The Effects and Cost Impact of Poor Airtightness—Information for Developers and Clients

Per Ingvar Sandberg, PhD **Claes Bankvall, PhD** **Eva Sikander**

Paula Wahlgren, PhD **Bengt Larsson, PhD**

ABSTRACT

Air movements in and through the building envelope affect the flows of not only heat, but also moisture, gases and particles, in a building. They often play a decisive part in determining moisture conditions, and thus indoor environmental conditions in the building, and ultimately, the durability of the building structure. Air flows affect thermal comfort and ventilation, and thus air quality. In addition, they also cause heat loss, both directly via ventilation, and through their effect on the performance of what are intended to be high-insulation structures.

A previous joint project between SP Technical Research Institute of Sweden and Chalmers University of Technology investigated the importance of airtightness in the construction process. The project found that many types of damage and problems were caused by poor airtightness, that airtightness was seldom given the proper consideration that it deserved and that there was a major need for information on the effect of poor airtightness. One of the conclusions was that it is important to get developers/ clients to treat airtightness more seriously.

The objective of the follow-on project that is described here is therefore to make developers/clients (more) aware of the potential damage that can be caused by poor airtightness, together with the "cost" of this damage/problem in a life-cycle perspective. Hopefully, developers/clients will then specify and monitor airtightness requirements more clearly. The aim is therefore to develop tools and methods for informing developers/clients of the importance of good airtightness, and of the resulting extra costs that incur from paying insufficient attention to airtightness.

The project has identified and assessed various consequences of poor airtightness, such as increased energy use, reduced thermal comfort, reduced air quality and moisture damages.

The cost calculations show that the developer/client would benefit in most cases from an increased standard and follow up on airtightness. We have projected the work with three different levels of ambition: 0.2, 0.4 and 0.6 l/m2s (at 50 Pa pressure difference), and believe that the optimal airtightness lies somewhere in the region of these values, depending on the buildings use and equipment.

INTRODUCTION

Air flow in and around the construction and materials of a building influences the moisture and heat transport in a building. These air flows often play a decisive role in the moisture transport in a building, and ultimately the moisture balance in the building envelope. This affects the durability of the construction, leading to possible material emissions and a risk for surface mould growth, which in turn leads to a poorer indoor environment. Air movements through the building envelope influence the building's thermal comfort and ventilation and ultimately the indoor climate. These air movements cause heat losses directly, by their influence on ventilation, and by their effect on the function of the thermal insulation. Energy use is also affected and this influences the buildings environmental impact. All these factors lead to demands on choice of materials, design of construction, workmanship and quality assurance in the building process.

In the program **"Air flows in and around construction"**, carried out in cooperation between SP and Chalmers (Sandberg and Sikander 2004, Sandberg and Sikander 2005), a

P.I. Sandberg *is Deputy Head in the Department of Energy Technology and* ***E. Sikander*** *is Head of Building Physics, SP Technical Research Institute of Sweden, Borås, Sweden.* ***Claes Bankvall*** *is an adjunct professor in the Department of Building Physics, Chalmers Institute of Technology, Gothenburg, Sweden, and previous head of SP Technical Research Institute of Sweden.* ***P. Wahlgren*** *is a senior researcher in the Department of Building Physics, Chalmers Institute of Technology.* ***B. Larsson*** *is a professor in the School of Business and Engineering, Halmstad University, Halmstad, Sweden.*

project was undertaken that investigated questions regarding airtightness during the construction phase. This project, completed in 2004, showed amongst other things that:

- A number of damages and troubles were as a result of poor airtightness.
- Questions regarding airtightness were seldom taken seriously by all those involved in the building process.
- There is a great need for information and consequences as a result of deficient airtightness.

The most important reason why good airtightness is not sufficiently prioritized is most likely that the damage/trouble caused by these deficiencies seldom show themselves in a distinct manner. One of the conclusions from the project was that it was important to get the developer/client to take airtightness questions seriously. This could happen by the group being informed of the damaging consequences of poor airtightness and what this would cost regarding a life cycle perspective. Poor construction or workmanship leads to direct costs (remedial work) and indirect costs (for good will/bad will, complaints, health etc.). Stricter demands from the developer/client for an improvement in airtightness should stimulate an increase in the effort from the consultants, contractors and the material manufacturers for better airtightness.

