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HEALTH, COMFORT, AND ENERGY PERFORMANCE IN BUILDINGS GUIDELINES TO ACHIEVE THEM ALL

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1 INTRODUCTION

The salient features of high quality buildings include indoor air quality (IAQ), thermal comfort, visual and acoustic characteristics, as well as low impact on the environment. Within the HOPE research project, the following definition has been adopted:

A healthy and energy-efficient building does not cause or aggravate illnesses in the building occupants, assures a high level of comfort to the building's occupants in the performance of the designated activities for which the building has been intended and designed, and minimises the use of non-renewable energy, taking into account available technology including life cycle energy costs.

According to the Rio agreement, sustainable buildings should take account of environmental, economical, and social stakes. This includes, among others, low energy use, good indoor environment quality (IEQ) and health. The three stakes have a similar importance: a building cannot be good if it fails in one of them.

In some case, especially when appropriate studies are not performed, there may be a conflict between strategies to reduce energy use and to create healthy buildings. However, studies and existing high performance buildings show that it is possible to realise healthy, comfortable and energy performing buildings, named below High Quality or HQ buildings (Roulet 2004).

The final goal of the project HOPE was to provide the means to increase the number of energy-efficient buildings that are at the same time healthy, thus decreasing the energy use by buildings and consequently resulting in a reduction of CO_2 emissions from primary energy used for ventilation, heating, cooling and humidity control.

A set of performance criteria for healthy and energy-efficient buildings has been developed, based on available knowledge. These criteria have been tested in existing buildings by performing a multi-disciplinary study in 164 buildings (98 apartment buildings and 66 office buildings) of which approximately 75% have been designed to be energy-efficient, and half of them are indeed. This investigation has been carried out in nine European countries, and was followed by a detailed study in a sub-set of 29 of the investigated buildings in 8 countries. The multi-disciplinary study was performed using three kinds of screening methods: (a) an inspection of each building, (b) interviews with management and maintenance personnel and (c) questionnaire surveys of occupants. These studies provided data supporting the guidelines presented below.

These guidelines then result from experience gained in the European HOPE project. They contain advice on how to design, build and maintain buildings to ensure good indoor environment quality together with high energy performance.

The guidelines are organised according to main issues such as indoor air quality, thermal comfort, etc. These are dedicated to designers and architects, but building occupants may also take advantage of several recommendations given in this booklet..

2 OVERALL DESIGN

2.1 Design intentions

The building is (or at least should be) designed and constructed first to bring a good indoor environment to its occupants. There could be other objectives, such as:

- prestige, image;
- low cost;
- energy saving;
- real estate business, speculation;

but these should have the highest priority. Indeed, sustainable development requires that HQ buildings should be designed, built and maintained, taking account of environmental, economical, and social stakes.

Healthy, comfortable and energy efficient buildings are the result of a conscious design keeping constantly these three objectives in mind. It is not by chance that most of the 16 apartment buildings and 7 office buildings fulfilling at best the HOPE criteria for these objectives were designed that way (see 8.2.2). Some of these buildings are shown as examples to illustrate the guidelines.

Basic recommendation that could be given to reach these objectives are:

- Prefer passive methods to active ones wherever possible
- Think about the user comfort, needs and behaviour
- Adapt the building to its environment

2.2 Passive and active ways to get HQ buildings

2.2.1 Passive ways

These are architectural and constructive measures that naturally provide a better indoor environment quality without or with much less energy use. Examples are:

- Improving winter thermal comfort with thermal insulation, passive solar gains, thermal inertia, and controlled natural ventilation[1]
- Improving summer thermal comfort with thermal insulation, solar protections, thermal inertia, and appropriate natural ventilation
- Ensuring indoor air quality by using low-emitting materials and controlled natural ventilation
- Providing controlled daylighting
- Protecting from outdoor noise with acoustical insulation, adjusting the reverberation time for a comfortable indoor acoustics

Passive means are often cheap, use very few or no energy, and are much less susceptible to break down than active means. However, they often depend on meteorological conditions and therefore cannot always fulfil the objectives. They should be adapted to the location and therefore need creativity and additional studies from the architect, and a design error may have dramatic consequences.

[1] Natural ventilation can be controlled by installing (automatically or manually) adjustable vents in an airtight building envelope.

2.2.2 Active (or technological) ways

These allow reaching the objectives by mechanical actions, using energy for complementing the passive ways or even for compensating low building performance. Examples are:

- Heating boilers and radiators for winter comfort
- Artificial cooling by air conditioning or radiant panels for summer comfort
- Mechanical ventilation
- Artificial lighting
- Actively diffusing background music or noise to cover the ambient noise.

Active ways, when appropriately designed, built and maintained, are perfectly adapted to the needs. The architect does not have to take much care of them, since these are designed and applied by specialised engineers according to known technology. Flexible and relatively independent on meteorological conditions, they allow correcting architectural errors. However, the required technology is often expensive, uses much energy and may break down. Furthermore active means require a higher maintenance input. The fact that they allow correcting architectural 'errors' can also be considered as a disadvantage….

2.2.3 Strategy

Passive ways are preferred, but cannot always fulfil the comfort objectives. Therefore, the appropriate strategy is to use them as much as reasonably possible and to compensate for their insufficiencies with active systems, which will then be smaller. This strategy often allows more freedom in choosing the type and location of active systems.

2.3 Taking account of the user

The occupant of a building expects that the building provides an acceptable indoor environment, according to his wishes. The occupant likes to have a control on this environment and even needs such a control to adapt it to his needs.

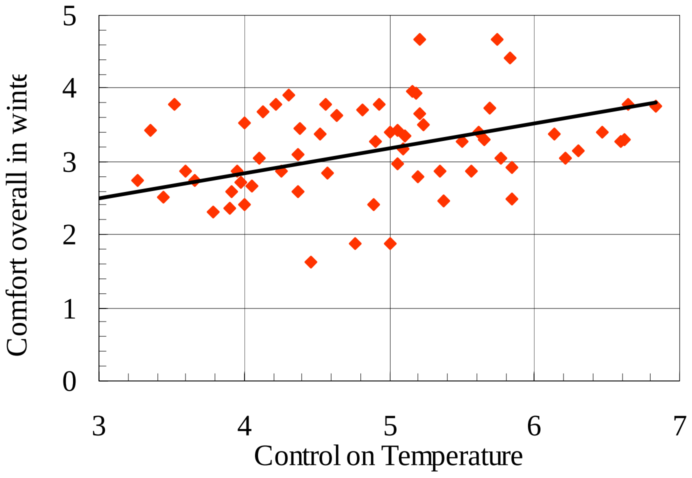


Figure 2.1: Perceived comfort correlates with the perceived control of the occupants over their environment.

Scale for both axes goes from 1 = satisfactory to 7 = unsatisfactory.

Well-being of occupants can be measured with personal questionnaires as follows. Occupants are asked if they have had two or more episodes of 8 symptoms in office buildings and 10 symptoms in apartment buildings, and if they feel better on days out of the office. A symptom that does disappear when out of the building is assumed to be building-related. The list of symptoms includes those commonly related to sick building syndrome, i.e., in office buildings: dryness of the eyes, itchy or watery eyes, blocked or stuffy nose, runny nose, dry throat, lethargy or tiredness, headaches, dry, itching or irritated skin. In homes, additional symptoms are sneezing and breathing difficulties. From these replies, a building symptom index (BSI) is calculated to get the average number of building-related symptoms per occupant.

The control an occupant has over his environment not only affects his perceived comfort, but is linked in some way with his well being, as measured by the BSI.

Therefore, the building design as well as the system must take into account the user's needs and wishes, and allow the user to adapt its environmental conditions to his needs as much as possible.

Where the environment cannot be modified by official means, the occupant finds another way: bringing in heaters, opening the window in winter instead of putting the (non existent) thermostat down, using tape or paper to close draughty ventilation openings, etc.

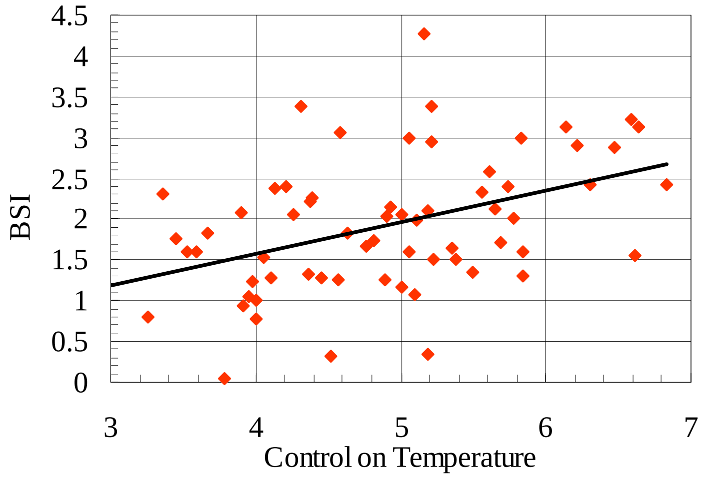


Figure 2.2: Building Symptom Index correlates with the perceived control of the occupants on their environment.
Scale for abscisae goes from 1 = satisfactory to 7 = unsatisfactory.

2.4 Adaptation to the environment

The outdoor environmental characteristics (temperature, solar radiation, wind, dust, pollution, noise, etc.) change with the location of the building. Therefore, a design that is well adapted in a place may be completely unsuitable to another one: Bedouin tents, igloos, tropical huts, all well adapted to their environment, cannot be used elsewhere. This is also valid for contemporary building design: it is of course possible to compensate for environmental changes using active techniques, but this often decreases the indoor environment quality and increases the energy use.

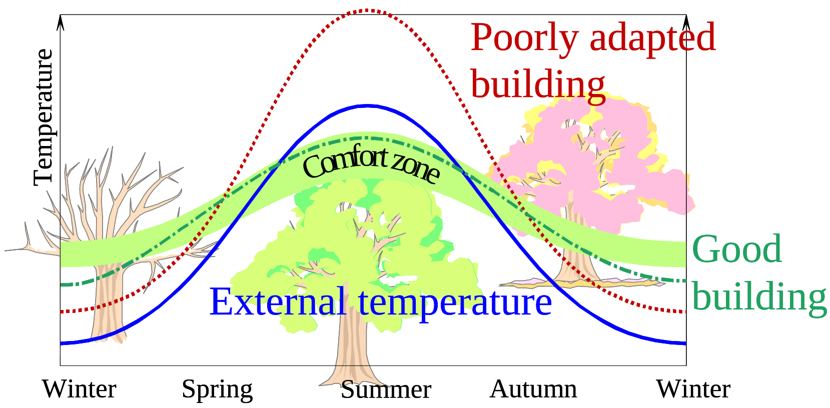


Figure 2.3: A good building should be without any heating or cooling, ***at least as comfortable*** *as the external environment*

Adaptation of the building to the environment includes the following:

- Adaptation to climate: Appropriate thermal insulation, solar protections and ventilation openings. An acceptable architecture should ensure that the building is, without any heating or cooling, *at least as comfortable as the external environment*. In many cases, it is easy to do better by passive means.
- Adaptation to noise: Improve acoustical insulation in noisy areas, for example by using a double skin, and installing mechanical ventilation with sound barriers.
- Adaptation to pollution: Locate air intake as far as possible from pollution sources, install mechanical ventilation with appropriate filters and ensure appropriate maintenance.

Nevertheless, it should be mentioned that clothing is the most natural first step for temperature control. A building management has justified air conditioning because full casual dress was mandatory in the company. Allowing clothing adaptation in buildings certainly improves comfort and may save much energy!

2.5 A few examples

All these examples are selected among the buildings that have good comfort, healthy occupants and low energy use.

2.5.1 Apartment buildings

Figure 2.4: ACH03 building, seen from North-West

ACH03 was constructed in 1973. Initially high in energy demand, the apartment complex was renovated in 1999 with the intention to reduce energy use and improve comfort.

All windows were changed, additional external thermal insulation was added to walls and roof, and a dual duct mechanical ventilation with heat recovery was installed to ensure sufficient ventilation and reduce the energy use. Existing ducts are used for extraction, and new supply ducts are integrated in the external insulation.

The energy concept includes also glazed balconies, local district heating burning gas, wood and wastes, high efficiency lighting, and saving water devices. All these measures allowed to divide the energy and water uses by half, to reach annually (90 kWh/m² and 45 litre/habitant and day of water.

ACH06 was designed with the strong intention to build a healthy, low energy and comfortable building. The complex consists of 3 apartment buildings built around a central place. It hosts 82 apartments and 1700 m^2 of commercial surface. The three buildings each have 5 floors and an underground parking. During the design and construction, aspects of eco-biology, geo-biology and bio-construction are taken into account. The aim was to realise an “ecological” building, meaning that for instance its life cycle has a relatively low impact on the environment (= positive eco-balance), that the building has a maximum of energy saving features, and that it preserves the health and quality of life of its inhabitants For example, several measures are taken to reduce the impact of electromagnetic radiations of electrical wires and -equipment. Also the apartment building is built and equipped in such a way that it minimises of the use of non-renewable energy sources for its operation.

Most of the roof surface (1400 m^2) is covered by an integrated solar roof made of flat plate, unglazed solar absorbers with a selective black chrome coating. They are used to heat up water in two 50 m^3 tanks per building. This hot water is used for the building's heating system and for sanitary use (including the washing machines). The solar panels have sufficient capacity to cover 100% of the warm water demand in the June-October period, and provide yearly more than 500 kWh per m^2 collector area.

As a result the total energy consumption is relatively low: The energy index is less than 75 MJ/m^2 (50 MJ/m^2 for heating and 25 MJ/m^2 for electricity)

Figure 2.5: ACH06 building, with a close view on the solar roof.

ADK11 was constructed in 1996, with a total of 40 apartments in three buildings in an open green area. The buildings were constructed based on a new industrial flexible building concept, with good sound insulation. Focus was on building quality, design, indoor climate and installations, durability, ecology. The windows and façades were constructed to take advantage of passive solar energy.

Figure 2.6: ADE19 buildings

ADE19 was constructed in 1993 outside the city centre of Frankfurt on the Main. The buildings have three floors and the total floor area is 7073 m². Windows naturally ventilate the buildings.

These buildings were designed with the strong intention to built low energy houses. The planed energy use was 75 kWh/m²a. The total (heating and electricity) energy demand of the building measured in 2002 was actually 140 kWh/m²a.

According to its low BSI 10 (0.64) the building is classified as healthy. The main comfort problem is a high and uncomfortable temperature during summer.

ANL03 is a 17 floors high rise apartment building, built in 1999.

The building has insulation levels in agreement with the building codes at that time. High efficiency glazing is used (U = 1.8 $W/m^{-2}.K$).

A salient feature is the (preheated) supply of air in the central hall with flow to the individual flats via slits beneath the front door. This type of supply is not promoted by the members of the HOPE team, since it distributes contaminated air and increases noise transfer.

Ventilation grilles are mounted in the windows of each dwelling, which is also equipped with mechanical exhaust in kitchen, toilet, bath room and storeroom.

Energy for heating and hot water is coming from a central power plant quipped with co-generation and gas-fired boilers.

