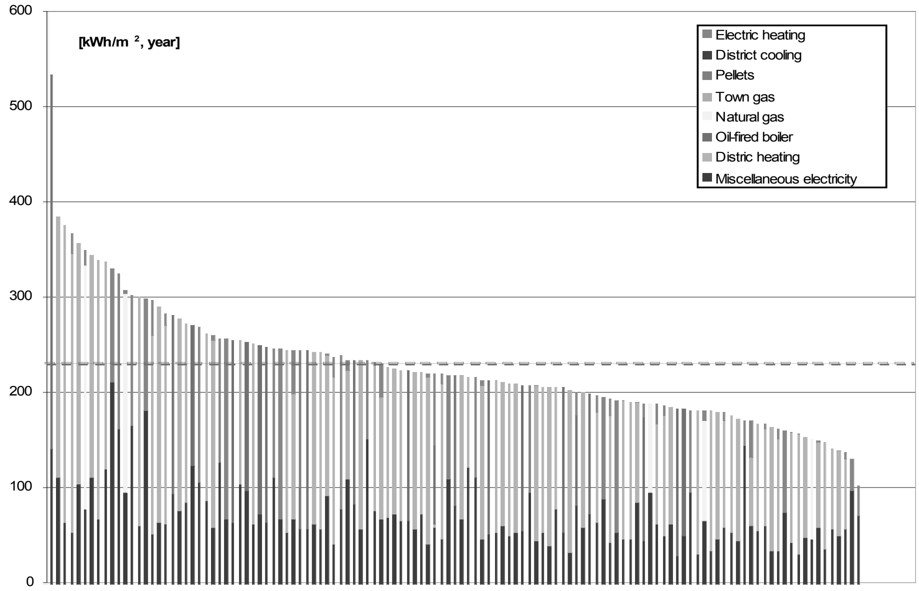

Figure 1: Annual total specific energy use by form of energy and per school [kWh/m2], distribution and mean.

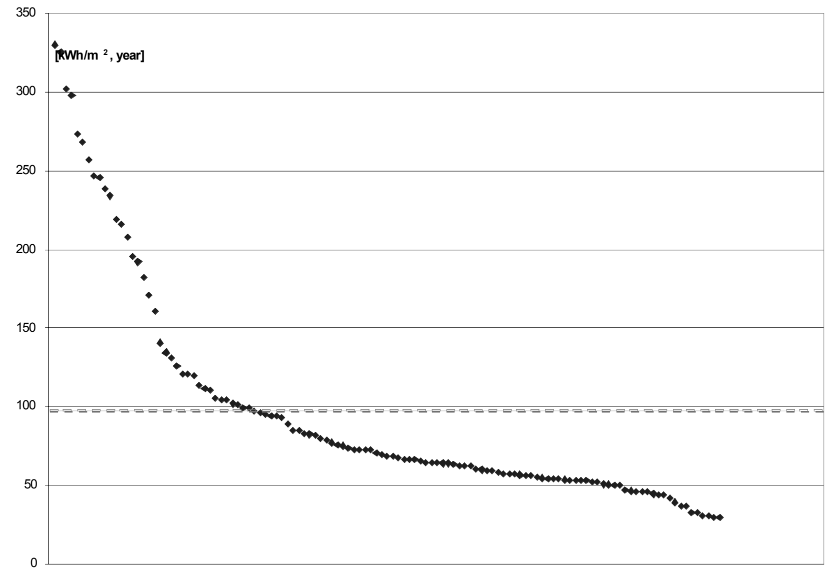

Figure 2: Annual specific electricity use for non-heating purposes per school [kWh/m2], distribution and mean.

Air change rate [1/h]: The total flow, including all ventilation aggregates times the total indoor air volume, calculated from OIDt and estimated average room height.

Specific air flow [lit/s, m²]: The weighted sum of each ventilation aggregates' flow divided by the area of the building or building section it serves.

Specific fan power: The total electricity used by the fan divided with the larger of the incoming and outgoing air flow rate.

Fans' electricity requirement, specific per area [kWhel/m², year]: The total annual electricity used for fans in each school, divided by the schools area.

Lighting electricity requirement, specific per area [kWhel/m², year]: The total annual electricity used for lighting in each school, divided by the schools area.

Annual specific electricity use kWh/m²: For each school its electricity use divided by its area.