A project financed by SBUF (the Development Fund of the Swedish Construction Industry) and Byggkostnadsforum (Forum for Building Costs) was started in 2006 to investigate the status of these questions, and will be completed during 2007.

PROJECT AIM

The main aim of the project is to show that an improvement in airtightness is "profitable/beneficial" because it leads to a better indoor environment and a cost reduction. Furthermore, the developer/client is a determining factor on how airtight a building must be through the requirements they demand. This group will therefore be involved in the work investigating the consequences of deficient airtightness and what it costs.

The starting point of the project is that we often find ourselves at position A as shown in Figure 1. It should be beneficial to increase airtightness to, for example, position B in Figure 1. The increased cost of an improved airtightness (training, checking, more expensive solutions etc.) should be more than compensated by the reduced cost due to air leaks. This is shown in examples in the project. These relationships are also significant when the developer decides how airtight she/he wants the building to be.

The purpose is consequently to develop tools and methods to give the developer/client a better decision support. The aspects that need to be dealt with are:

- Consequences of poor airtightness (energy, moisture, comfort, ventilation etc.
- The cost of poor airtightness
- How to make requirements on airtightness and how to check that these requirements are being met.

CONSEQUENCES OF DEFICIENT AIRTIGHTNESS

According to the survey in Sandberg and Sikander (2004, 2005) the most important negative consequences due to deficient airtightness are:

- Increased energy use
- Reduced thermal comfort
- Reduced air quality
- Moisture damages

The different types of damage and trouble are discussed later in this paper. The negative consequences are quantified as best as possible in order to incorporate them in economic calculations. In many cases, the consequences are so uncertain that it is only possible to describe them in qualitative terms. This does not mean that they are not essential, but that the client/developer must set a value to them with respect to the individual project's requirements. The consequences that have been easiest to quantify are increased energy use, and for the others, help will be provided to estimate a value where it is possible.

Consequence: Increased Energy Use

A building with airtight deficiencies leads to an increase in energy use for many reasons. If air is allowed to flow through the insulation, then this will lead to a **reduction in its thermal resistance**. In other words, an increase in heat flow through that part of the building.

Poor airtightness also leads to an increase in energy use, since in most cases **ventilation air flow increases**. Cold and windy weather can lead to a considerable extra air flow in the building, which must be warmed up if a comfortable living environment is to be maintained.

In the case where the building is equipped with a **heat recovery system** and there are airtightness deficiencies, then

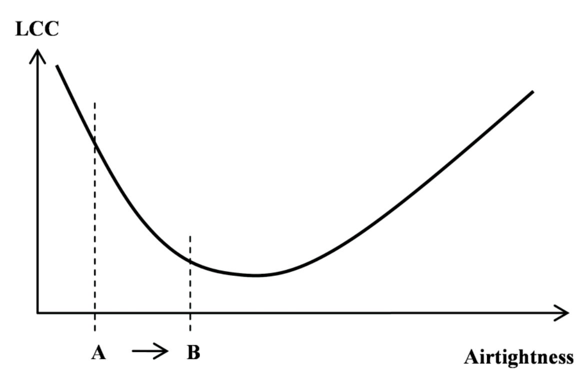

Figure 1 *Life-cycle cost (sum of the cost of creating airtightness + the cost of poor airtightness) as function of airtightness.*

this means that the air flow doesn't go through the heat exchanger as intended. Air coming in is not warmed up and the energy content of the air coming out is not reclaimed, when the air is taken in and out of the climatic shell instead.

The increased energy use (kWh) is used later in the specific costs calculations.

Example calculations are shown here for a typical building which has increased energy use as a result of airtight deficiencies. The simulation was carried out using Simulink (a Matlab-tool, www.mathworks.com) where measured climate data for Landvetter (in south west Sweden) for one year (1991) has been used for energy calculations in three different cases.