Figure 2.7: ANL03 building

The building complex ANL11, includes two renovated apartment buildings and a newly constructed apartment building. The building blocks are coupled by an atrium. The atrium has automatically controlled natural ventilation with grilles in façade and roof. The individual apartments in the newly built block have mechanical exhaust ventilation with supply grilles in the windows. The exhaust is automatically switched to low flow rate at night. The building has a high level of insulation, including high efficiency glazing, U=1.2 W/m^2K. In each flat there is a high efficiency boiler installed for heating and hot water supply. The flats are equipped with a conventional radiator heating, with a thermostat in the living room, but without thermostatic valves in the other rooms. The dwellings are aimed to be inhabited by elderly people.

Figure 2.8: ANL11 building

Figure 2.9: APT03 building, south facade

APT03 was built in 1996. Its design was awarded 1st prize of PLEA 88 international design competition. It is a building designed to be energy climate responsive (passive solar systems including a Trombe wall, heavy construciton giving a high thermal inertia and solar water heating systems). That is why energy uses for heating are very small or non existent and summer comfort is fulfilled.

APT05 was built in 1994. It was designed taking in consideration all the thermal insulation measures recommended by legislation at this time, including external wall insulation and double-glazing. Construction considered as being of high quality by the common market standards.

APT06 was built in 1998 integrated in the EXPO'98 site. It was designed as a passive solar building in tune with the energy strategy defined for the urban planning of the EXPO site.

It takes into account orientation, good external insulation, passive solar systems (direct gain and Trombe walls) and it has a central solar water heating system with a natural gas boiler as auxiliary for both hot water and heating. About half of the apartments don't have heating systems installed or connected.

Figure 2.10: APT06 building on the Expo98 site

ADE09 is constructed in 1999. It was designed with the intention to build a healthy and low energy building. The apartment building is situated outside the city centre of Berlin.

The building has three naturally ventilated floors and the total floor area is 20000 m².

The total (heating and electricity) energy demand of the building is 141 kWh/m²a. Some flats have a wall heating.

A photovoltaic plant is installed on three roofs of the housing department. In order to reduce the consumption of water, toilets are equipped with a 4 l flush and body form bathtubs with 85 l content are installed. This building has a low BSI 10 (0.73).

Figure 2.11: ADE09 building

Figure 2.12: ADE14 building

ADE14 was constructed in 1986. The apartment building is situated in Berlin close to a busy road. This naturally ventilated building has twenty-two floors and its total floor area is 26'000 m².

The total (heating and electricity) energy use of the building is 133 kWh/m²a.

The façade was renovated in 1990 with the idea to present a new management plan for skyscrapers. A 70-meter high photovoltaic plant was assembled at the south façade. The 426 m² photocell area produces annually 25.000 kWh electrical energy. A part of it is used for the building equipment, so 12 € can be saved per apartment.

This building has also a low BSI 10 (0.94. The main comfort problem is a high and uncomfortable temperature during summer. Additional problems exist with the air quality and the noise.

Figure 2.13: ADE21a building

ADE21a was constructed in 1991 outside the city centre of Berlin. This naturally ventilated building has six floors and the total floor area is 4234 m².

Its total energy performance index is 144 kWh/m²a, and the building has a very low BSI 10 (0.57). Only 10% of the inhabitants who answered the questionnaires and reported any symptom suspect that the building is related to their symptoms.

The main comfort problem is a high and uncomfortable temperature during summer

Figure 2.14: ADE21 building

ADE21 was constructed in 1965 and renovated in 1995 with the intention to improve the insulation of the facade.

This naturally ventilated apartment building is situated outside the city centre of Berlin. The building has seven floors with a total floor area of 12000 m².

The total energy performance index of the building is 202 kWh/m²a. According to the BSI 10 (0.17) the building is classified as healthy. The main comfort problem is a high and uncomfortable temperature during summer based on the analysis of the questionnaires and checklists. Additional problems exist with the air quality in winter, the noise and draft.

2.5.2 Office buildings

ONL01 was designed as a sustainable, energy saving (70% below standard), human friendly building. The building can be characterised as relatively small (gross floor area of 2000 m^2), with a strong integration of building technique and systems (a.o. HVAC system). The building is equipped with balanced ventilation (VAV) using displacement flow in the office rooms. Much attention is given to energy saving systems, using a ground coupled (aquifer) heat pump system. Further characteristics are:

- optimisation of volume and surface area
- 90 m^2 photovoltaic panels
- demonstration project for LON (local operating network) technology

Figure 2.15: ONL01 building

Built in 1998 to bring the best possible comfort to the occupants with a minimum energy use, the OCH02 building has large passive solar gains. Good thermal insulation, hybrid ventilation system with heat recovery from exhaust air and computer centre leads to an energy performance index lower than 100 kWh/m² floor area. Passive cooling by natural ventilation improves summer comfort in more than 80% of the space. Only spaces that have large internal gains (meeting rooms) have artificial cooling. The source of energy for heating is natural gas with significant contribution of 120 m² thermal solar collectors with seasonal heat storage.

Figure 2.16: S-E facade of the OCH02 building

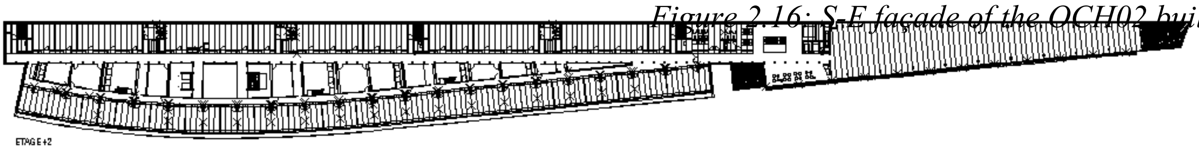


Figure 2.17: Plan of OCH02 building

The narrow plan facilitates air distribution in warm season, the air entering through the windows and being evacuated by central staircases.

2.5.3 Office buildings

Figure 2.18: ODE06 building

ODE06 is constructed in 1996 with the intention to build a low energy house. The office building is situated outside the city centre of Karlsruhe. It has three floors, with a total floor area of 3124 m². The total (heating and electricity) energy demand of the building is 101 kWh/m²a.

The building is naturally ventilated through slots in the façade. The exhaust air is leaving over a shaft inside the building by stack effect, without fan. The shaft is build out of black walls. The energy of the solar radiation heat the shaft's walls, helping the stack effect.. The system is used in summer for cooling the building, and in winter it is a heat recovery system on the exhaust air.

According to its low BSI, the building seems healthy. From the questionnaires, the main comfort problems are high temperature in summer and cold temperature in winter. Additional problems exist with the air quality and noise.

ODE04 was renovated in 1993 with the intention to improve the insulation of the façade. The office building is situated in Berlin.

The building has two floors and the total floor area is 3172 m². Windows naturally ventilate the building. The total (heating and electricity) annual energy demand of the building is 186 kWh/m².

According to it low BSI (0.79) the building is classified as healthy. The main comfort problem is a high and uncomfortable temperature during summer and cold during winter based on the analysis of the questionnaires and checklists. Additional problems exist with the air quality, the noise and light.

Figure 2.19: ODE04 building

3 LAYOUT OF OCCUPIED SPACE

3.1 General

The layout of the occupied and occupant's well-being are linked as shown in figures below.

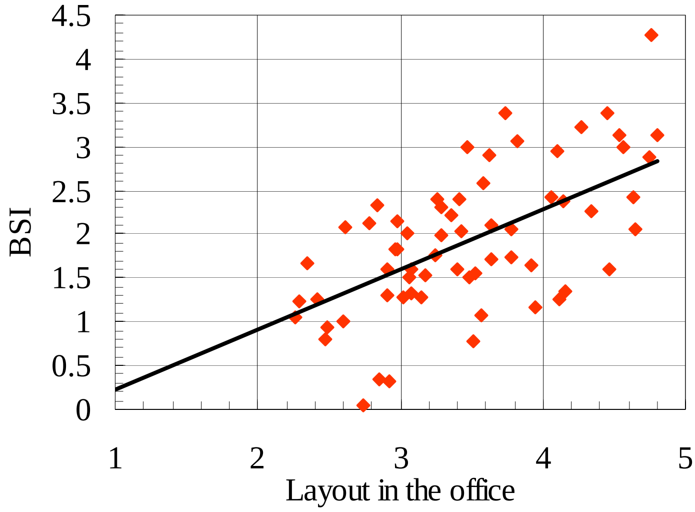


Figure 3.1: There is a strong correlation between the BSI and the layout as perceived by the occupant.
Scale for the layout goes from 1 = satisfactory to 7 = unsatisfactory.

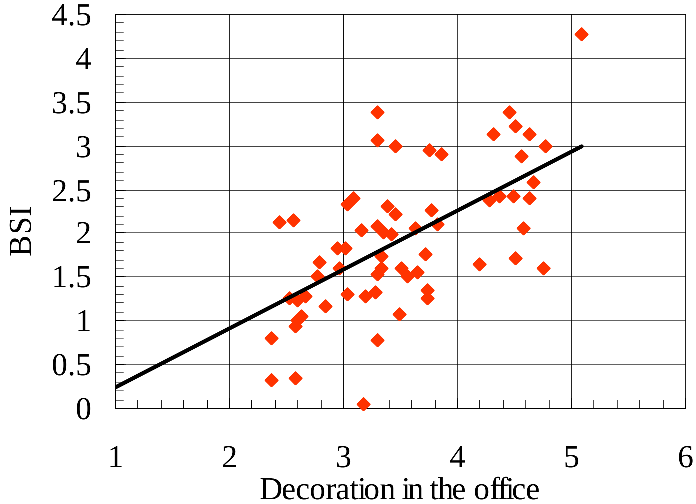


Figure 3.2: Correlation between the BSI and the decoration as judged by the occupant.
Scale for decoration goes from 1 = satisfactory to 7 = unsatisfactory

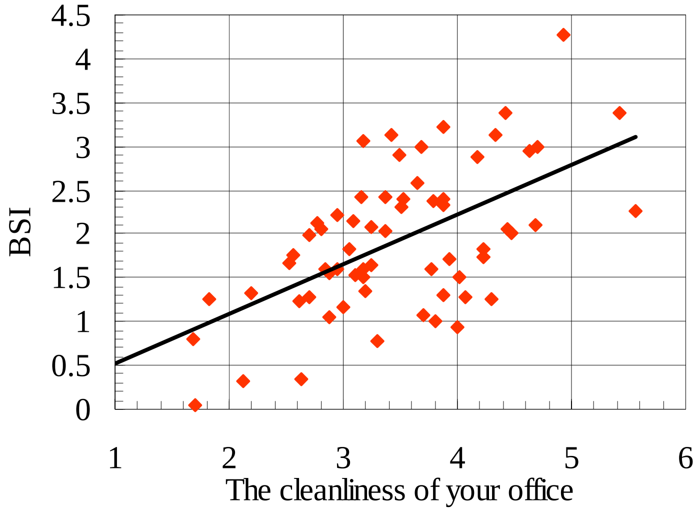


Figure 3.3: Correlation between the BSI and the perceived cleanliness.
Scale for cleanliness goes from 1 = satisfactory to 7 = unsatisfactory.

Therefore, it is important that the layout of occupied spaces be designed to please to the occupant.

3.2 Open plan office buildings

3.2.1 Description

A particular layout often found in offices is the open plan office, in which workers are grouped in large rooms, sometimes with separations at head's height with light, mobile walls, furniture or plants.

Foreseeable comfort problems are disturbing noise, problematic individual control of the environment, not solved in most open office buildings

3.2.2 Observations

In office buildings audited within the HOPE project, the BSI shows a significant positive correlation (P = 0.1 %)[2] with the percentage of occupants in the building having 6 or more neighbours in the same room (Figure 3.4).

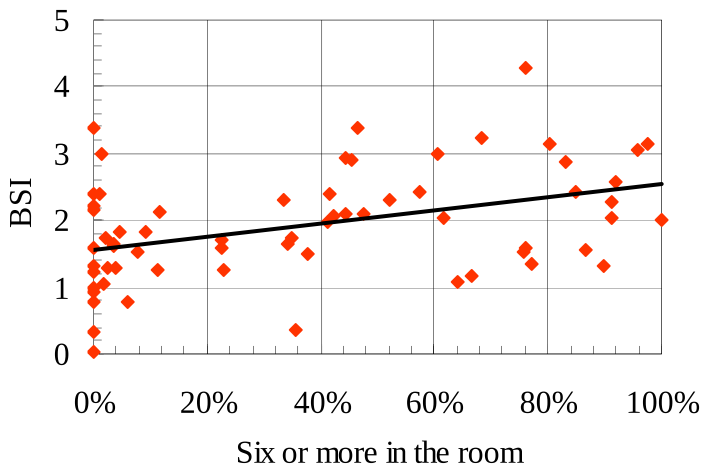


Figure 3.4: Correlation of BSI with the percentage of occupants in the building having six or more neighbours in the same room.

This confirms results from the former European IAQ Audit (Bluyssen, De Oliveira Fernandes et al. 1995) (Figure 3.5)

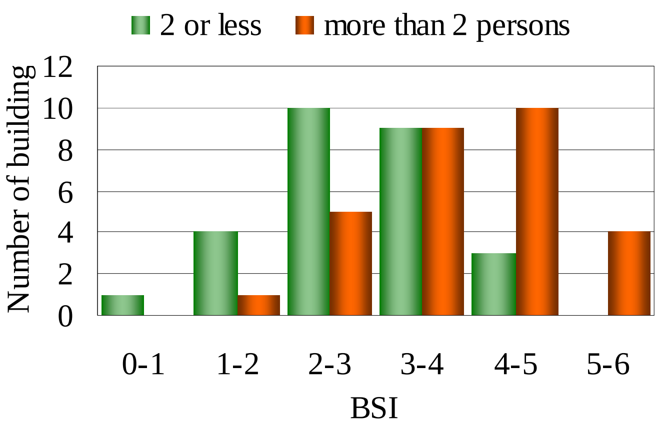


Figure 3.5: Distribution of BSI in cellular and open offices (from European IAQ audit).

[2] P is the probability that the conclusion (in this case a positive correlation) drawn from the data is wrong

There is also a significant correlation (P = 1%) with the perceived noise (Figure 3.6)

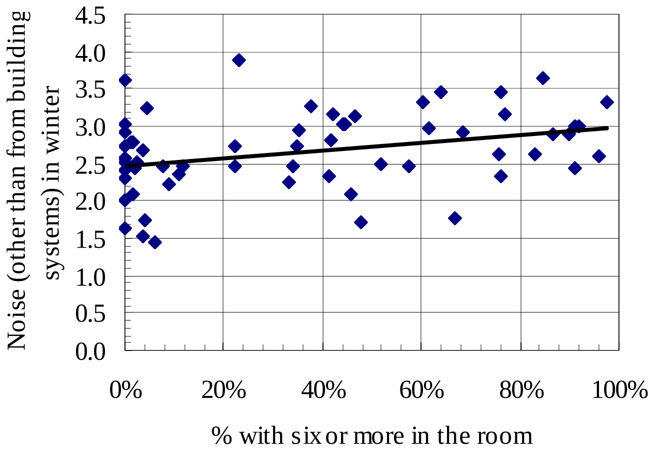


Figure 3.6: Correlation of perceived noise from within the building, other than from building systems, with the percentage of occupants in the building having 6 or more neighbours in the same room.