Annual specific electricity use for heat kWh/m²: For each school its electricity use for heat divided by its area

U-value: The weighted average of the estimated U-value for the walls, window and roof for each school

Findings

Annual specific total energy use in the 130 schools vary between 102 and 535 kWh/m², the mean value is 232 kWh/m² and the median 220 kWh/m². Of this between 30 and 331 kWh/m² is electricity for non-heating purposes, the allocation of which will be looked further into. Other energy supply than electricity is typically district heating, oil and gas for heating and hot tap water, refer to Figure 1. Mean specific electricity usage for non-heating purposes is 102 kWh/m², refer to Figure 2, and the median is 73 kWh/m².

Lighting and fans constitute major electricity use categories in the school sector, on average 20,0 and 18,2 kWh/m² each. Other prevalent purposes of electricity use are kitchen

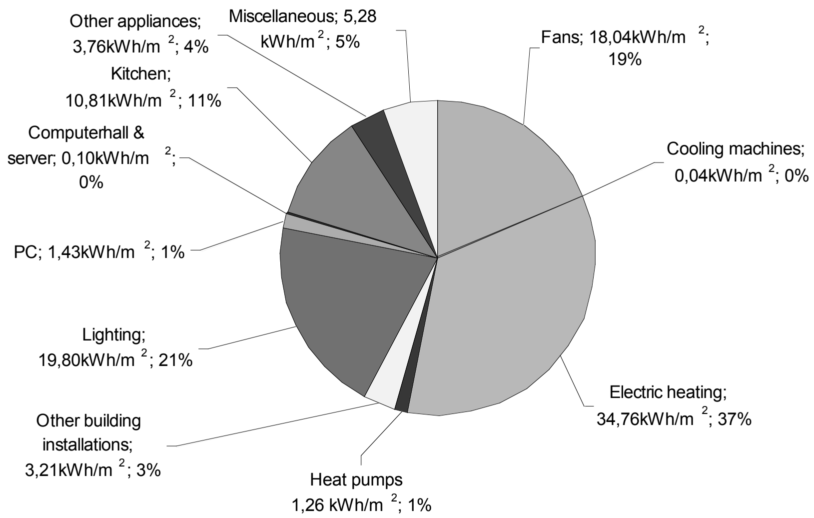

Figure 3: Allocation of specific electricity use in different end-use categories, inclusive of electric heating, mean for all schools [%].

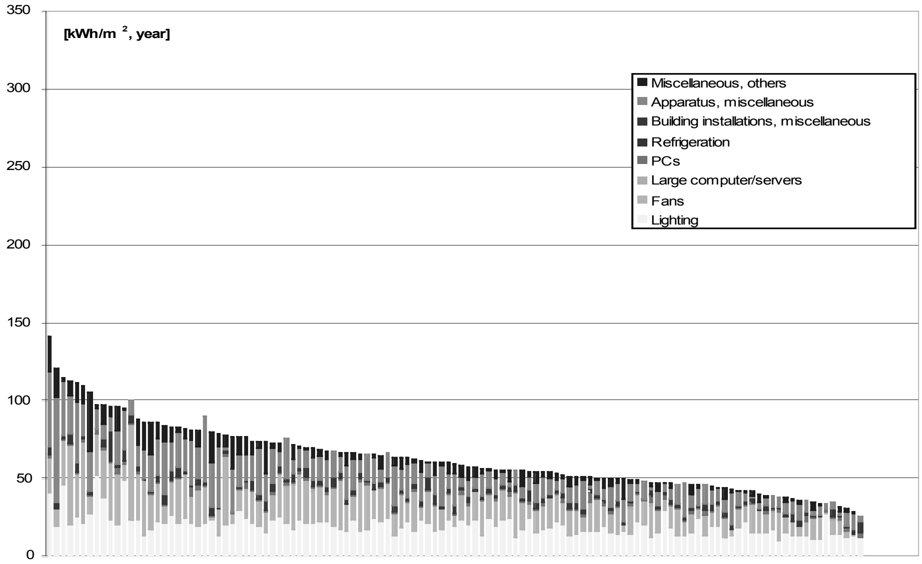

Figure 4: Annual total specific non-heating electricity use by purpose and per school [kWh/m²], distribution and mean.

(11,3 kWh/m²), pumps (3 kWh/m²), and cloth-washers and tumble-driers (2,8 kWh/m²), where averages include all schools. Refer also to Figure 3.

The spread between the school consuming least and most energy, one to five, as can be seen in Figure 1, can also be observed for electricity demand for non heating purposes, Figure 2 and Figure 4, and for specific electricity demands such as lighting, Figure 5, and ventilation Figure 6. There is consequently a considerable window of opportunity for reducing the energy demand in Swedish schools. For lighting we know that there are still many incandescent lamps as well as old fixtures with magnetic ballasts. Almost all schools are now mechanically ventilated, but operating hours and system performance vary quite a lot. The main issue is however are the best energy performing schools also acceptable from an indoor environment point of view? We will look into this in the two following chapters.