The building has six stories, a plan area of 1050 m^2 and a mechanical ventilation system. Two values of airtightness were used in the simulation. The first, corresponding to the Swedish building code (0.8 $l/m^2 \cdot s$ at a pressure difference 50 Pa) and the second corresponding to what is often found when buildings are measured in practice (2.0 $l/m^2 \cdot s$).

The energy calculations include solar radiation, wind speed and direction plus stack effects to assess the pressure difference and thus the air leakage. The buildings are placed in two different locations, one exposed to wind in open country and one less so in town.

The results from the simulation, as shown in Figure 2, are described in the form of energy loss per m^2 per year. These are divided into transmission losses (through windows, walls, roof and floor), mechanical ventilation losses and infiltration losses through leaks.

Energy use for a house in town with poor airtightness compared to that built within the regulations differs by ~20 $kWh/(m^2 \cdot year)$. If the location in town is changed to open country the energy use for the leaky house increases with an additional ~50 $kWh/(m^2 \cdot year)$ and corresponds in that case to 45% of the total energy use. Similar results have been obtained by, amongst others Herrlin (1992), Emmerich and Persily (1998) and Emmerich et al (2005).

Consequence: Thermal Comfort

A person exchanges heat with the surroundings by convection (moving air), radiation to surrounding surfaces, conduction to the surrounding air and by breathing and evaporation. How much is of course dependant on parameters such as surrounding temperature, clothing and activity. The concept PPD (Predicted Percentage of Dissatisfied) is used to describe how a person experiences thermal comfort. This concept states how many in a large group of people are dissatisfied with the comfort. This can concern total comfort (freezing or sweating) or local discomfort (a localized cooling of the body). The most common cause of local discomfort is a draught. However, local discomfort can also be also caused by an unusually large vertical temperature difference between the head and the feet, by a too warm or cold floor or large differences in the radiation temperatures. The factors related to airtightness that affect thermal comfort are in the first instance air velocity and cold surfaces.

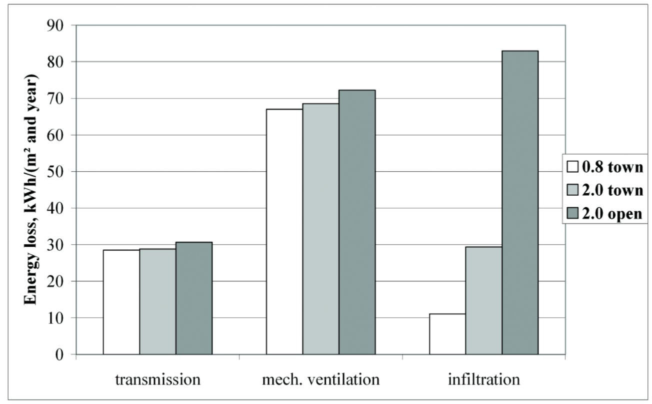

Figure 2 *Calculated energy losses for houses with airtightness according to the normal building code (in a town environment) and houses with a below standard airtightness according to the normal building regulations (town environment and open environment).*

Building owners can always choose between taking care of the problems or paying the costs that incur. In the first case this means building and/or technical installation remedies. It is possible to make windows and doors more airtight and improve insulation around joists etc. to varying degrees, and it is possible to estimate this particular cost.

In the second case, which is mainly about the hidden costs and/or lost revenues, the costs are much more difficult to estimate. There are no available direct relationships between poor comfort and increased cost for building owners. To get an impression of the different types of cost there now follows some examples.

Unchanged Operative Temperature. Localized cooling causes a reduction in the operative temperature (mean of the air temperature and surrounding surface temperatures). This reduction can be compensated by an increase in air temperature, which leads to an increase in transmission and ventilation losses, and thus an increase in heat cost. One way of estimating this local cooling is to calculate the increase in energy cost whilst maintaining a constant operative temperature.

Air leaks (air flows in joists/beams) are assumed to cause local cooling of the ceiling, whilst all other surfaces are at room temperature (see Figure 3).