Correlation with the lack of perceived control and larger number of neighbours are also very significant for control of temperature ($P = 10^{-5}$), of ventilation ($P = 5{\cdot}10^{-4}$) of lighting ($P = 10^{-5}$) and of noise ($P < 10^{-6}$).

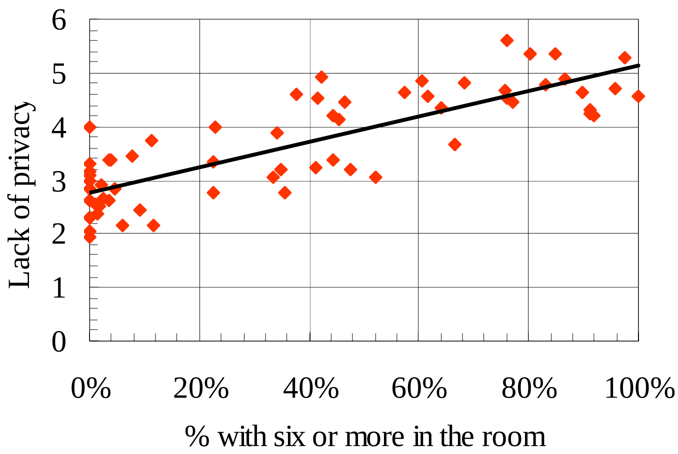


Figure 3.7: The lack of privacy increases with the percentage of occupants having 6 or more neighbours in the same room.

Not surprising is that the average perception of the lack of privacy in a building strongly increases with the number of neighbours. Figure 3.7 shows the results for six or more neighbours, but similar results are obtained for 4 or more neighbours.

3.2.3 Recommendations

- Don't mix in the same room noisy activities with those requiring silence or concentration and increased attention (e.g. listening).
- Prefer, as much as possible, cellular layout to open office.

4 ENSURING THERMAL COMFORT

4.1 Thermal insulation

A good thermal insulation not only reduces heating and cooling energy use, but also improves comfort by reducing the unpleasant effects of cold or warm surfaces. In temperate climates, where buildings require essentially cooling, a good thermal insulation reduces the heat gains from outdoor air and solar radiation. However, it should be combined with passive cooling (see 4.5), to evacuate internal heat gains. HQ buildings are better insulated (lower U-values for roofs, walls and glazing) than other ones (see 8.2.2).

4.2 Preheated ventilation

Use of preheated supply air improves thermal comfort in cold climate. This can be achieved by placing air inlets close to the radiators, by installing ground air exchangers ("Canadian wells"), or by installing mechanical air supply with heat recovery.

Table 4.1: Rating of thermal environment and air movement in winter in apartment buildings with and without supply air heating in Finland (scale from 1= satisfactory to 7= unsatisfactory; averages over 5 and 6 buildings)

	Heated supply air		Unheated supply air		
	Mean	σ	Mean	σ	P[3]
Thermal comfort	2.65	0.37	3.43	0.33	0.04%
Thermal sensation	3.96	0.22	4.18	0.27	3.27%
Temperature stability	3.10	0.32	3.56	0.44	1.10%
Feeling draughts	3.82	0.21	4.34	0.30	0.07%
Overall comfort in winter	2.57	0.33	2.76	0.39	13.06%

4.2.1 Ground heat exchangers

Air is preheated or precooled in a network of underground ducts (Figure 4.1) before being supplied to the building. The ground temperature is colder than outdoor air in the warm season and warmer than outdoor air in the cold season.

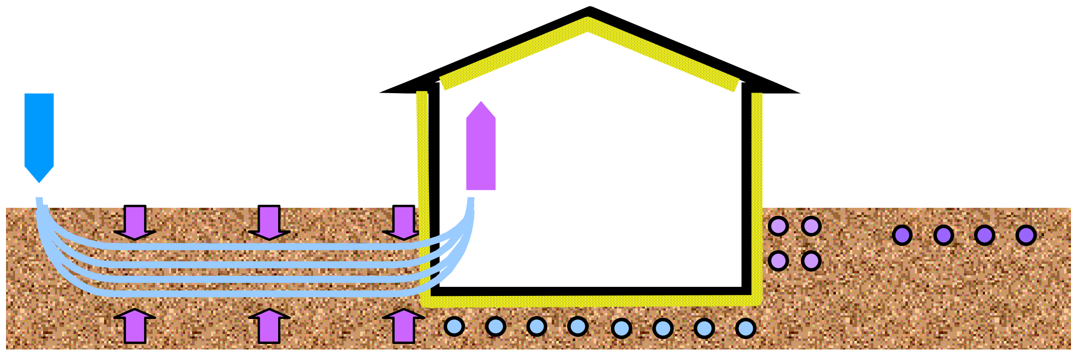


Figure 4.1 : Principle of a ground heat exchanger Circles represent possible ducts locations.

The following guidelines should be followed to get good results:

- Place cleaning openings at least at each turn
- Ensure draining of the whole network: water should not stay in the ducts.

[3] *P* is the probability that the conclusion (in this case a significant difference) drawn from the data is wrong.

- Ensure, if necessary, enough thermal insulation between the building and the ducts. Heat for the air should not come from the building!
- Ensure a good thermal contact between the external duct surface and the soil. A thin air layer could strongly reduce the heat exchange efficiency.

Figure 4.2 : Two HQ buildings audited within the HOPE project equipped with ground heat exchangers (photos EPFL).

Duct's material should fulfil the following requirements (Fraefel, Huber et al. 2000) :

- Resist to ground pressure,
- Resist to soil acidity,
- Air- and gas-tight(water vapour, radon),
- Smooth, to make cleaning easy
- Easy to install, low cost.

The length of the ducts should not be larger than 30 meter, to avoid too large pressure drop, for the same reason and to ensure a good heat exchange, the air velocity in the ducts should be between 2 and 3 m/s.

A distance of 20 cm between two ducts is good enough to smooth daily temperature variations, but the distance should be 2 to 3 meter for seasonal storage. According to (Hollmuller 2002), the heat exchange area should be about 1/15 m^2 for each m^3/h airflow rate for dayly storage and half this for seasonal storage.

4.3 Solar gains and solar protections

4.3.1 Passive solar heating

Solar energy enters freely in the building, mainly through the windows, thus contributing to heat the building. In order to take the best profit of these gains during the cold season without being overheated, the following conditions should be met (Figure 4.3):

The building should be well insulated, to avoid excessive losses.

It should have large collecting areas on the sunny side of the building (from south-east to south-west in Northern hemisphere). Collecting areas are mostly windows, but can also be sunspaces or walls with transparent insulation.

These windows should be equipped with mobile, controllable ***solar protections***, in order to control the gains. Good solar protections for mid-season and summer are external, since only these can significantly reduce the gains to avoid overheating. Internal solar shading might be necessary to control lighting conditions (glare). In winter, internal shadings are preferred, since they avoid glare but allow solar heat gains. Fixed solar protections are not ideal, since they don't allow any control: they either are not sufficient on some sunny days, or reduce daylight on overcast days. Vegetation with deciduous leaves may help by bringing a seasonal solar protection. However, it also shadow the building the whole day long, even when more daylight is necessary.

The heating control should cut the heating system as soon as solar gains suffice to keep a comfortable internal temperature, and switch it on as soon as necessary.

A large thermal mass (heavy construction) allows to store heat, thus avoiding overheating during sunny day and maintaining a mild indoor climate during the night.

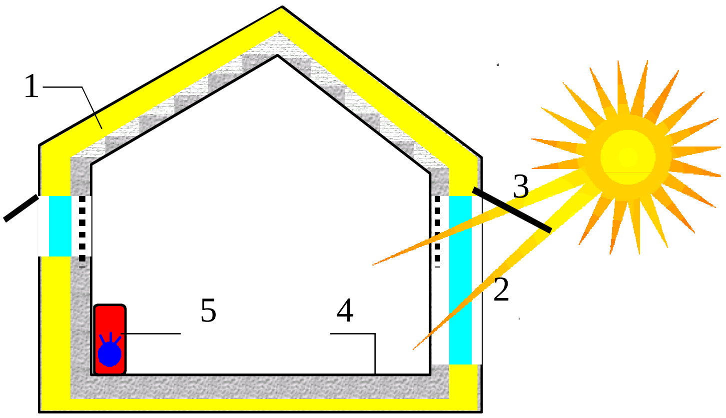


Figure 4.3: Requirements for passive solar heating

1. *Good thermal insulation*
2. *Large windows on the sunny side*
3. *Mobile solar protections*
4. *High thermal mass*
5. *Adequate heating and control systems.*

Passive solar gains can be useful to improve comfort at low cost during the heating season, but may be uncomfortable when poorly controlled, especially in mid- or hot season.

4.3.2 HOPE observations

Few of the audited buildings, in particular among offices buildings have efficient solar protection. In many cases, external solar protections are not allowed, either for architectural reasons (!) or because of too high wind pressure in high rise building.

Expected comfort problems are too hot on sunny days, possible glare, increasing cooling energy use, increases the cooling load or encourages the use of mechanical cooling.

In buildings with natural ventilation, the risk of having too high temperature increases in buildings without solar protections. However, there were not enough (only 2) office buildings of the last type in the sample to get significant statistical confirmation of this obvious risk.

If all buildings are taken into account (both uncooled and cooled), there are still significant differences ($P < 5\%$) in the perceived temperature (Figure 4.4), thermal comfort and temperature stability between buildings with and without solar protections. All these differences are in favour of buildings with solar protections.

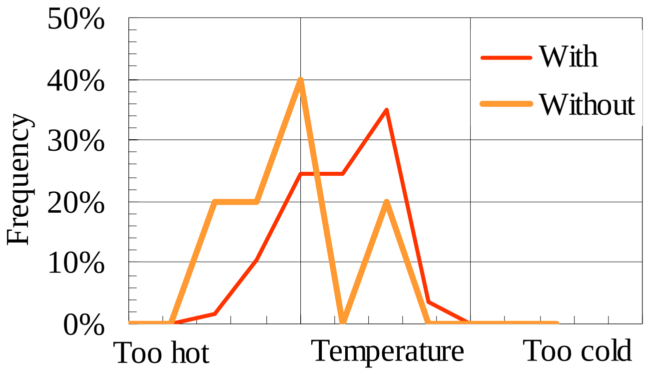


Figure 4.4: Vote on the perceived temperature in summer in buildings with and without solar protections.

4.3.3 Recommendations

Good solar protections are outside. Solar radiation is partly reflected by the solar protection, but a large part is absorbed in it, and transformed into heat, which increases the temperature of the solar protection. If this protection is outdoors, this heat is released to outdoor air and does not enter the building. If the solar protection is inside, this heat is delivered to indoor air, thus heating the building.

Use wind proof external solar protection, if necessary use solar protection behind a second skin. In this case, the space between the two skins should be well ventilated, with openings at least every second floor.

The use of sun reflective glazing decreases daylighting, hence increases artificial lighting and heat load. The sun is the most efficient light source: only 1 W/m² heating for 100 lux.

Daylight changes naturally as well as solar radiation, and these are sometime very useful (passive solar gains, daylighting) and sometime uncomfortable (glare, too hot). Therefore, solar protections shall be moveable to control the solar radiation entering the building. An automatic control with possibility for individual override is preferred.

4.4 Overheating in summer

4.4.1 Description

The building may be at risk of being too hot in summer for various reasons:

- Located in a warm climate
- Large glazed area without solar protection
- Neither passive or active cooling
- Too high internal heat load

Expected comfort problems are transpiration, reduced performance and productivity, increase of human errors. The risk of reduced air quality (smells, humidity) also exists.

Hot buildings increase the cooling load or encourage mechanical cooling.

4.4.2 HOPE observations

A high perceived temperature in summer decreases the perceived productivity (Figure 4.5). This relationship is not observed in winter. The negative slope in Figure 4.5 has a probability smaller than 10^{-5} to be zero or positive.

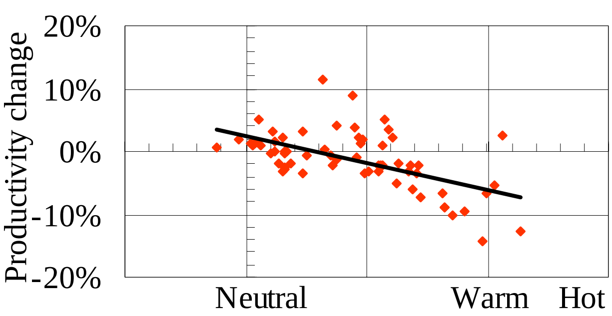


Figure 4.5: Perceived productivity and temperature in summer

Not surprising also is that the average vote on temperature in Summer is closer to the comfort value in office buildings with mechanical cooling (mean vote is 0.75) than in buildings without mechanical cooling (mean vote is +1.17). This difference is very significant ($P = 10^{-6}$)

However, the difference between the perception of thermal comfort between these two groups of buildings is smaller: votes are both close to 4 (3.93 and 4.29) on a scale from 1 "comfortable" to 7 "uncomfortable". The difference in average votes on this question is also less significant ($P = 0.5\%$).

This confirms that occupants of buildings without mechanical cooling are more tolerant than those in fully conditioned buildings.

The productivity is perceived as not changed in cooled buildings and decreased by 3% in the other buildings. This difference is not large but significant ($P = 0.01\%$)

4.4.3 Recommendations

Reducing inside air temperature by improved insulation and solar protections, together with passive cooling using night ventilation is sufficient to prevent discomfort and energy problems in many cases.

Install external solar protection and use night ventilation (passive cooling).

Mechanical cooling improves thermal comfort but increases energy use.

4.5 Passive cooling

Passive cooling through night-time ventilation is a comfortable, cheap, and energy-efficient way to keep the indoor environment within a comfortable temperature range in most European climates, in particular in central Europe, north, west and higher altitudes in Mediterranean areas. In well adapted buildings, it can ensure a comfortable indoor climate in summer without artificial cooling, provided that internal heat load is not too large.