ENVIRONMENTAL INVENTORY

Background

To save energy without jeopardising the environmental performance of the building it is vital to survey the technical status of the building. During the oil-crisis prices on oil vent up and a great effort was made to decrease oil consumption for heating this was made in Sweden mainly by additional insulation, decrease in unintentional ventilation (air leaks) and intentional ventilation as well. These actions have been blamed for a degradation of the indoor environment and increase in problems in connection with moisture and dampness in buildings.

In the early ninetieth century the Decree (1991:1273) on performance inspection of ventilation systems was implemented to safeguard sufficient ventilation in buildings. This inspection target individual systems for air distribution and frequency of inspection depends on the kind of technical system in question.

The indoor environment for children is prioritized in Swedish legislation children and infants are especially susceptible to infection and decease. The inspection interval for schools

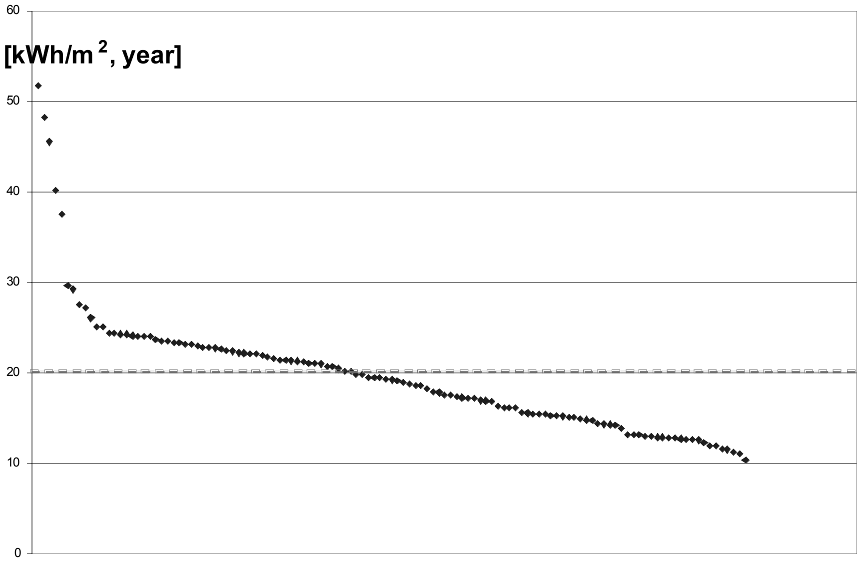

Figure 5: Lighting, annual specific electricity [kWh/m^2], distribution and mean.

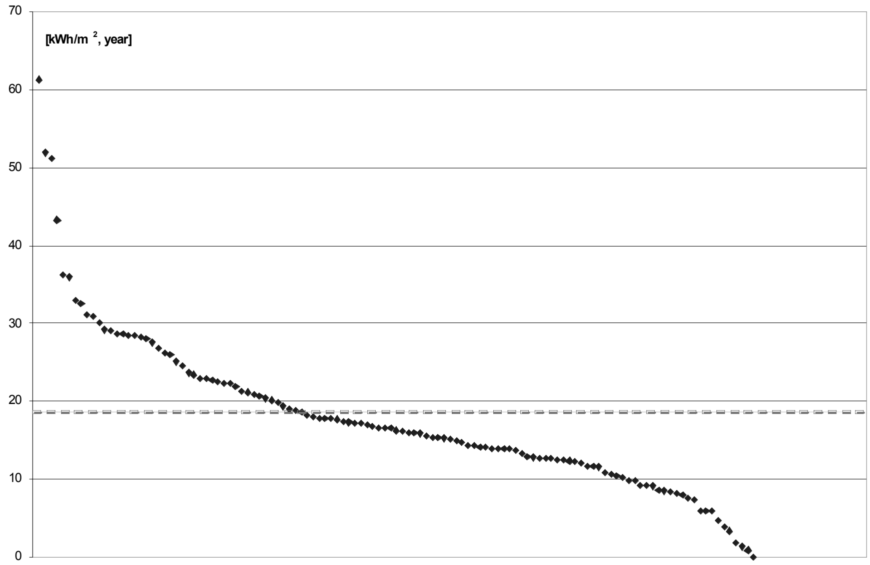

Figure 6: Fans, annual specific electricity [kWh/m^2], distribution and mean

is therefore every second year for schools, kindergartens and hospitals.

In the Swedish environmental goals the school environment is therefore especially important and is singled out in terms of radon (<200 Bq/m^3) and ventilation (documented well functional ventilation). This survey of Swedish schools is intended as a follow-up on these goals.