Assume that the ceiling represents 1/6 of space angle. An increase in the air temperature is required in order to maintain the same operative temperature. A simple estimate can be obtained using the following equation:

$$\frac{1}{6} \cdot \frac{T_l + 8}{2} + \frac{5}{6} \cdot T_l = 22; \; T_l = 23.3°C$$

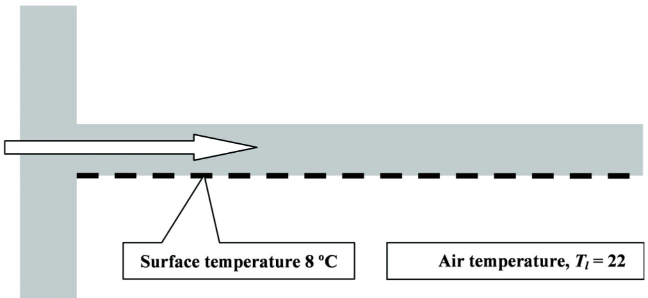

Figure 3 *Localized cooling of the ceiling as a result of air flow between the joists.*

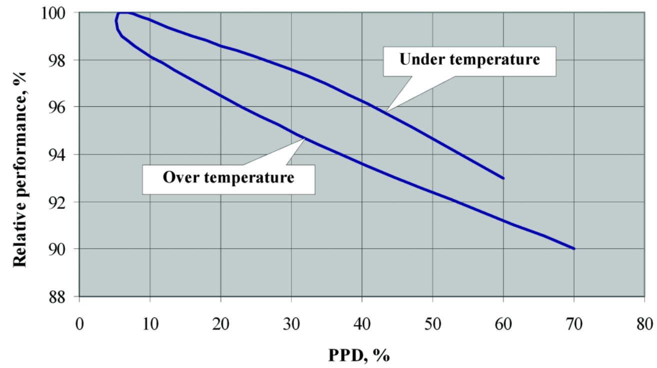

Figure 4 *Connection between the relative office work performance (in percent) and the percentage of dissatisfied with the thermal comfort.*

The required air temperature increase is ~1ºC, which (in southern Sweden) causes approximately a 5% increase in the energy loss for that room.

Cost of Productivity Reduction in Office Work. Extensive studies have shown that productivity in for example, an office, reduces as a result of deficiencies in thermal comfort (Seppänen and Fisk 2005). By combining productivity information with data from ISO 7730 on operative temperature and PPD, using normal office parameters (0,75 clo and 1,2 met), we obtain the relationship shown in Figure 4 below.

With the help of the relationship shown in Figure 4, reduced productivity can be estimated by the number of dissatisfied with different climate factors in the thermal indoor environment. The cost can then be calculated by means of the actual personal cost.

Cost of Bad Will, Complaints etc. Tenants that experience poor thermal comfort are most likely to complain to the landlord and/or speak badly of him and his property. One common complaint can be cold floors caused by air leaks between the concrete slab and the sill. Figure 5 shows the calculated floor temperature for the parameters -10 ºC external temperature, 22 ºC room temperature and a pressure difference of 20 Pa for two different seals between the concrete slab and the sill (extruded polystyrene strips and asphalt felt direct on the concrete). According to the Swedish building code, the floor temperature should generally be over 16 ºC, over 18 ºC in the bathroom and more than 20 ºC in children's rooms. The residency zone starts 0,6 m in from the outer walls. The figure shows that the asphalt felt doesn't meet any of the requirements and the XPS seal in only the bathroom.

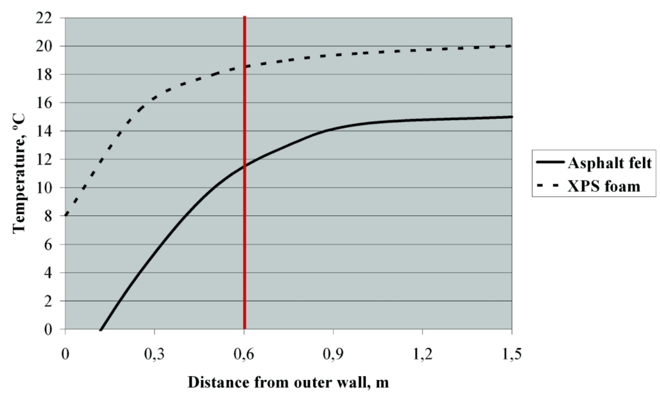

Figure 5 *Calculated floor temperature as function of distance from outer wall, using two different seals between sill and concrete slab, (further information in Sandberg and Sikander 2004).*

Consequence: Air Quality

Air flows through leaks in the building envelope can carry with them gases and particles. These airtightness deficiencies can in that case contribute to the spread of different unwanted substances that have a negative effect on the air quality. This can lead to inconvenience and unpleasantness for the tenants and to complaints, bad will etc. for the landlord.