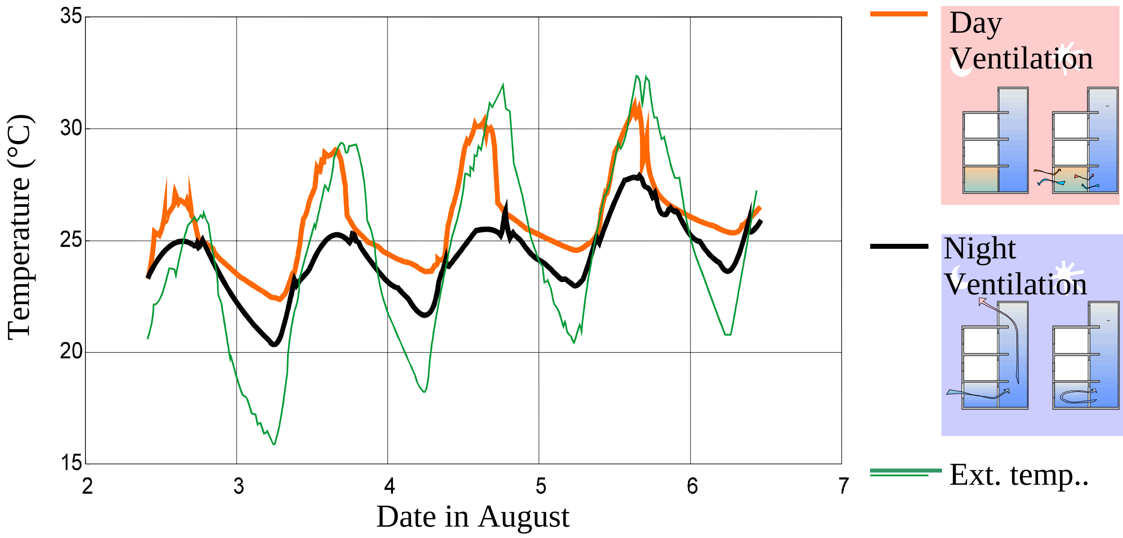


Figure 4.6: Temperatures in two identical office rooms. One is aired as usual, only during the day. The other one is aired mainly at night. Thin line is outdoor temperature.

Figure 4.6 shows the evolution of internal and external temperatures in two identical office spaces (40 m^3) of the LESO[4], which have been ventilated following two different strategies:

(1) the usual strategy in office buildings, with ventilation during the day but not at night; and

(2) the passive cooling strategy with natural ventilation at night.

4 The LESO building is a passive solar office building at the EPFL.

The office spaces have considerable thermal inertia and external solar blinds. The night ventilation rate corresponds to about 10 building air volumes per hour. One person occupies the office during 8 hours per day, often with a personal computer running. This experiment, along with many others, shows that summer comfort can be greatly improved at low cost using passive cooling.

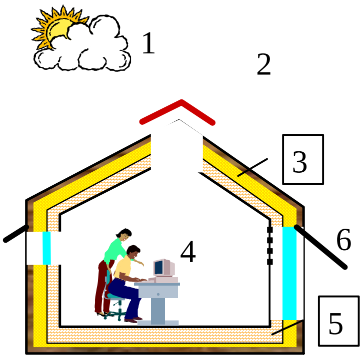


Figure 4.7: Requirements for an efficient passive cooling

1. Adequate climate
2. Large openings, one at the top of space
3. Good thermal insulation
4. reduced internal gains
5. High thermal mass
6. Efficient solar protections
7. Airing night, not during the day!

Principles of passive cooling are compatible with those of passive solar heating. As shown on Figure 4.7, they are:

1. avoid internal heat load by promoting daylighting and low energy appliances;
2. avoid heat gains by using good thermal insulation, efficient shading systems (external and movable), and minimum ventilation rate during hot hours,
3. store the remaining heat gains in the building structure. For this, the heavy building structure should be in direct contact with the indoor environment.
4. cool the building structure with a large ventilation rate when the external temperature is lower than the internal temperature. Large ventilation rates are easily obtained by natural ventilation through windows and doors.

Such a strategy can be applied only in climates where the daily average outdoor temperature is within comfort limits, and where there is a significant temperature swing between night and day. This is fortunately the case in most European climates.

In addition to the heavy structure, the building should have large and well located openings, and these openings should be safe enough to remain open at night.

Figure 4.8 : The LESO building, in which measurements shown in Figure 4.6 were performed (Photo EPFL). This is the south façade, with large windows and special daylight devices.

The LESO building is a passive solar office building (Figure 4.8). Its total energy performance index is less than 60 kWh/m², including all appliances. This massive building is very well thermally insulated (20 cm insulation thickness, low-emissivity coated double glazing).and has large passive solar gains controlled by external movable solar protections. For passive cooling, there are safe openings at the bottom and the top of the building, so that a large airflow rate may cool down the staircase during the night, as well as all offices that have their door open to the staircase. It is also possible to ventilate each office room individually by leaving the windows open ajar. This way is however less efficient.

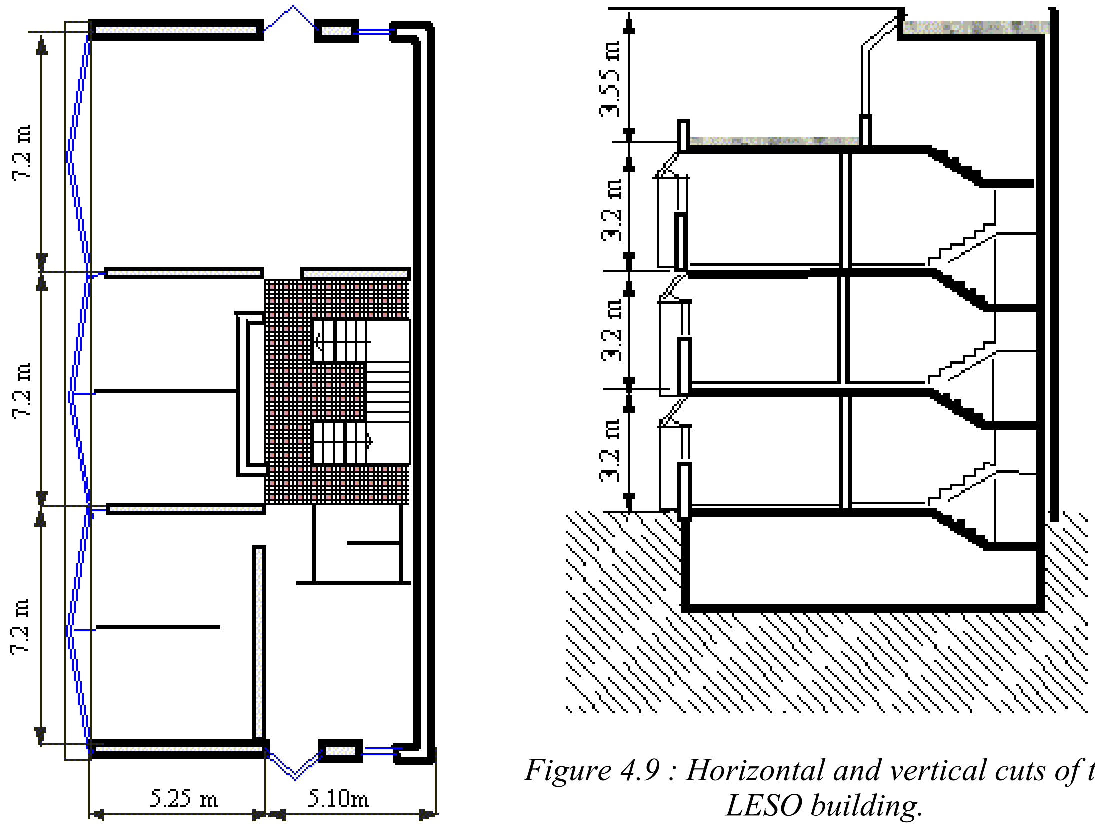


Figure 4.9 : Horizontal and vertical cuts of the LESO building.

If passive cooling is not possible, mechanically driven night ventilation is an alternative that should be considered. This issue was addressed within the European project HybVent. Comprehensive reports can be downloaded from http://hybvent.civil.auc.dk/

5 GOOD AIR QUALITY

5.1 External sources of pollution

5.1.1 Description

There is a risk of pollution from external sources such as car parking, attached garage, busy road, power plant, industry, cooling towers, landfill site, or agriculture.

Potential IAQ problems are infiltration of toxic gases such as benzene, CO, NO_x, etc., dust and bad smells.

5.1.2 HOPE observations

93% of audited office buildings had nearby external sources of pollution, most of these being busy road (69%), car parking (59%) or attached garage (24%).

No statistically significant differences were observed for BSI and odour in the air between office buildings with and without nearby source of pollution such as car parking, busy road, power plant, etc. The reason maybe either relatively low strength of the external sources, or measures taken to avoid the effect of these sources.

However, in the measurements carried out in the detailed field investigations, the presence of VOCs or dust was shown to be present in several buildings close to pollution sources and in which appropriate measures were not taken.

Note also that there were not many buildings close to power plant, industry, cooling towers, built on a landfill site, or near agricultural sources. Therefore, no conclusion for these sources can be obtained from the HOPE results/data.

5.1.3 Recommendations

Avoid outdoor sources:

- Build garage in a separate building.
- Build an airtight wall or deck (no door) between garage and living space.
- Install a ventilated lock or an airtight door and ensure a positive pressure difference between living space and garage.
- In radon area, design radon ingress control with proper construction of foundation (occupied space separated from the ground by a ventilated space) or ventilation (control of pressure difference), or other measures (e.g. mechanical ventilation).
- Buildings with more susceptible occupants that should be protected from outdoor sources (e.g. hospitals, homes for elderly, schools) should not be located in city centres, or at least placed far from busy roads, power plants, industrial area, and landfill sites.

In case of outdoor sources:

- Use appropriate filters: F7/EU7 for particles; Install active charcoal filters in the outdoor air inlet of buildings close to airports or other significant VOCs sources.
- Ensure appropriate maintenance of the filters.
- Install balanced mechanical ventilation, locating air inlet as far as possible from pollution sources, ensure a slight overpressure in building.

5.2 Internal sources of pollution

5.2.1 Introduction

Since the buildings should be designed and built for occupants, the occupants and their activities should be the only internal source of pollution. As it was shown in several studies (Fanger 1988; Bluyssen, De Oliveira Fernandes et al. 1995), this is by far not the case. The building itself and its installations are often the main source of pollution (Figure 5.1)

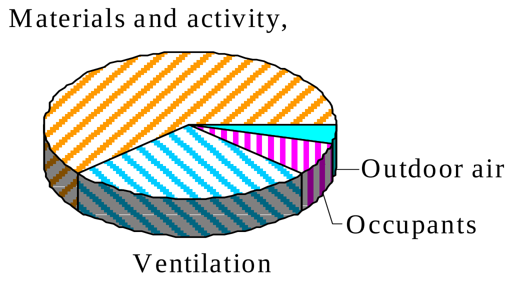


Figure 5.1: Average source strength for bad odours in buildings audited within the European Audit.

It is however possible to reduce the number and the strength of the internal pollution sources by applying the following recommendations:

- Choose materials that do not emit pollutants or that have low source strength. More and more providers and the SOPHIE database (Bluyssen, de Oliveira Fernandes et al. 2000) give information on the emissions of their materials and products.
- Avoid polluting activities indoors, or ventilate strongly and locally the areas where these activities are performed.
- Use cleaning agents and maintenance material such as paints that do not contain toxic solvents or components
- Do not smoke in buildings (prohibited in office buildings in most countries).
- Follow the AIRLESS recommendations (see 5.3) in mechanically ventilated buildings

5.2.2 HOPE observations

Unexpectedly, the perceived air quality, stuffiness or odour is not significantly correlated with the percentage of smokers in office buildings, and is only slightly in homes.

It was however noticed that smoking in buildings designed as no smoking lead to problems. The ventilation and zoning are not designed for the heavy pollution load brought by smokers. Even when smoking is allowed only is restricted zones, odours spread and lead to complaints.

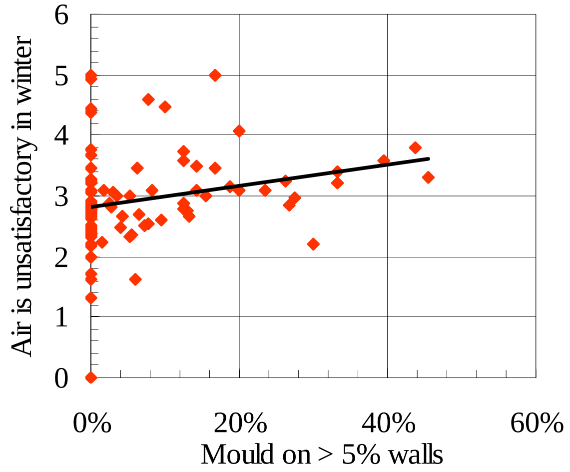


Figure 5.2: Perceived indoor air quality in homes is correlated with the presence of moulds.

In homes, the correlation between perceived air quality and the presence of mould is significant, but not in office buildings (Figure 5.2)

5.2.3 Specific recommendations

From observations within the HOPE project, the following specific recommendations can be given:

Reduce indoor pollution sources

- Install proper flue gas pipes or chimneys for combustion appliances (heater, boiler, gas stoves).
- Use cooking fuel other than gas, or use a kitchen hood evacuating the fumes outside.
- Heating with coal or wood in ordinary furnaces, not equipped to burn them properly, produces toxic fumes that could enter in the building.
- Install the central heat plant or local heater outside the building.
- Don't use radon bearing materials (gypsum, alum shale, granites and volcanic tuffs).
- Choose low-emitting or formaldehyde-free furniture, flooring or floor covering.
- Choose low-emitting (VOCs) paint, fabrics, flooring.
- Provide enough space, at least 10 m^2/ocupant in office rooms.
- Avoid sources of moisture: no humidifier; tumble driers or other such sources should vent outside.

Appropriate ventilation rate

Ventilation rates were checked in some buildings and not always found at the design value. For example, in one building, the exhausts in kitchen and bathroom were so dirty than the measured exhaust airflows were much lower than design values. It was also found that airflow rates were closer to the design values where the air-handling unit was properly commissioned.

5.3 AIRLESS recommendations

5.3.1 The recommendations

The EU project AIRLESS[5] proposed several recommendations for improving the indoor air quality and energy performance of mechanical ventilation. These are remembered below, together with HOPE complements.

Recirculation should be avoided, except in some specific cases like clean rooms

Since air is not a good vector to transport heat, the airflow rate required for cooling or heating a building is usually much larger than the hygienic airflow rate. Recirculation was therefore used where air heating or cooling was provided by air: only the hygienic airflow rate is taken outdoors, while heat is given or taken to air circulating in the building. Recirculation diffuses pollutants produced at one place into the whole building. At constant indoor air quality, recirculation just increases the airflow rate, thus increasing the electrical energy for moving the air. Therefore, recirculation in itself is not actually a way to save energy.

Simulations showed that the electrical energy demand for ventilation decreases with about 40% if no recirculation is used compared to 50% recirculation rate.

[5] Contract JOR3-CT97-0171, AIRLESS final report, Ph. Bluyssen et al.. TNO, Delft, NL 2001.

Use a heat recovery system that is well-installed and in a building that is not leaky

In a mechanical ventilation system, heat recovery is an efficient way of saving energy while ensuring a good indoor air quality. Heat recovery is however efficient where and only where the following actions are taken:

- airtight building envelope;
- no leakage in the ventilation unit;
- no parasitic recirculation.

The global heat recovery efficiency, η_G, is defined by the ratio of the heat recovered during a given period of time by the heat loss by ventilation if there were no heat recovery. This figure depends not only on the heat exchanger itself, but also on the building and the ventilation system. A quantity easy to measure is the nominal heat recovery effectiveness of the device itself, defined by:

$$\varepsilon_{HR} = \frac{\theta_s - \theta_o}{\theta_x - \theta_o}$$

where θ is the temperature of supply air (subscript *s*), of outside air (*o*) and of extract air (subscript *x*). This quantity, which characterises the heat recovery device, is in most cases larger than the global heat recovery efficiency (Roulet, Heidt et al. 2001).