Method

13 persons trained in using the chosen evaluation model carried out the assessment of the indoor environment. The model consists of 29 aspects that are investigated on site while conducting a survey of the building. Prior to the on site survey it is preferable if as much knowledge as possible is gathered from drawings, known problem areas and other relevant documents that can be provided by the staff and caretaker organisation. Each of the 29 aspects is generally a result of several different parameters. The survey relies heavily on the expertise of the persons involved and the co-operation of the maintenance staff responsible for the building. From this set of parameters an overall grading is made in 5 levels. 5 being the most preferable, 3 represents acceptable but with room for improvement and 1 the most negative grading. The result from the 29 aspects gives an evaluation for the building of thermal comfort quality (5 aspects), cleaning efficiency (3 aspects), magnetic fields (1 aspect), radon(1 aspect), indoor air quality (8 aspects), indoor light quality (2 aspects), indoor noise performance (5 aspects), risk of legionnaire's disease (1 aspect), and problems related to dampness (3 aspects). Evaluations referred to in this article are:

- Total indoor quality
- Thermal comfort quality
- Indoor air quality
- Indoor light quality
- Quality of sound (noise)

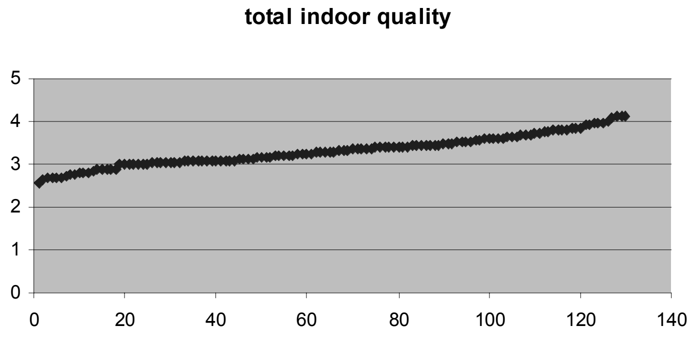

Figure 7: Distribution of indoor quality

Findings

The overall assessment of the indoor environment is given by total indoor quality, the average value of all 29 questions. This value ranges within the schools from 2,55 to 4.14 with a mean value for all schools of 3,32. The distribution is close to linear, as is seen in ***Figure 7***, with a standard deviation of 0,36. As a whole this portraits a standard for these buildings that is slightly above acceptable but there is much that can be improved.

Table 1 shows the spread over different evaluations of technical status of the buildings. It is important to note that for example one question of the eight that make out indoor air quality only carries 12,5 % of the weight when compared to magnetic fields that has only one question of the 29. This means that for one building the average for the evaluations listed in table 1 is probably not the same as the average for all 29 questions.

It should be noted that only two of the averages of technical status of the buildings for the total sample is below acceptable (grading 3).

The first of two is cleaning efficiency that grades how easy it is to keep clean in the building, important aspect here are the height of shelves, how much things are left on surfaces which are to bee kept clean and the properties of the surfaces. As most cleaning is made by contractors the result of their effort is dependent on the properties of the facilities.

The second is assessed risk of legionnaire's disease; amongst the things noted here are length of blind pipes and the temperature of water in the boiler and also the temperature that can be reached in the most distant faucet. If energy is to be saved by decreasing the temperature in the boiler actions to minimise risk of legionnaires decease must be taken in the water system.

The distribution of the parameters referred to in this article for each school is as shown in Figure 8. All four of the individual parameters display a similar distribution. It can be noted that thermal comfort shows the largest range and indoor light quality the smallest range in grading. It is possible that the spread in these gradings is reflecting our adapting to and understanding of the subject in question. Air and light quality is readily adapted to and not seen as such an important problem, whereas noise and thermal comfort is noted instantly but difficult to influence, especially if you already have put on all your available clothing or can not bare the thought of taking of any more when it is to warm.

Table 1: Results for the best and worst environment evaluations with average for total sample

	Best	worst	average for total sample
Thermal comfort quality	4,8	2,5	3,39
Cleaning efficiency	3,6	2,5	2,95
Magnetic fields	5	3	3,03
Radon	5	3	3,84
Indoor air quality	3,5	2,5	3,13
Indoor light quality	4,5	2,5	3,96
Indoor noise performance	4,5	3	3,58
Risk of legionnaires disease	4	3	2,36
Problems related to dampness	4,6	2	3,17

Energy use and healthy buildings

Parameters from the energy inventory have been plotted against the various grades for indoor quality. The linkage between energy use and indoor quality is generally weak. There is a slight tendency that energy efficient schools have better total indoor air quality, as seen in Figure 9.