Dispersion Between Flats. Airtight deficiencies in the dividing walls between flats leads to a risk that the smell of cooking food, tobacco smoke etc. spreading into other flats. Depending on the wind and the adjustment of the ventilation system, there is often a pressure difference between flats, which leads to air leaks and the dispersion of unwanted substances. The entrance door to the stair well is often another cause of unwanted air circulation, because the stack effect causes an air flow from the flats to the stair well in the lower floors and vice-versa in the upper floors.

Dispersion of Fire Gases. Flats are normally designed so that if fire did break out it would be contained in one cell (flat) by the use of separate special dividing walls. According to the Swedish building code "the walls that divide each fire cell must be impermeable to gas and flames". Deficiencies in airtightness in this instance are not acceptable, because of the serious consequences to life and health if there is a problem. Experience in Sweden has shown that this is seldom checked, and there are no quantified requirements in the building code regarding airtightness.

Spread of Ground Radon. Radon is a radioactive noble gas which is formed when radium decomposes. Radon decomposes still further into different radioactive isotopes, so called radon daughters. These daughters are metal particles that can easily fasten to dust particles and thus pass into our lungs through the air we breathe in. In the lungs the isotopes continue to decompose and give off different types of radiation, which damage the lung cells. This is the start of lung cancer, and at least 400 people die each year in Sweden because of it.

Radon in the ground is the usual source of radon in a building. It is transported into the building through "soil air" that is sucked in through leaks in the foundation/ground construction. The following three requirements must be met if radon is to be transported into the building:

1. Radon in the ground
2. Air pressure difference (internal under pressure)
3. Leaks in the parts of the building in contact with the ground.

Radon is present in the ground in many areas of Sweden, and the communities have particular maps showing the location of the dangerous radon ground. The air pressure relationship in a house is often that the house has an under pressure with respect to the ground. The stack effect contributes to this as well as ventilation systems such as self draught ventilation or mechanical ventilation that draws air out of the building (exhaust-ventilation). The only sure way of avoiding the flow of radon into the building is to ensure that the foundations in contact with the ground are impermeable. Special attention must be given to the service pipes (water, drains, electricity etc.), the floor/wall joints as well as cracks due to settlement or shrinkage. Permeable building materials such as lightweight breeze blocks should be plastered on both sides to give the required airtightness.

Dispersion from Outside. The strategy required for a good air quality inside a building is to reduce the pollutant sources and through ventilation dilute those that cannot be avoided. In order for this to work the outside air must have lower pollutant content than the indoor air. This, however, is not often the case. In many instances, the outer air is more contaminated than is acceptable, so it is necessary to filter it first or move the air intake to a more suitable location (if possible) where the air quality is better. In an area of poor air quality, it is very important that the ventilation is carried through the system itself, and not uncontrolled filtration through leaks in the building envelope. Good airtightness is also a basis for good sound insulation in the facades.

Ventilation System Function. Airtight deficiencies can also cause a ventilation system to malfunction, thus at certain parts of the building the rate of air change is too low. This in turn can mean that pollutants in the building cannot be removed as fast as they should be, resulting in poorer air quality. The consequences of this to the occupants in the building are unhappiness, complaints etc., the largest of which have been found at workplaces and schools.

Many experimental investigations have shown that productivity reduces by approximately 1% with an increase in the number of dissatisfied by 10%, and that absence due to illness, especially short term illness, increases. (See for example Olesen 2005, Seppänen & Fisk 2005)

Consequence: Moisture Damage

Indoor air that escapes through leaks in the building shell cools down. If the temperature sinks to the dew point, then the moisture in the air condenses out and collects in the construction. This process is usually called moisture convection, and can cause damage since large amounts of moisture can condense out in a short period. Most susceptible are the upper parts of the building where there is often an internal over pressure as a result of the stack effect. Moisture convection that is described here is applicable to cool temperate climates. In warmer climates the same problem occurs when warm moist air leaks into cooler air conditioned parts of the building.