In systems well-installed in airtight buildings, the real heat recovery efficiency can be as high as 85% of the efficiency of the heat recovery system itself, so about 75% in the best cases. At the contrary, the global efficiency may be zero if the system is not well designed, and installed in a leaky building. Exfiltration and internal recirculation reduce the global efficiency as shown in Figure 5.3. External recirculation also reduces the global efficiency, but in a smaller extent.

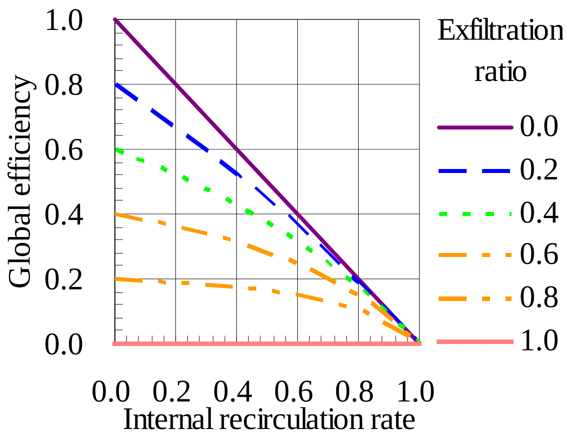


Figure 5.3: Reduction of heat recovery efficiency when exfiltration or recirculation is present.

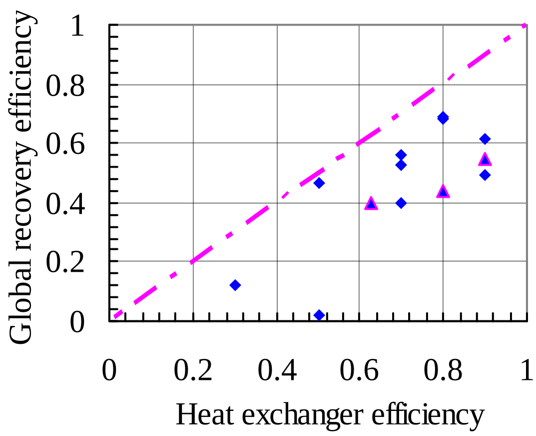


Figure 5.4:Actual heat recovery efficiency versus heat exchanger efficiency measured in several units(Roulet, Heidt et al. 2001).

As shown in Figure 5.4, this reduction is observed in practice. In a few cases, the actual heat recovery is reduced to nothing, and in many cases the recovered heat is not worth the invested money.

Simulations showed that the total heating energy demand with a global heat recovery efficiency of 75% instead of 85%, increased with 3 to 5% in cold and mild climates and with 15% in warm climates (in absolute values only 2 to 3 MJ/m^2 differences). Comparing the use of a heat exchanger with an efficiency of 50% with no use of heat recovery resulted in a 67 to 137% higher heating energy demand for ventilation.

Sometimes the outdoor air is at the appropriate temperature, while the exhaust air could be too warm or too cold. For these situations, a bypass should be installed, allowing the supply air to pass by the heat exchanger.

Use a rotating heat exchanger with purging sector, and only if recirculation of certain odours is not a problem

Rotating heat exchangers have in principle a better heat recovery than other types of heat exchangers, and this is the reason why they are used instead of other models (heat pipes, plate exchangers, etc.). However, they do transfer a part of the pollutants from the exhaust air into the supply air (Schaeffler, Schultz et al. 1988; Roulet, Pibiri et al. 2002; Fujii, Cha et al. 2005). Therefore, heat pipes or plate exchangers should be installed instead of rotating heat exchangers where some recirculation of odours cannot be accepted. In office buildings audited within the HOPE project, the perceived air quality in winter in the 14 buildings equipped with rotating heat exchangers is, on the average, significantly worse than in the 36 buildings with no heat recovery or with another airtight heat recovery system. There is however no significant difference on average perceived air quality between buildings with and without heat recovery.

When using a rotating heat exchanger, supply and exhaust fans should be located and sized so that a positive pressure difference of about 200 Pa is achieved between supply and exhaust ducts at the wheel level.

Hygroscopic materials increase in most case the efficiency of the heat exchange. However, odours and other contaminants are also better adsorbed on such surfaces. Avoid hygroscopic wheels when contamination is an important concern..

The addition of a purging sector is recommended. Simulations showed that the use of a purging sector only decreased the efficiency with 3%, which has a negligible effect on the energy demand, but decreases by half or more the amount of transferred contaminants. Check that the wheel turns into the correct direction, so that the wheel passes from exhaust to supply ducts in front of the purging sector.

Clean dirty wheels according to instruction of the manufacturer, with either compressed air or vacuum cleaner, or pressurised water.

Also check that the wheel control stops the wheel when no heat can be recovered.

Avoid humidification whenever possible, and always avoid too high humidity

The use of energy by humidifiers during the operation of an HVAC system, is related to:

- Use of humidification;
- Level of relative humidity required in respect to temperature and relative humidity of incoming air;
- Type of humidifier.

In most European climates, humidification is not necessary. It may be needed only in very cold climates, or to avoid material shrinkage (museums, archives). A lower relative humidity seems to result in a better perceived air quality. However, eye complaints might occur with a too low humidity.

No significant difference was however found for "itchy eyes", BSI or for "too dry air" complaints in audited office buildings with and without humidification in the air handling unit, but the perceived air quality in winter was found significantly more satisfactory in office buildings without humidification. Statistically speaking, humidification does not seem to have a significant positive impact.

Too high humidity favours mould growth. Relative humidity should be adapted to thermal insulation, in such a way that it overpasses nowhere 80%, including on internal surfaces of thermal bridges.

Simulations showed that adiabatic humidification to a relative humidity of 30% lead to an increase in heating energy demand for ventilation resp. 3% (Rome) to 20-25% (Oslo, Zürich). A relative humidity of 50% required almost 100% additional heating energy for ventilation.

Apply operation strategies focussed on shutting the system down when no air is required.

A reduction in operation hours will consequently result in a reduction of energy use for ventilation. However, make sure that the system is restarted early enough before air is required in order to purge the building from contaminants accumulated during off time before occupants arrive. During the warm season, the ventilation could nevertheless be turned on outside occupation hours for cooling down the building. However, the very large airflow rates needed for this free cooling are best provided by natural ventilation through large openings.

Use a filtering system that "cleans" the air and has a resistance as low as possible

Filtering of the air is necessary to clean the air (from particles) for the occupants and to protect the HVAC-system. Common filter techniques (bag filters) are such that filtering leads to an increasing film of dust collected on the filter. The fact that fresh outdoor air is transported through dirt accumulated on the filter is asking for problems. Therefore, filters should be changed or cleaned often enough to prevent that the filter becomes a source of pollution.

The energy needed for air to pass through a filter is related to the resistance of the filter. The higher the resistance of the filter, the more energy it takes to get the same air through the system. Dirty filters have a larger pressure drop than clean ones, have a higher filter efficiency for dust but emit gaseous pollutants

Use ductwork that is clean (free of oil residuals and dust), smooth, as large as possible and has as less curves as possible

Source control should be emphasised for ducts: start with clean ducts, and then avoid dirt to get in by efficient filtering. Quality management on the construction site should be focussed on this.

The use of energy by ducts during the operation of an HVAC-system is related to the resistance of the ducts to the airflow. This resistance depends on the air velocity in ducts, the length of the ducts, the amount of curves in the ducts, the smoothness of the interior surface of the duct, and the amount of deposits (obstacles) in the ducts).

Simulations showed that the pressure difference over the system of 1600 Pa instead of 1000 Pa leads to an increase in electric power use of 60%. The increase in total electric power depends on the geographic location and ranged from 25 to 55%.

Reducing air velocity in ducts from 5 m/s down to 2 m/s theoretically divides energy use to move air in ducts by a factor 6. This requires ducts 60% larger in diameter to keep the airflow rate at its original value.

If cooling is applied use a cooling coil with a droplet catcher

Simulations showed that a droplet catcher behind a cooling coil results in a negligible effect for the energy demand, but increases air quality by avoiding droplets humidifying the filters or sound absorbers that are located downstream. Humid filters increase the risk of microbial growth.

Increase/decrease the set point for cooling/heating as much as possible (with respect to comfort conditions of occupants)

An increment of the set point for cooling resulted in decrease of cooling demand by a factor 3 to 8, for the simulations made. In several cooled buildings, occupants found the temperature too low. These buildings are indeed overcooled and use more energy to decrease the comfort!

The perceived air quality is perceived as being better when the air is cooler.

Commissioning the air handling system after installation is essential.

Commissioning is not only checking that the fan rotates when turned on. The effective airflow rates and pressure differentials should be measured and compared to the design values. Where the differences are outside tolerance limits, measures should be taken to fix the problem. It is also advised to check the energy efficiency of all systems.

From investigations in many buildings in several countries, it was confirmed that the functioning of a building and its systems is seldom checked, even when new techniques or combinations of techniques are applied. It was also found that ventilation systems for which a commissioning report was available has airflow rates closer to the design values than the others.

5.3.2 Summarised recommendations

Perform a comprehensive commissioning of all building systems, just after construction and before using them.

Additional recommendations for ventilation systems

- No air recirculation, supply only fresh air
- Rotating heat exchangers only where contaminant transfer is not a problem
- Avoid humidification. In any case with clean water and not too high
- Don't filter air through dirt! Change filters regularly.
- Keep ducts clean

Additional recommendations for heating and cooling

- Keep heat exchangers clean
- Droplets catcher downstream cold exchanger
- Use water to transport heat instead of air
- Heat recovery in exhaust air requires airtight building envelope and air ducts.
- Avoid overheating
- Avoid under-cooling

5.3.3 HOPE observations

Buildings equipped with mechanical ventilation or air conditioning, which fulfil the AIRLESS recommendations are healthier and more comfortable than those fulfilling them partly or not, as shown in Table 5.1. However, the energy use of such apartment buildings is smaller, and there is no significant difference in the energy use of office buildings

Table 5.1: BSI, perceived IAQ and comfort as well as energy use in buildings equipped with mechanical ventilation or air conditioning fulfilling or not the AIRLESS recommendations.

		Residential buildings				Office buildings			
		Yes	**Partly**	**No**	**P**	**Yes**	**Partly**	**No**	**P**
Ventilation	Number	**3**	**10**	**4**		**12**	**10**	**7**	
	BSI	0.55	1.85	1.2	0.5%	1.6	1.9	2.6	1%
	IAQ	2.34	3.12	2.73	0.4%	3.3	3.9	4.4	0.01%
	Comfort	2.3	2.8	2.6	2%	3	3.4	3.6	0.1%
	kWh/m²	109	202	238	NS	275	190	211	NS
Heating & Cooling	Number	**3**	**8**	**3**		**9**	**10**	**8**	
	BSI	0.54	1.88	1.33	2%	1.7	1.7	2.7	0.2%
	IAQ	2.29	3.11	2.86	2%	3.4	3.8	4.3	0.6%
	Comfort	2.3	2.8	2.7	9%	3	3.3	3.6	4%
	kWh/m²	109	205	292	2%	276	198	207	NS

P is the probability that the differences result from chance. NS means that the difference is not significant.

5.4 Mechanical and natural ventilation

5.4.1 Advantages and inconveniences

Natural ventilation is the passive way to evacuate indoor contaminants. Wind and air density differences, resulting mainly from temperature differences, induce pressure differences that blow air through ventilation opening or natural ventilation ducts. Other openings such as doors and windows are also used for natural ventilation when large air flows are needed. The advantages or natural ventilation are the following:

- It is generally well accepted by the occupants, who understand and control it easily.
- Its cost is very low.
- The energy for moving the air is small and free.
- It allows very large airflow rates (more than 10 volumes per hour), in particular for passive cooling.
- It does not break down.

It has however some drawbacks, which are:

- It cannot be used in noisy or polluted areas.
- It is efficient only in rooms with a depth-to-height ratio smaller than 3 or having openings on both sides.
- Heat recovery is nearly impossible.
- The airflow rate varies with the meteorological conditions, and an adequate control is needed to ensure the ventilation requirements. An alternative solution is using self-regulated (pressure-controlled) ventilation grills.

Mechanical ventilation is often used where natural ventilation cannot fulfil the requirements, either because of poor outdoor conditions (noise, pollution, climate) or in locations that cannot be naturally ventilated. It has the following advantages:

- Allows ventilating deep spaces with low ceilings and rooms that are not accessible to natural air flow.
- Where well designed and built in an airtight building, it ensures a total and continuous control of air flows and also allows a better control of the indoor climate.

- It can protect from outdoor noise and pollution.
- Heat recovery from exhaust air is relatively easy.

Its drawbacks are however:

- Mechanical ventilation is often not well accepted by the occupants, who lack control on it (see 2.3)
- The system, especially air ducts, uses a large part (up to 25%) of the building volume.
- The installation and exploitation costs are high.
- It uses energy not only to condition the air but also to move it.
- It can be noisy, especially at low frequencies
- The quality of delivered air may be poor if special caution is not brought to it when building and maintaining the system (see 5.3).
- It may break down or function in an improper way.

5.4.2 HOPE observations

Table 5.2 and Table 5.3 show that, on the average, the BSI is higher in buildings with mechanical ventilation than in those with hybrid and natural ventilation, and in buildings with sealed windows than in buildings with operable windows. There are no significant differences for the the perceived air quality and comfort, and energy use.

Table 5.2: BSI, perceived IAQ and comfort as well as energy use in residential buildings ventilated with various systems.

	BSI	IAQ	Comfort	kWh/m²
Natural	0.78	2.85	2.96	157
Mechanical	1.47	2.96	3.12	206
Hybrid	1.00	2.65	2.99	141
P	0.2%	NS	NS	NS

Table 5.3: BSI, perceived IAQ and comfort as well as energy use in residential buildings ventilated with various systems. NS means "Not significant".

	BSI	IAQ	Comfort	kWh/m²
Openable Windows	1.7	3.7	3.8	199
Some openable	2.4	3.9	3.9	226
Not allowed to open	2.1	3.9	4	198
Not openable	2.5	3.9	3.7	288
P	2.5%	NS	NS	NS
Natural	1.4	3.6	3.8	224
Mechanical	2.3	3.9	3.9	212
Hybrid	1.8	3.7	3.7	213
P	0.1%	NS	NS	NS

However, it should be emphasised that there are, in the HOPE sample of buildings, buildings equipped with mechanical ventilation or air conditioning that are healthy and comfortable. It is those that fulfil the AIRLESS recommendations and in which the design was appropriate.

6 LIGHTING

6.1 Introduction

Light is necessary for human activities and well-being. It not only allows vision but controls the internal biological clock as well as several essential body functions. To ensure a good vision, the illuminance level should be adapted to each task (CEN 2003). Further, the colours in the environment, of objects and of the human skin, are rendered naturally, correctly and in a way that makes people look attractive and healthy. The colour temperature should be adapted to the illuminance and to the room colours, e.g. high illuminances ask for high colour temperatures and low illuminances for low colour temperatures. Finally, the luminance ratio compared to the central field should not exceed 3 in the ergorama and 10 in the panorama.