Thermal features of the building envelope plays a role in this relation as can be seen in Figure 10, and the lower overall U-values, the higher thermal comfort grades, as shown in Figure 11. The overall U-value includes windows and the better the windows are, from an energy performance view, the better thermal comfort they provide. Schools built before 1978 had only two pane windows. After 1978 three pane windows were required, at first specifically in the building code and after some years indirectly through building code demands on an overall mean low U-value. Even if we see a correlation between overall U-value and Thermal Comfort Quality as shown in Figure 11 the spread is considerable. Possible explanations are the role of building tightness, the ventilation distribution performance and the amount of air changes per hour.

Air quality grades increase a little with increasing specific air flow as shown in Figure 12. Although all schools by far fulfill the minimum air flow level (0,35 liter/s, m^2) for buildings set by the National Board of Housing, Building and Planning, it appears that air change rates impact the quality of indoor air. This minimum air flow is set without regard to the number of people meant to occupy the building. When taking that into account an additional 7 liters per person and second is required by the Swedish Work Environment Authority. However here is also a considerable spread. We can see many schools with a low specific air flow giving an indoor quality index greater than three, see Figure 12. Further analyses are required to properly understand this relationship. At least we can say that a higher air flow does not automatically mean that the indoor quality gets better. Data from enquiries with personnel in each school have been made but were not available in time for this paper. The relation between the electricity demand for the fans per m^2 in relation to indoor air quality, Figure 13, shows hardly any trend. This would suggest that it is much better to measure the specific air flow than fan electricity.

It is interesting to observe that schools with a better lighting quality use less electricity refer to Figure 14. There are two possible explanations for this. Modern efficient fixtures which use high frequency ballasts have less flicker than the old inefficient fixtures. This hypothesis has not yet been verified, but available data is enough to do this analyses. The second explanation could be that schools which use little electric lighting might be optimized for day lighting. Day lighting might be perceived as more positive than electric lighting.