As for radon, there are three requirements for moisture convection to occur:

1. Moisture in the air
2. Air pressure difference (over pressure on the warm side)
3. Leaks in the building envelope.

There is always moisture in the air, and there is always an air pressure difference of some magnitude present in some parts of the building. Stack effect, wind and ventilation system all contribute to the pressure difference. Therefore, it is essential to ensure good airtightness if damage by moisture convection is to be avoided.

In existing houses, it can be difficult to localize and fix all the air leaks. A last method of avoiding moisture convection is then to actively affect the pressure distribution in the building to avoid an over pressure on the warm side. An example of a solution that has been tested in attics with leaking joist beams and moisture damage is the use of a fan which draws air into the attic space, thus reducing or almost eliminating the internal overpressure.

The risk costs associated with the consequences of moisture damage are difficult to judge, since reliable statistics are not available. The probability of moisture damage is fairly low, but on the other hand the consequences are very costly. The cost is discussed in a later section.

WHAT IS THE COST OF "AIRTIGHT DEFICIENCIES"?

To construct an airtight building costs extra money in the production phase. This cost, according to profitability calculations, is recovered over the following years, by, for example, energy saving, increased rent income etc. A simple model is described in this section, which can help with the decision whether to build airtight or not. The model has however two inbuilt problems. Firstly, it is difficult to replicate the effects associated with poor airtightness, and secondly, it is hard to put an economic value on the many benefits which come with having an airtight building.

Decision Time: How Airtight?

In the first instance it is the property owner's decision about how airtight to build or if to carry out remedial work on existing buildings. In this section we have the perspective of the property owner. The costs/revenues calculated are refined and related back to the property owner company, with two alternatives: either demand an improved airtightness or "carry on as usual".

If the property company actually uses the building themselves or hires out parts of it, then this puts a whole new complex on the decision. The property company makes a direct profit from improvements in the first case, and in the second case an indirect profit from an increase in the value of the property, coupled with a possible higher rate of rent. If the property company owns apartments to live in, then there is no difference since the accommodation is always hired out.

Specific Revenues and Specific Costs

In an earlier section it was described how different troubles/damages are caused by airtightness deficiencies. An increased airtightness will lead to a reduction of these consequences and therefore give a **specific revenue** for the property owner. Even though it may not be possible to quantify this by calculation, it must be considered when making "the decision". We have chosen, as shown below, to try and quantify the consequences in US dollars (one Swedish krona equals ~0.14 USD). In reality however, the figures must be based on the individual companies' own experiences.

Energy Use. Calculations (see earlier section) show that a change from an airtight poor building to a normal airtight building (as per regulations), will lead to a reduction in energy usage in the region of 50 kWh/m^{2}year. Today's energy price can be set at about 0.15 $/kWh and a reasonable prediction would be that this will rise faster than the consumer price index. This applies to both living accommodation and office buildings.

Thermal Comfort. Draughts, vertical temperature differences, cold floors and uneven radiation are all causes of poor thermal comfort. This in turn leads to dissatisfaction amongst the people who live in the building. A closer analysis of these factors and actual weather information, show that it is reasonable to assume that the wind and temperature relationship for 25% of the year is such that deficiencies in thermal comfort can be experienced by 20% of the people living in properties with poor airtightness.

This means that tenants living in rented accommodation who experience poor thermal comfort often complain to the landlord, criticize him, or even move to another flat. This leads to a direct cost for the landlord, including telephone calls, surveys and other administration. One can think that poor accommodation has a lower rent level and hence a higher turnover of tenants. It is difficult to give a concrete value of the cost of this, but an assumption of a 0,5-1% lower rent for a property with poor airtightness, and an average rent in the region of 150 $/m^{2}year can give a hint about the specific revenue if the property is improved. The everyday value of the property should give a few % increase in the rent, say 2-4%.