Figure 6.1: Central field, ergorama and panorama.

Since Edison, these requirements can be achieved by either daylight or artificial light.

6.2 Promote dayligting

Our eyes are used to sunlight for millions of years, and adapted to it by evolution. Therefore, it is not surprising that we prefer daylight over artificial light. Its spectrum is ideal for biological stimulation and it is delivered for free. In addition, the sun is the light source that has the smallest heat load per lux (1 W for 100 lux). Therefore, daylight should be used wherever and as far into the room as possible.

Daylight is an issue that is addressed by the architect from the earliest design phase. It is achieved by placing transparent openings at appropriate locations.

Figure 6.2 shows several possibilities for light openings:

- Vertical windows are suitable to provide light at distances up to twice the window height. Properly selected daylight systems can increase this distance.
- Roof lights can bring daylight in deep rooms which are located under the roof. Roof lights should be oriented north or they should be placed so that they are not in the ergorama.
- Daylight guiding systems, such as lumiducts, may bring some light in locations that don't have direct access to outside.

For best daylight supply, the following guidelines should be applied:

- Use clear glazing and avoid fixed solar protections such as overhangs, at least in climates where there is not too much sun the whole year long. Permanent solar protections reduce daylight even when it is most needed.
- Install daylight control systems such as Venetian blinds or shutters, since daylight is sometimes too strong.

- Use clear colours (preferably white) inside for ceiling, walls and even floor and furniture.
- Design high windows. For the same area, a narrow and high window brings more light into the room than a broad and low window. The top of the window brings more light into the back of the room than the bottom.
- Avoid glare by placing the work places perpendicular to the openings or vice versa. Openings should be out of the ergorama.
- Special devices such as lightshelfs, anidolic mirrors or holographic glazing cannot solve all problems and may even be worse that simple glazing. If planned, ensure by (full) scale experiments or simulations that they will bring the expected advantages, without causing discomfort.

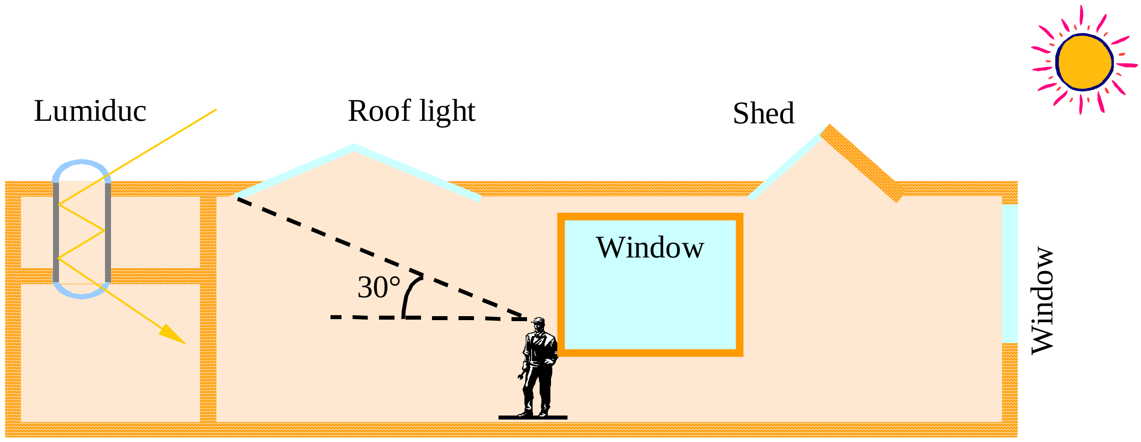


Figure 6.2: Various ways to bring daylight inside.

6.3 Artificial lighting systems

Artificial lighting should be designed as an addition to the available daylight and to replace daylight in case of insufficient supply. Various electric lamps found on the marked use several ways of producing light, and their efficiency and colour rendering strongly vary with type.

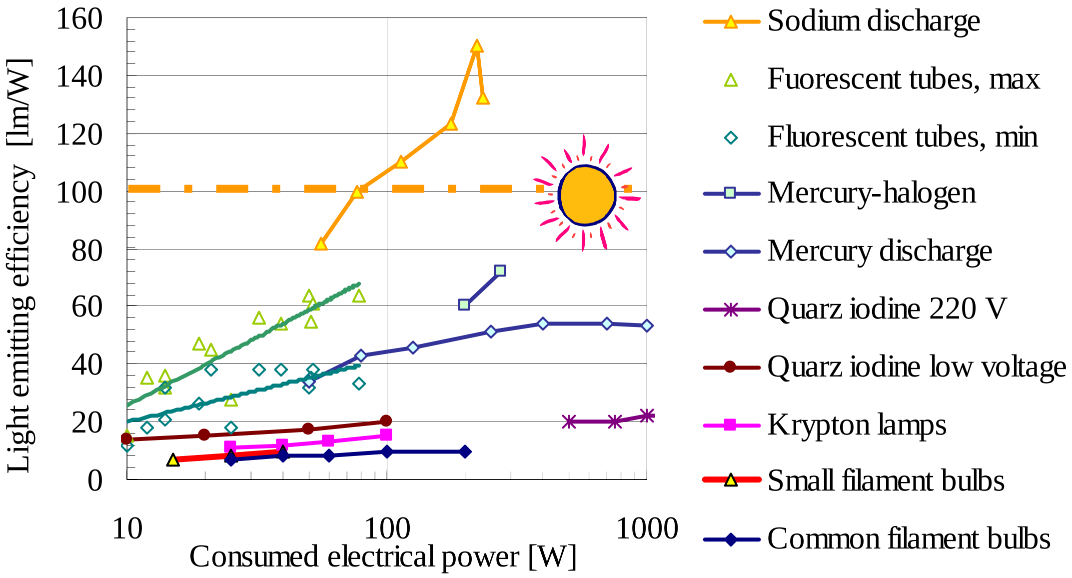


Figure 6.3: Light emitting efficiency of various light sources, compared to sunlight

It is of course recommended to install high efficiency light sources having an adapted spectrum. Sodium discharge lamps are very efficient but a poor colour rendering. They are adapted to street lighting. Best fluorescent tubes, equipped with electronic control avoiding flickering are very efficient and provide a good light spectrum.

An additional daylight responsive control system can decrease the light output of the lamps in case daylight supply is sufficient and thus save energy. Further, efficient lamps and well-designed luminaries that reflect or diffuse most of the light emitted by the light source to the place needing light should be applied.

Well designed lighting may be more comfortable at 250 lux than poorly designed lighting at 500 lux.

7 PROTECTION AGAINST NOISE

7.1 Introduction

Noise produced outside or at some place in a building is transmitted to other places in the building by the air itself and by the building structure. This is illustrated in figure 7.1.

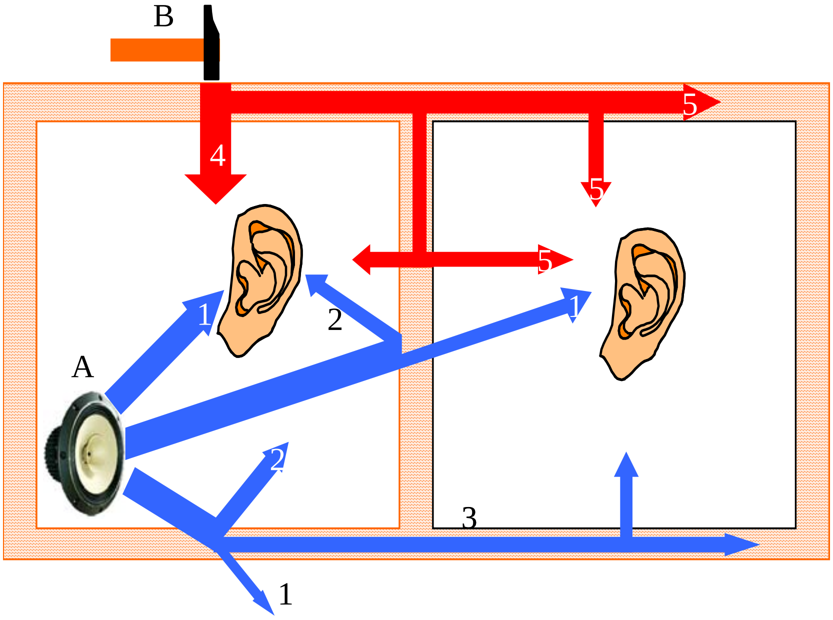


Figure 7.1: Sound transmission paths
A – airborne noise source;
B - impact noise source

1 - direct transmission (through air and structures) for airborne noise
2 – reflection (causing reverberation)
3 – flanking transmission (through structures) for airborne noise
4 – direct transmission (through structures) for impact noise
5 – flanking transmission (through structures) for impact noise

The maximum acceptable noise level (A-weighted sound (pressure) level) in the building depends on the activity:

In rooms in dwellings (living rooms, bedrooms, kitchens)	30 to 40 dB(A)[6]
Small offices and meeting rooms	30 to 40 dB(A)
Large offices to open, busy offices	40 to 60 dB(A)[7]
Hand work (e.g. in factory buildings)	80 dB(A)

Permanent damage to the hearing system occurs above 85 dB(A).

These limits can be respected first by reducing the intensity of the noise sources, and second by acoustic insulation.

The acoustic comfort in a room is determined by the noise level in the room (as mentioned before) and by the room acoustics or acoustic ambience. A measure of this ambience is the reverberation time, i.e. the time required for the sound level to be reduced by 60 dB after having switched off the noise source. The optimal reverberation time depends on the size of the room and its use[8]:

In rooms in dwellings (living rooms, bedrooms, kitchens)	0,5 second

[6] Sometimes lower levels for night time activities and sources, such as concert halls and cinemas.

[7] The levels result from the measure of concentration and communication. Levels of 50 dB(A) to 55 dB(A) are allowed in case there is a need of sound masking (sound masking may not be realised by high levels from service equipment).

[8] The mentioned reverberation times are for empty rooms. Values of 0,5 second are for furnished rooms.

Offices	0,6 to 0,8 second
Large offices to open, busy offices	0,5 to 0,7 second
Meeting rooms	0,7 to 0,9 second
Hand work (e.g. in factory buildings)	0,5 to 1,5 seconds[9]

There is an optimal absorption area and arrangement of absorbing and reflecting materials, which provides the most convenient acoustic ambience.

7.2 Nearby sources of noise

There are several sources of noise around buildings, some of them, such as road traffic or parking being linked to the activities in the building. These sources may disturb the occupants of buildings. Within the HOPE office building sample, occupants of buildings close to a potential noise source such as a busy road, an airport or a car park are significantly more disturbed by outdoor noise than those located in a more silent area.

When such sources are present, the building - in particular its acoustic protection - should be designed so that the indoor sound level remains within acceptable limits.

7.3 Internal sources of noise

Internal sources of noise are mainly the activities of occupants, but could also be the building systems. Within the HOPE office building sample, occupants of buildings with natural ventilation are significantly less disturbed by noise from building systems than those in mechanically ventilated buildings.

Figure 3.6 also shows that occupants of open office rooms are disturbed by their neighbours. Also BSI in office buildings where occupants are complaining about noise is significantly larger than in more silent buildings (2.2 versus 1.6, $P = 5 \cdot 10^{-6}$).

7.4 Acoustic protection

There are mainly three ways for improving the acoustic protection:

- Reducing the intensity of the noise sources
- Installing sound barriers between the noise source and the occupant
- Increasing the sound absorption in the occupied room.

7.4.1 Reducing the intensity of the noise sources

When it is possible, it is the most efficient way for reducing the noise. For example, good design of fan propellers increases their efficiency and reduces the produced noise. Reducing the air velocity by increasing air ducts diameters reduces noise and pressure drop. Laser printers are much less noisy than mechanical typewriting machines. Porous bituminous layer on streets reduce the noise produced by the tyres and, by efficiently removing surface water, improves the road safety.

7.4.2 Installing sound barriers between the noise source and the occupant.

Sound waves propagate in air and in materials. However, the sound velocity varies with, among other things, the density and elasticity modulus of the material. Therefore, each boundary between two materials is a partial mirror for the sound waves. In addition, sound waves are absorbed and transformed in heat by friction in porous and in soft materials.

[9] 0,5 to 0,8 second for small rooms (up to 50 m^2) and 1,0 to 1,5 seconds for large rooms (from 50 m^2 on).

Efficient sound barriers are obtained by successive layers of heavy and stiff materials and light and soft materials (Figure 7.1).

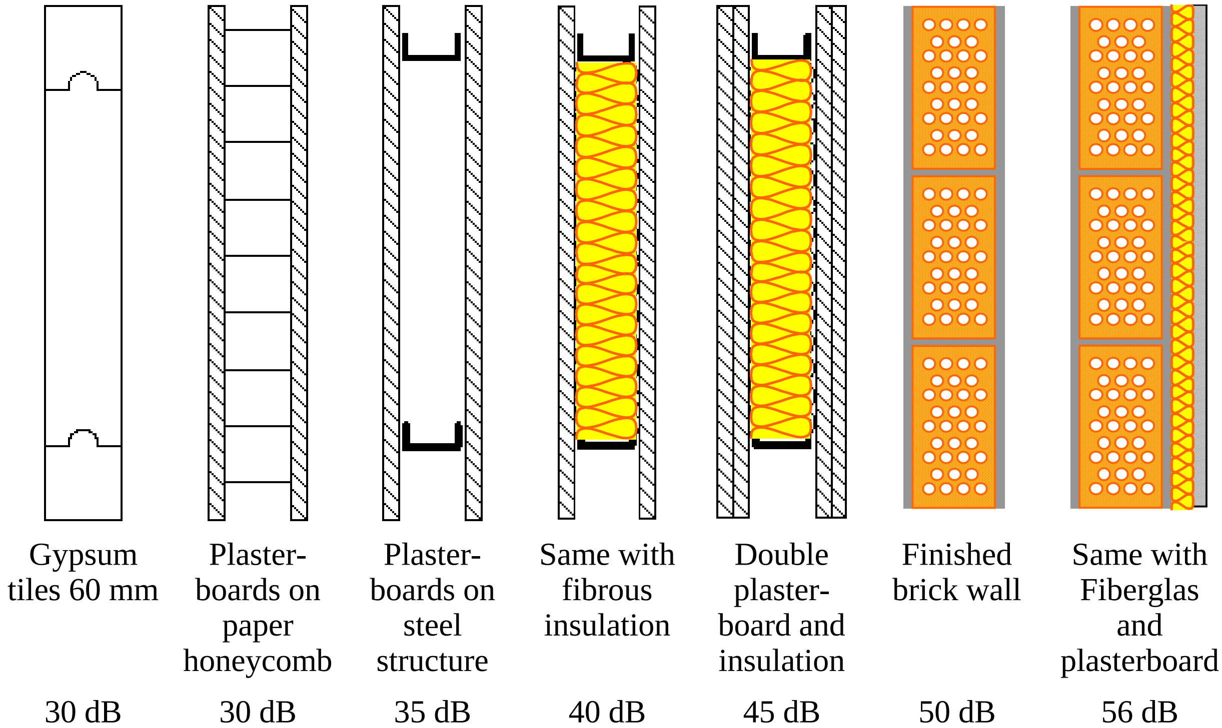


Figure 7.1 : Sound attenuation index of various walls.