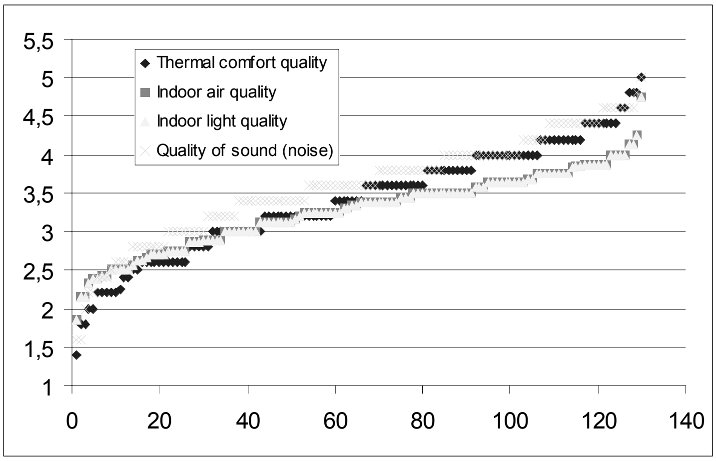

Figure 8: Distribution of four indoor environment evaluations

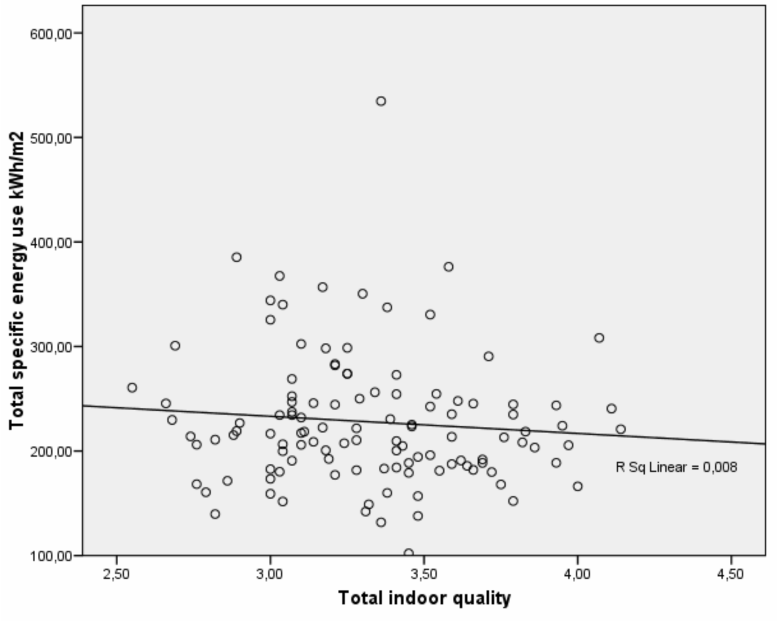

Figure 9: Total energy use and overall indoor quality

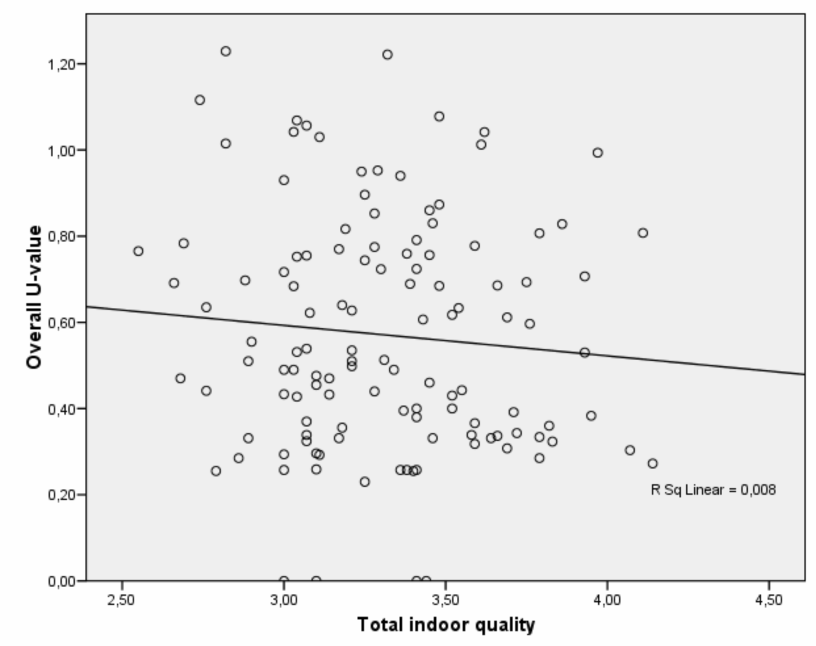

Figure10: Building envelope and overall indoor environment quality

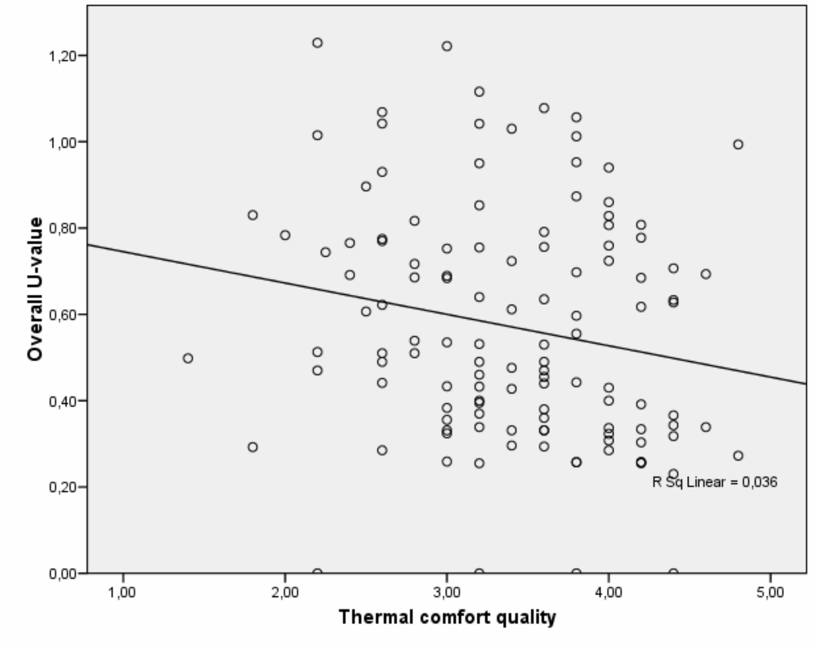

Figure 11: Building envelope and quality of thermal comfort

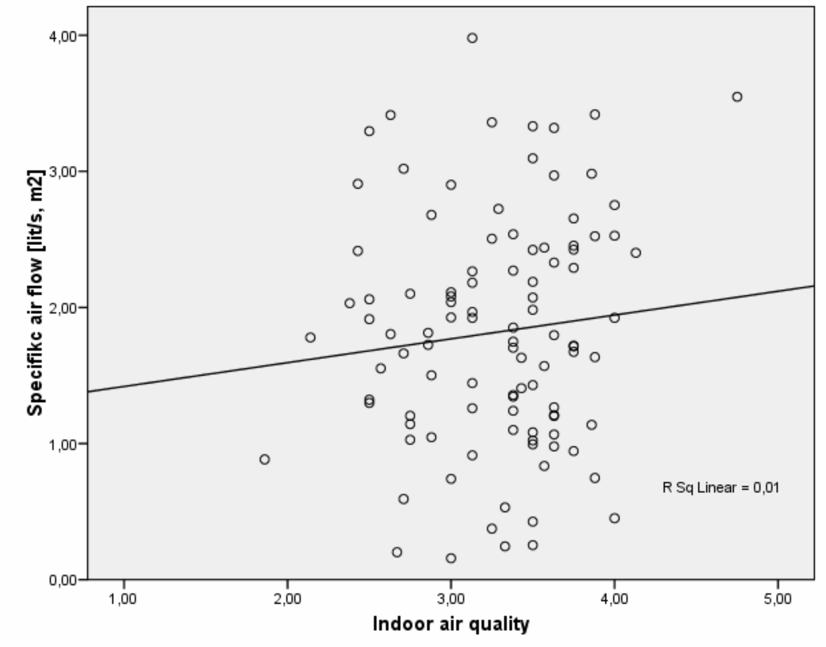

Figure 12: Specific air flow and indoor air quality

It is indicated in Figure 15 that the more fan power the school has the more noise it will make. However here we also have a significant spread. Noise can be related to other factors such as absorptive qualities of walls and ceiling, duct sizing versus air velocity and noise dampers in the ventilation system.

Discussion

Ever since the rapid introduction of energy efficiency technologies in buildings in the mid 1970's there has been a rumour that making your building energy efficient also means that you get sick a building with moisture and mould. This did happen in some cases but the cause was bad solutions and bad craftsmanship. Some buildings were made airtight without taking into account the need for ventilation. Sweden has introduced several measures to avoid this potential problem, both within the building code and with the mandatory ventilation inspection scheme.

Our hypothesis was that buildings could be both energy efficient and healthy. The findings in this survey indicate that this could be the case, see Figure 9: Total energy use and overall indoor quality. This graph actually shows the opposite, the lower the energy demand the better the indoor quality. However the spread is significant and we can of course find individual schools that have a low energy demand and bad total indoor quality.

But is this the truth? Total specific use includes all energy used, heating, hot water, and electricity. Is for example electricity for computers relevant? What about total indoor quality, in-