Air Quality and Sound Insulation. Air flow through leaks in a building can carry with them a quantity of gas and particles. Consequences of this could be an increase in absence due to illness, that people don't feel well and that there is an increase in staff turnover. We have not quantified this in the calculations, but noted instead that a specific revenue can be had if one chooses to build airtight. Another such consequence is that if sound isolation is poor, then airtightness is poor, which leads to more bad will for the landlord.

Moisture Damage. Poor airtightness leads to an increased risk for moisture damage and mould in the construction. It has been difficult to find statistics of how common this is and how much it costs. A rough estimate shows that such damage presumably has no large economic consequence in a large property, provided it is not a serious systematic problem. Let us assume that a building of 2000 m^2 is affected by moisture damage once every ten years which costs 20 000 $to put right. This means an average cost of 2000 $/year and 1 $/m^2 per year. In comparison with other specific revenues/costs this figure is negligible.

The main **specific cost** is made up of the extra construction costs to build airtight. This in turn is divided into:

Work Cost. To build airtight means in the first instance to be careful and accurate during the building process. This means that the air barriers must be whole and tight. It is important that all sections of the construction workforce are aware of this. One can presume also that there will be a noticeable "running in" or "learning curve" for everybody to get used to this. For new build we will assume that the airtightness requirements increase the number of man hours by 0,5-1 hour/m^2. The work cost including all extras has been set at 55$/hour. It is necessary that all categories of the workforce are trained in the requirements of airtight construction, and what they are expected to do. For a normal project the cost of a half day course and the lost time because of it, is in the region of 3000 – 5000 $.

Supervision Costs. The demands of building airtight means that a certain amount of supervision is necessary. The drawings must be inspected as well as the construction as it progresses on site. A test must also be carried out to measure the airtightness at the end of the project. This means a total supervision cost of approximately 0,05 hour/m^2.

Other Costs. It is probable that certain methods, special tapes and tools must be used to construct an airtight building. A reasonable cost for this is in the region 3 - 5 $/m^2.

Calculation Example

There now follows our model example analysis of what it means to build airtight as opposed to build “as usual”. In the calculations we have used values from the section “specific revenues and specific costs”. The specific costs for the construction occur only once. The economic life length has been set at 10 years and the discount rate to 5%.

Example: Property company that own and rent out accommodation in a multi family house.

The dominating factor for rented accommodation will be the amount of energy that can be saved, see Table 1. Other “weaker” factors such as increased well being and better sound insulation will be included in the calculation. The increased construction costs in this case appear to be rather minimal.

DEVELOPER’S REQUIREMENTS FOR AN AIRTIGHT BUILDING

Increased airtightness was shown in most cases to be beneficial/profitable. A part of this project was to develop tools to help those developers/clients who want to require a higher standard of airtightness. These tools have many similarities with those that have been produced for moisture safety during construction (Sikander et al, 2004) and covers:

- Checklists for the developer’s work, including levels of requirement, allocation of responsibility, competence and follow-up.

Table 1. Calculation for an Apartment House

Input Data			Cost Estimate	Once-for-All Cost		Annual Cost	
Additional working hours house # 1	0.8	hour/m^2	Costs				
Work cost	55	$/hour	Extra hours worked	44	$/$m^2$		
Supervision	0.05	hour/m^2	Increased supervision	3.5	$/$m^2$		
Cost of supervision	70	$/hour	Training of workers	2	$/$m^2$		
Economic life length	10	years	Other costs	4	$/$m^2$		
Calculated rent	5	%	Sum of costs	54	$/$m^2$	7	$/$m^2$ and year
Annuity factor	0.1295						
Training costs	4000	$/project	Revenues				
			Reduced energy use			7.5	$/$m^2$ and year
Number of houses	1		Reduced remedies for moisture damage			1	$/$m^2$ and year
Area per house	2000	m^2					
			Increased rent grade			1.5	$/$m^2$ and year
Reduced energy use	50	kWh/m^2 and year	Increased rent level			4.5	$/$m^2$ and year
Energy cost	0.15	$/kWh					
			Increased well-being, comfort etc.			?	
Remedies for moisture damages	1500	$/year	Sum of revenues			14	$/$m^2$ and year
			Annual profit			7	$/$m^2$ and year
Rent level	150	$/$m^2$ and year	Total annual profit			14643	$/year
Increased rent grade	1	%					
Increased rent level	3	%					

- The developer's level of requirement with respect to airtightness. Furthermore, there can be requirements for checks on construction solutions, durability (of materials), education, self checking and verified measurements/surveys.
- A simple developer's project control checklist.
- Example of checking plan to build airtight.
- Example of verification and measurement method.