There are indeed two possibilities for getting a good sound attenuation (Figure 7.2) :

- Increase the mass of walls and decks
- Make a multilayer structure alternating stiff and soft materials.

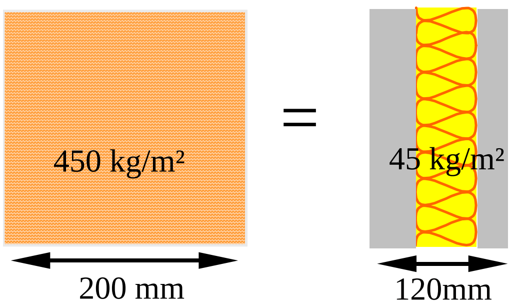


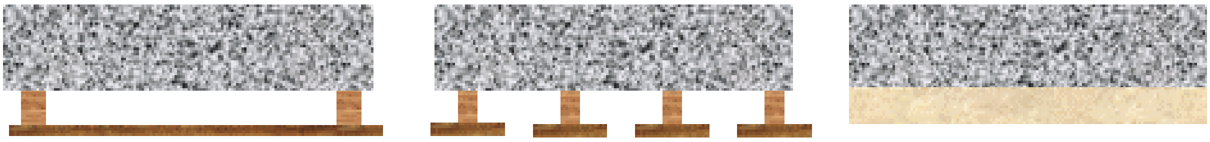
Figure 7.2 : Two very different walls may get the same sound attenuation. Left, using mass, right using sound absorption.

Important is that these barriers have no weaknesses at all, especially if a large sound insulation is required: a small sound bridge such as a rigid connection between two light, flexurally soft panels or a small hole in a wall may completely destroy the efficiency of the sound barrier.

7.4.3 Increasing the sound absorption in the occupied room.

Sound waves present in a room are reflected by the walls, floor, ceiling and the furniture. Reflected waves are added to the original ones and increase the sound level. Reducing the reflection by placing absorbing materials on walls, floor, ceiling and furniture therefore reduce the sound level in rooms.

Sound absorbing devices are (1) oscillating panels closing off cavities, which are generally good for absorbing sound at low frequencies, (2) porous materials which give better absorption of sound in the (mid and) high frequency range, and (3) resonators, i.e. open cavities whose dimensions can be adjusted to absorb any specific frequency (Figure 7.3.).



Oscillating panels *Resonators* *Porous panels*

Figure 7.3: Sound absorbing devices.

There is an optimal absorption area and arrangement of absorbing and reflecting materials, which provides the most convenient acoustic ambience. A measure of this ambience is the reverberation time, i.e. the time required for the sound level to be reduced by 60 dB after having switched off the noise source. The optimal time depends on the size of the room and its use. In homes and office rooms, it should be between 0,5 is small rooms and 1 second in large rooms.

When the reverberation time is too high in rooms where occupants have discussions, they speak louder, trying to cover the echo, which therefore increases and so forth. The room then becomes quickly very noisy.

Adding sound absorbing material is however not very efficient to reduce the sound level in rooms with strong noise sources: The absorbing area should be multiplied by ten to reduce the sound level by 10 dB. Doubling the absorbing area reduces the sound level by 3 dB only. It is often more efficient to reduce the source itself.

Other measures to improve the room acoustics are the prevention of specific, irritating sound reflections (e.g. by placing walls under an angle or adding sound absorbing panels) and the application of sound absorbing, head-high partitions, e.g. between desks in open offices.

8 ENERGY AND WELL-BEING

8.1 Introduction

Directly following the oil cost crisis in the seventies, measures were hastily taken in many buildings to reduce their energy use. These measures were planned with only two objectives: energy efficiency and return on investment. The effects of these measures on indoor environment, health or comfort were completely neglected. Therefore, in many cases, the results were dramatic. Not only comfort was decreased, but cases of mould growth, increased indoor pollution, and health hazards were observed. Since then, there seems to be a conflict with the aim of saving energy in buildings and the aim of creating a good indoor environment quality

Table 8.1: Functions of the building requiring energy, together with some ways to save energy and effects of these energy saving measures on comfort.

Energy required for	**Ways to save energy**	**Impact on indoor environment**
Compensation of transmission heat loss in winter	Better, thicker insulation, low emissivity-coated multiple glazing.	Improves comfort Improves health by preventing mould growth.
Compensation of ventilation heat loss in winter	Lower ventilation rate Limit the ventilation rate to the required level Use heat recovery on exhaust air.	May result in low IAQ Less drafts, less noise, good IAQ Generally improves IAQ in winter.
Winter heating in general	Improve solar gains with larger, well placed windows. Improve the use of gains by better insulation and good thermal inertia.	If windows are poor: cold surfaces. Over-heating if poor solar protections. If well planned: good visual contact with outdoor environment, excellent summer and winter comfort.
Elimination of heat gains during warm season	Use passive cooling Use efficient, well commissioned and maintained systems Higher internal temperature	Very comfortable in appropriate climates and buildings. Better IAQ and comfort Should be kept within comfort zone.
Internal temperature control	Comfortable set-point temperature, improved control	Avoids over- and under-heating
Humidification	Switch it off.	No effect in many cases.
Lighting	Use daylighting Use efficient artificial lighting.	Comfortable light, with limited heat gains when well controlled. Comfort depends on the quality of light. Limited heat gains.

Of course, some energy conservation opportunities (ECO's) may destroy the indoor environment. Measures such as low internal temperature or too low ventilation rate should therefore either be avoided, or taken only in case of emergency and for a limited period of time.

Some other ECO's should be used only in conjunction with others. For example, retrofitting windows in poorly insulated dwellings lead to a risk of mould growth, and improving the envelope air tightness without taking care of ensuring and controlling a minimum ventilation rate may decrease the indoor air quality.

In buildings, energy is required, among others, for purposes given in Table 8.1. This table also proposes known ways to save energy, and presents some effects of these energy saving measures on comfort or indoor environment quality. It can readily be seen that there are many cases where ECO's, when well planned and executed, improve the indoor environment quality.

8.2 HOPE observations on groups of buildings

Audited buildings are sorted into separate groups for their performance. In the first section of this chapter, the buildings having less or more than the median value of the energy performance index are compared. In the second section, a multicriteria selection allowed sorting buildings that perform well not only for energy, but also for perceived health and comfort, and to compare their characteristics with those building that perform poorly for these three criteria.

8.2.1 Health and comfort in low energy buildings

75% of the buildings audited within the HOPE project were chosen for being designed to have a good energy performance. An indicator of the energy performance of is calculated as follows. **T**he amounts of all energywares (litres of oil, m³ of gas, kWh of electricity) delivered to the building, converted to kWh using the lower heating value are summed up to get the total delivered energy use. A rough approximation of primary energy use, in which a weight 2.5 was allocated to electricity, a unity weight being kept for the other energywares was also calculated. This total delivered energy use, in kWh, is divided by the conditioned floor area to take account of the building size[10]. Since energy for heating and cooling was not metered separately from the other energy uses in most buildings, no correction is made for climate.

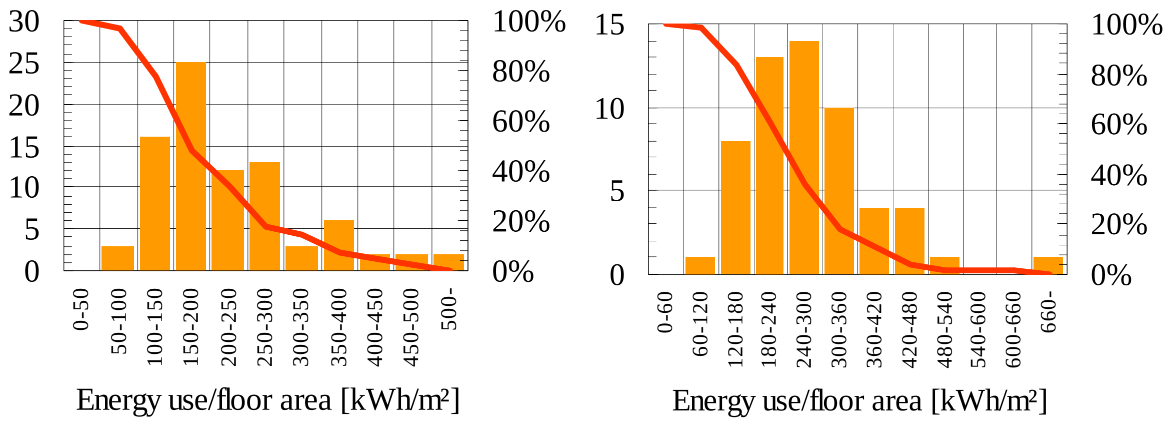


Figure 8.1: Distribution of the energy performance indicators in homes (left) and office buildings (right)

Figure 8.1 shows the frequency and cumulated distributions of the energy performance indicators in the audited homes and office buildings. It should be noticed that these distributions are not representative of the European building stock, since the sample is biased by the selection of low energy buildings for 75% of them. The median value for apartment buildings is 140 kWh/m² and 200 kWh/m² for office buildings.

[10] Other indicators such as final energy use per heated floor area, per person, per building volume, etc. could be used. The conclusions will not change much by using other indicators.

Significant differences are found between buildings that use less and more than these median values. Some of these differences are reported in Table 8.2.

Table 8.2: Some statistically significant differences between "low" and "high" energy buildings in the HOPE sample. P is the probability to get the difference by pure chance.

Characteristics	Mean values for "low" energy	Mean values for "high" energy	P
Mean number of SBS symptoms per person in apartment buildings	0.98	0.86	16%
Mean number of SBS symptoms per person in office buildings	1.95	2.11	2%
Comfort overall in offices in Summer (scale from 1=satisfactory to 7=unsatisfactory)	3.21	3.47	2%
Comfort overall in offices in winter (scale from 1=satisfactory to 7=unsatisfactory)	3.08	3.26	6%
How comfortable is your home? (scale from 1=satisfactory to 7=unsatisfactory)	2.97	3.22	0.2%

On the average, low energy buildings are perceived as more comfortable than other buildings. Also low energy office buildings are healthier than high energy ones. The same difference is not observed on apartment buildings, where there are slightly more symptoms in low energy buildings. This difference is however not significant.

There are of course healthy and comfortable buildings that use much energy, and also low energy buildings that are neither healthy nor comfortable. Therefore, the correlation between energy performance index and BSI is not very high (Figure 8.2). It should however be noticed that this correlation is positive: the higher the energy use, the higher the BSI.

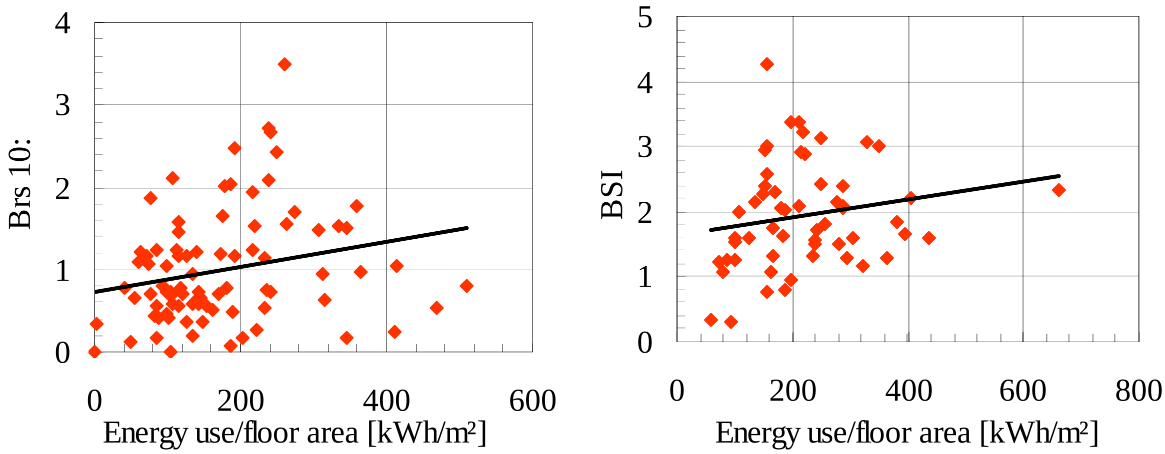


Figure 8.2: Correlation between BSI and the energy performance indicators in homes (left) and office buildings (right)

8.2.2 Multicriteria analysis: "good" and "poor" buildings

From the collected data, the following information was selected for a multiciriteria analysis: Energy performance index, i.e. delivered energy use per unit floor area., BSI and perceived comfort.

For perceived comfort, questions were asked to occupants in the questionnaire. The basic question was: *How would you describe typical working conditions in the office?* Then for each item, the occupant should cross one box, from 1 to 7. The same questions were asked at the same time for winter and summer seasons. The items and qualifications corresponding to extreme marks are given in Table 8.3. The results for a building are the average marks of all respondents for each question.

Table 8.3: Questions related to comfort

	Item	Grade 1	Grade 7
Thermal comfort	Temperature Temperature* Temperature Air movement*	Comfortable Too hot Stable Too still	Uncomfortable Too cold Varies during the day Too draughty
Air quality	Air quality* Air quality Air quality Air quality	Dry Fresh Odourless Satisfactory	Humid Stuffy Smelly Unsatisfactory
Light	Natural light Glare from sun and sky Glare from sun and sky Light overall	Satisfactory	Unsatisfactory
Noise	Noise from outside Noise from building systems Other noise from within the building Noise overall Vibration in the building	Satisfactory	Unsatisfactory
Comfort	Comfort overall	Satisfactory	Unsatisfactory

* Items marked with an asterisk are two-sided: the best mark for them is 4, both 1 and 7 being not satisfactory.

Sorting buildings

for each criterion (energy, BSI or comfort characteristics) buildings are sorted basically into two classes, those which are "poor", "not satisfactory" or "red" on one hand; and those which are "good", "satisfactory", or "green" on the other hand. A "veto" class is added to take account of very poor level for a given criterion. If the position of the building is not clear, it is sorted in an intermediate, uncertain or yellow class.

For comfort, average marks below 2.5 on the unilateral 1-7 scale are considered as satisfactory, while average marks larger or equal as 4 are taken as unsatisfactory, more than 6 being considered as a "veto" mark. Bilateral scale was first transformed into a -3 0 +3 scale by subtracting 4 from the average mark. Marks between -0.75 and +0.75 are green, outside ± 1.5 are red, and outside ±2.5 are veto.

Well-being is assessed by the Building Symptom Index (BSI). Since there are no well established limits for SBS symptoms prevalence, relative limits are used. A BSI lower than that of the best 35% of the audited buildings is considered as acceptable or green. A BSI larger than or equal to that of 70 % of the buildings is not acceptable and the veto level is placed at two standard deviations above the average BSI of all buildings. Therefore, thresholds for office buildings are not the same as those of apartment buildings.

The building energy performance is judged satisfactory below 150 kWh/m², not satisfactory above 250 kWh/m² and unacceptable above 500 kWh/m². These limits don't take account of the climate, since there is a very poor correlation between energy use of building and climate.