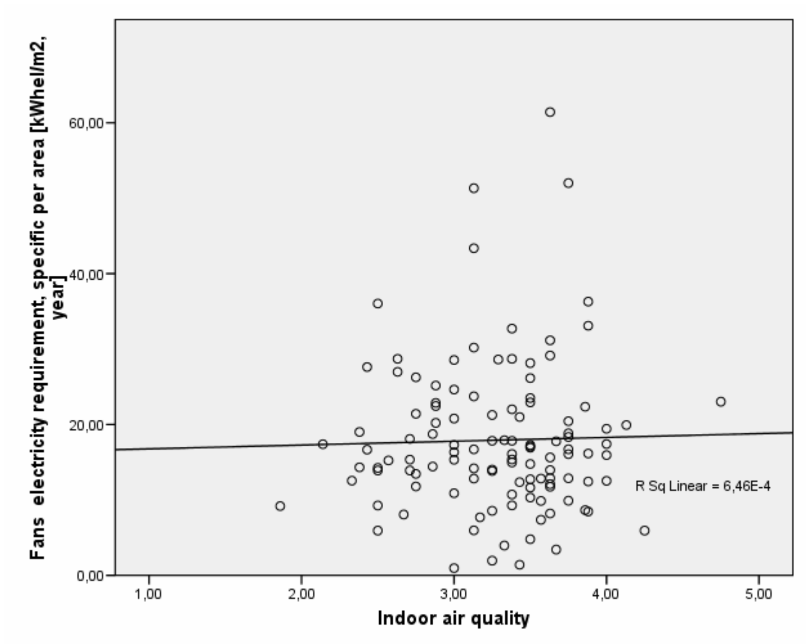

Figure 13: Fans specific electricity use and indoor air quality

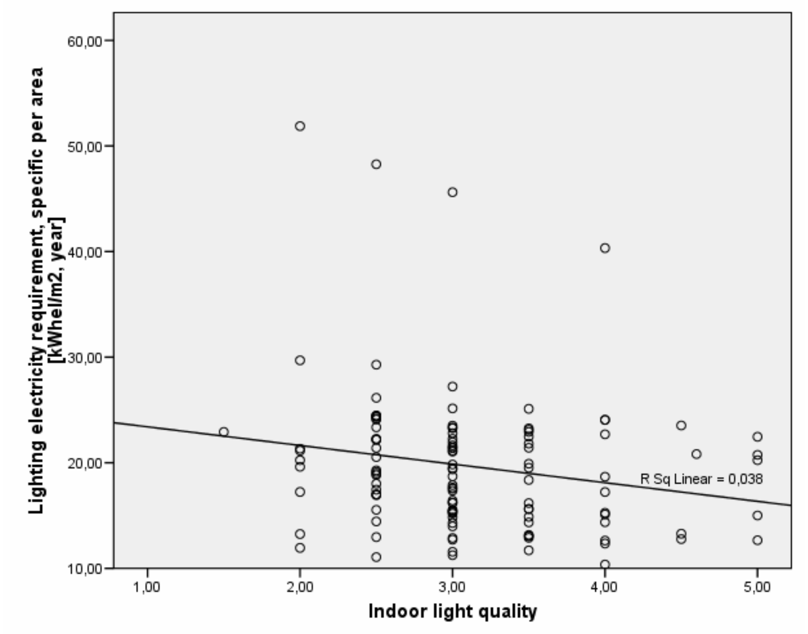

Figure 14: Specific lighting electricity requirements and quality of indoor light

cluding thermal comfort, moisture and noise. Is noise relevant in relation to heating?

Next step is to look at the overall U-value and relate it first to total indoor quality, Figure 10, and then to thermal comfort quality Figure 11. As could be expected we start to see a relation between overall U-value and thermal comfort, but the spread is still considerable. The U-value could possibly also represent the age of a school. A modern school might have a modern HVAC system for example, thus being better equipped to maintain a better thermal comfort in the building in addition to having a better U-value.

Finally the more interesting relation between indoor air quality and specific air flow, Figure 12, shows that an increase in air flow increases indoor quality which might be expected, but there is still a considerable spread so further analyses are required. If we look at fan electricity consumption as related to indoor air quality, Figure 13, the relation is not that strong any more. HVAC equipment might be more efficient with larger air flows and with motors well suited for powering the fans (low specific fan power)?

In order to find out the strongest relations a multiple regression analysis with moisture, air and thermal climate as dependent variables and annual total specific use, number of children/students per area, specific air flow (lit/s, m^2), annual total electricity for heat per area (kWh/m^2), room height, overall U-value, and annual total electricity per area (kWh/m^2) as independent variables. The only strong dependence was with children/students per area.

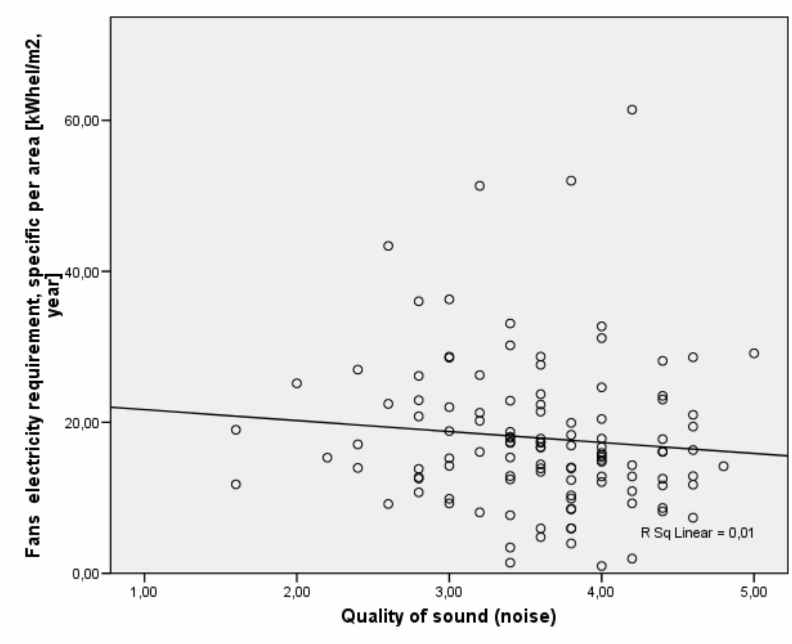

Figure 15: Fans electricity and indoor noise level

The analysis will continue and there is more data coming in from a questionnaire being put to the employees at the schools in this survey. The questionnaire aims to provide the user viewpoint and the user's opinion on the different aspects of indoor environment. The result is to be compared with the energy usage patterns as well as the indoor environment status. The data is available in excel format and as reports at STEM's homepage.

Lessons learnt

This has been a big operation taking a year and involving two government agencies, several consultant companies and personnel at 130 schools. It comes without saying that such an enterprise needs long and thorough preparations. The part of the operation which ran into problems was the enquiries with school personnel. This might have to do with the abundance of earlier enquiries to schools.

Another problem which should not be underestimated is the gathering of data such as drawings of the schools and utility bills.

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