COMPILATION OF INFORMATION

Since knowledge about the consequences of deficient airtightness is limited, there is a special need to decide how the project results should be presented in an educational manner, in order to reach the relevant parties. The results need to be presented in such a fashion that they draw attention and motivate developers to stipulate clear airtightness requirements.

The results of the three sub-projects are "packaged" like this:

- Scientific report, describing the work done, references, results and conclusions
- Book, written in a popular scientific style, 60 pages, "Airtightness manual – problems and possibilities". The goal has been to write a book which is brief and interesting enough to be read by a considerable number of people in the building sector
- PowerPoint-presentation, 50 frames with the most important results from the project
- Flyer, 4 pages, evening paper style with some striking results from the project and guidance how to get hold of more information. This flyer is disseminated to the building sector through all available channels.
- Poster with the message that air leaks will cause increased energy use and that buildings shall breathe through the ventilation system and not through the building envelope.

DISCUSSION AND CONCLUSIONS

Experience gleaned from the Swedish building sector has shown that questions regarding deficient airtightness are not taken seriously, and the consequences of such are on the whole unknown. The purpose of this project is to describe the damage/inconvenience caused by poor airtightness, and to try and quantify the consequences in an economic way. It has been relatively easy in some cases to carry out economic evaluations (for example, for increased energy use), however, in many other cases it is much more difficult. Minor faults create indirect costs that are difficult to quantify, and the risk of larger damages (that seldom appear) occurring is difficult to judge.

Another problem is that we are not particularly sure which the real air leaks are in the building, which makes the potential for improvements difficult to judge. This applies to both existing and newly built houses. The Swedish building code have had airtightness requirements for a long time, but these have seldom been checked, and when they have, the results have often been worse than those stipulated.

Despite these uncertainties, it is our judgment that the client/developer would benefit in most cases from an increased standard and follow up on airtightness. We have projected the work with three different levels of ambition: 0.2, 0.4 and 0.6 l/m^2s (at 50 Pa pressure difference), and believe that the optimal airtightness lies somewhere in the region of these values, depending on the buildings use and equipment.

REFERENCES

Emmerich, S. and Persily, A. 1998. Energy impact of infiltration and ventilation in U.S. office buildings using multizone airflow simulation. Proceedings of Indoor Air Quality and Energy, New Orleans, October 1998.

Emmerich, S. et al 2005, Investigation of the impact of commercial building envelope airtightness in HVAC energy use. NIST National Institute of Standards and Technology, NISTIR 7238, USA

Herrlin, M. 1992. Air-Flow Studies in Multizone Buildings. Bulletin no 23 from Department of Building Services Engineering, Royal Institute of Technology, Stockholm.

ISO. 2005. International standard 7730, Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort

Olesen, B. 2005. Indoor environment – health-comfort and productivity. Proceedings of Clima 2005, Lausanne.

Sandberg, P.I. and Sikander, E. 2004. Lufttäthetsfrågorna i byggprocessen – Kunskapsinventering, laboratoriemätningar och simuleringar för att kartlägga behov av tekniska lösningar och utbildning. SP RAPPORT 2004:22 from SP Swedish National Testing and Research Institute. In Swedish.

Sandberg, P.I. and Sikander, E. 2005. Airtightness issues in the building process. Proceedings of the 7th Symposium on Building Physics in the Nordic Countries, pp 420 427.

Seppänen, O. and Fisk, W.J. 2005. Some Quantitative Relations between Environmental Quality and Work Performance or Health. Proceedings of Indoor Air 2005, pp 40-52.

Sikander, E. et al 2004. The building developer's requirements, management and verification to ensure dry buildings by moisture control. Proceedings of Performance of Exterior Envelopes of Whole Buildings IX.