Aggregation

Using a multicriteria sorting method based on democracy rules called Hermione, (Flourentzou and Roulet 2002; Roulet, Flourentzou et al. 2003), the evaluations for each criterion are aggregated to sort buildings in the two classes. The following rules were used:

- The building is "satisfactory" or "green" if there is a majority (more than 50%) of criteria with "green" marks and no veto among the criteria.
- It is unsatisfactory if there are more than 50 % criteria with "red" marks or less than 50% "green" marks and more than 33 "red" marks, or at least one veto.
- If the percentage of criteria with "veto" marks is larger than 33%, the building is marked "black".
- It is "yellow", or not sorted, otherwise.

In order to give the same weight to comfort, energy and health, questions related to each type of comfort are first aggregated to get comfort classes for temperature, light, noise and air quality. Then these four evaluations are aggregated into one for comfort. This procedure is used once more to aggregate the evaluations according the basic three criteria mentioned above: comfort, well-being and energy. Note that this sorting does not assess the risk of health hazards mentioned by (Maroni, P.Carrer et al. 2005).

Results

Among the 97 apartment buildings and 64 office buildings for which enough information was available, 24 apartment buildings and 8 office buildings are found acceptable for all criteria (named "green" buildings below) while 34 apartment buildings and 15 office buildings are found not acceptable (the "red" buildings).

Some significant differences between these two groups, i.e. those for which the probability to get the difference by pure chance less than 5%, are summarised below. Differences in energy use, perceived comfort and symptoms of the sick building syndrome are of course very significant, since the groups are selected for these characteristics. For example, green office building use on average, per square meter floor area, half the delivered energy and less than half the primary energy than red ones. For apartment buildings, the ratio is 1:3.

Homes

There are no significant differences between green and red apartment buildings regarding population in each age class, presence of air pollution and noise sources, type and distance to sources of electromagnetic radiation such as power lines or cellular telephone antenna, number of storeys, density of nearby obstructions, height of surrounding buildings and heating fuel. Cleaning schedules, painting, decorating or other renovation during the last 12 months are similar. The use of appliances such as microwave ovens, refrigerators, freezers, humidifiers and dehumidifiers do not differ significantly either. For all these criteria, the probability is 20% or more to get the apparent difference by pure chance.

Some more significant differences are shown in Table 8.4 and others are listed below.

- Kitchens are more often equipped with cooker hood. Therefore, mechanical ventilation is often used in "green" kitchen, while windows are more often open in "red" kitchens.
- Windows of the majority of the green buildings are never closed in winter for noise, pollution, or security. In a minority of red buildings, windows are more often closed for these reasons.
- Nearly all green buildings have hot water circulation in insulated pipes, while half of the red buildings have no circulation.

- U-values of roofs and windows are slightly, but not significantly better in green buildings, Walls U-values are significantly better. The occupants complain more often in red buildings that thermal insulation and draughts are sources of heating problems.
- More green buildings are equipped with heat recovery on exhaust air than red ones.
- Condensation is significantly higher in red buildings. Mould growth on more than 5% of walls is not frequent, but more frequent (7%) in red buildings than in green ones (5%)
- Orientations of the windows are equivalent in both groups for all facades except for south, more frequent in green buildings.
- Pests are less common in green buildings, and pesticides are more commonly used in red buildings.

Table 8.4: Some significant (P< 5%) differences of average values between "green" and "red" apartment buildings.

	Green	Reds	
Number of buildings	24	34	P
Year completed	1989	1978	3.E-03
Delivered energy use/floor area [kWh/m²]	114	285	3.E-17
"Primary" energy use/floor area [kWh/m²]	147	332	3.E-15
Degree days during the heating season	2548	3278	2.E-06
Building-related symptom index	0.52	1.56	2.E-13
How comfortable is your home (1-7 scale)	2.26	3.32	3.E-11
Percent females	44%	38%	3.E-04
Percent recent smokers	23%	27%	5.E-02
Average apartment area [m²]	85.3	59.4	1.E-05
Smallest apartment [m²]	61.6	39.1	2.E-06
Floor area per person	38.4	29.0	4.E-03
Condensation in the flat: scale 1 to 7	1.89	2.56	6.E-05
Heaters below windows	39%	67%	6.E-02
Mechanical ventilation in the kitchen: cooker hood	49%	28%	1.E-04
Request for improvements to heating, ventilation	11%	17%	3.E-03
View from the windows	2.59	3.65	1.E-08
Heating on the flat satisfactory	2.25	3.00	6.E-08
Environment inside the flat affects the health	2.37	3.52	7.E-20
Environment inside the flat affects the ability to carry out work or necessary tasks	2.41	3.52	3.E-16

Offices

There are no significant differences between green and red office buildings regarding population in each age class and sex, percentage of women and ancient smokers, ownership, presence of air pollution and noise sources, height of surrounding buildings, and smoking allowance. Orientation of glazing is also similar.

Some more significant differences are shown in Table 8.6, others are listed below.

- The occupants of green buildings perceive that they have a better control of their environment, in particular for ventilation, than in red buildings. The decoration, layout and cleanliness, as well as the speed of response to complaints are all significantly better in green buildings.

- Occupants of red buildings spend more time working with a computer.
- In all green office buildings, all or a part (in one building) of the windows can be opened. in most of the 15 red buildings, windows cannot be opened (Table 8.5).

Table 8.5: Operable windows in office buildings.

	Green	Red
Windows are openable	88%	20%
Some are openable	13%	0%
Not allowed to open windows	0%	60%
Sealed windows	0%	20%

- Perceived productivity is better in green buildings, and absenteeism because of the indoor environment is smaller (95% of workers without absence against 87% in red buildings).

Table 8.6: Some significant (P< 5%) differences between "green" and "red" office buildings.

Characteristics	Green	Red	
Number of buildings	8	15	P
Year completed	1999	1976	2.E-04
Delivered energy use/floor area [kWh/m²]	133	221	5.E-04
"Primary" energy use/floor area [kWh/m²]	228	455	3.E-04
Degree days during the heating season	2593	3304	1.E-03
Building-related symptom index	1.07	2.71	7.E-10
Comfort overall in summer	2.86	4.11	1.E-06
Comfort overall in winter	2.71	3.69	6.E-08
Percent recent smokers	44%	61%	3.E-02
Typical floor area per person (including circulation)	63	38	3.E-02
Number of storeys above ground	3.3	6.8	6.E-06
Ceiling height [m]*	3.8	2.9	7.E-02
Roof U-value	0.2	0.7	5.E-03
Glazing U value	1.5	2.7	7.E-05
Walls U value (not significant)	0.6	0.8	*2.E-01*
Density of nearby obstructions	3.3	2.5	3.E-03
Light overall in winter	2.6	3.1	1.E-03
Noise from building systems in winter	2.2	2.8	3.E-04
Noise from outside the building	2.3	2.8	1.E-03
Vibration in the building in winter	1.6	2.3	6.E-06

* Difference in ceiling height is not very significant

Offices and homes

All types of ventilation system are present in both groups of buildings (Table 8.7). The global performance of the building depends probably more on the quality of the ventilation system than on the system itself. This is confirmed by the next observation below.

Table 8.7: Proportion of buildings in both groups with different ventilation systems.

	Homes		Offices	
Ventilation system	Green	Red	Green	Red
Operable windows	42%	55%	38%	20%
Other natural ventilation (e.g. passive stack)	0%	3%	13%	0%
Mechanical ventilation	17%	27%	38%	60%
Hybrid / mixed mode	38%	15%	13%	20%

The "Airless" recommendations for air handling units (see 5.3) are completely or partly followed in green buildings, while they are only partly or not respected in red buildings (Table 8.8).

Table 8.8: Proportion of buildings in both groups that comply with AIRLESS recommendations.

		Green buildings			Red buildings		
		Yes	Partly	No	Yes	Partly	No
Ventilation	Offices	40%	60%	0%	20%	0%	60%
	Apartments	56%	33%	11%	8%	77%	15%
Heating/cooling	Offices	25%	75%	0%	10%	40%	40%
	Apartments	67%	33%	0%	15%	62%	23%

8.2.3 Health risks

Perceived health does not give a full insight in the "healthiness" of a building. Some building characteristics (presence of asbestos or radon, VOC, etc) could be dangerous for health but may not (or not immediately) lead to SBS.

Within the HOPE project a method for such a health hazard assessment has been developed. This health hazard assessment tries to give a hint if a given hazard is present or possibly present (Maroni, P.Carrer et al. 2005).

The health and comfort hazards (from performance criteria) have been classified in three classes, based on the level of health outcome:

- **Class 1** - Hazards that represent risk of causing death or an illness with a high probability of being fatal (e.g. lung cancer): asbestos, radon, carcinogenic volatile organic compounds (VOCs), Environmental Tobacco Smoke (ETS) and a high carbon monoxide concentration.
- **Class 2** - Hazards that represent risk of causing illness (principally respiratory illness): ozone, nitrogen oxide, particulate matter, infectious agents (from the building or from occupants), house dust mites (only for residential buildings), fungi, other allergens, non-carcinogenic VOCs, CO at low concentrations.
- **Class 3** - Hazards that represent risk of minor diseases or causing discomfort: noise, lighting, too hot, to cold.

Using this approach, in the HOPE project it was shown that buildings with a low BSI not always show low presence of hazards. This was particularly the case for the apartment buildings. Perceived occupant health and comfort is obviously based on more than the physical environmental parameters.

Table 8.9: Percent of office buildings in both groups that are in the hazard categories assessed within the HOPE project.

Class	Hazard	Green Not present	Green Probably present	Green Present	Red Not present	Red Probably present	Red Present
1	Asbestos	100%	0%	0%	67%	27%	7%
	CO very high	100%	0%	0%	93%	7%	0%
	ETS	25%	13%	63%	13%	47%	40%
	Radon	88%	13%	0%	47%	53%	0%
	VOCs(Carcinogenic)	50%	50%	0%	40%	53%	7%
2	CO low	88%	0%	13%	33%	40%	27%
	Infection from building	0%	100%	0%	13%	80%	7%
	Infection from occupants	0%	100%	0%	0%	100%	0%
	NOx	88%	0%	13%	33%	40%	27%
	Ozone	88%	13%	0%	53%	47%	0%
	Vocs non carcinogenic	0%	88%	13%	7%	80%	13%
	Fungi	13%	88%	0%	47%	53%	0%
	Particulate matter	0%	88%	13%	7%	80%	13%
3	Lighting	0%	63%	38%	7%	40%	53%
	Noise	13%	25%	63%	0%	0%	100%

Table 8.10: Percent of apartment buildings in both groups that are in the hazard categories assessed within the HOPE project.

Class	Hazard	Green Not present	Green Probably present	Green Present	Red Not present	Red Probably present	Red Present
1	Asbestos	92%	4%	0%	82%	18%	0%
	CO very high	79%	17%	0%	82%	12%	6%
	ETS	0%	0%	96%	3%	9%	88%
	Radon	75%	21%	0%	62%	38%	0%
	VOCs(Carcinogenic)	17%	79%	0%	35%	59%	6%
2	CO low	13%	75%	8%	15%	76%	9%
	Infection from building	25%	71%	0%	18%	82%	0%
	Infection from occupants	0%	96%	0%	6%	94%	0%
	NOx	13%	75%	8%	15%	76%	9%
	Ozone	79%	17%	0%	97%	3%	0%
	Vocs non carcinogenic	0%	13%	83%	0%	21%	79%
	Fungi	0%	38%	58%	0%	50%	50%
	Particulate matter	0%	67%	29%	3%	56%	41%
3	Lighting	0%	79%	17%	3%	88%	9%
	Noise	4%	58%	33%	3%	71%	26%

However, as it is shown in Table 8.9 for offices and Table 8.10 for homes, the percentage of buildings having hazard present or possibly present is smaller among green buildings than among red ones. An exception is tobacco smoke, unfortunately found everywhere.

9 CONCLUSIONS

The following conclusions related to energy and well-being can be drawn from experience and surveys:

- Energy consumption varies strongly from building to building. In practice, it depends more on planning, construction, and management than on climate (Figure 9.1), building type or HVAC systems.

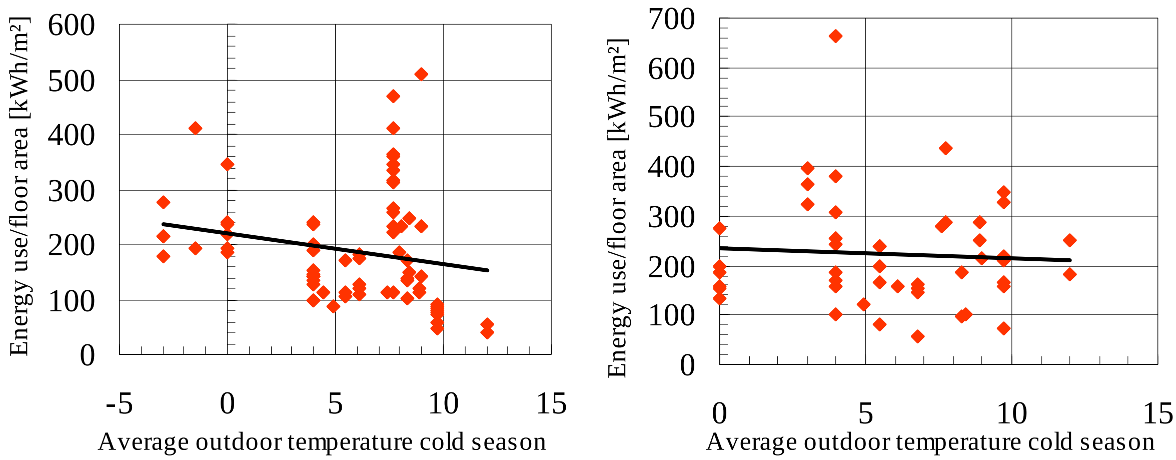


Figure 9.1: Energy performance indicator versus average external temperature for apartment buildings (left) and office buildings (right).

- It is hence possible to produce low-energy buildings with good indoor environment quality and pleasant architecture.
- Good design is essential to achieve these objectives. If planning, construction, and management are performed by energy conscious persons, the result will be a low energy consumption with a good indoor environment quality.
- However, a single bad step (e.g. poor management or poor planning) may destroy the qualities of a building or the effects of a conscious management.

Healthy and comfortable buildings do not necessarily require much energy, and can have a limited impact on the environment. Smart managers, architects and engineers construct and operate buildings in a way that both good indoor environment and low energy consumption can be achieved. By contrast, expensive measures to improve the indoor environment are sometimes counterproductive: even when technical requirements (temperature, airflow rates, etc.) are met, occupants may not feel well because they lack control on the system or don't trust it.

The EU Directive 89/106 (1989) considers good "*hygiene, health and environment*" as well as "*energy economy and heat retention*" as essential requirements. The more recent directive on energy performance in buildings (Council 2002) requires that "*The measures further to improve the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. They should not contravene other essential requirements concerning buildings such as accessibility, prudence and the intended use of the building.*" Energy savings should not be achieved to the expense of poor indoor environment, since this is not only at the opposite of the purpose of buildings, but would also result in a bad perception, and may generate unexpected waste.

The existence of buildings that are healthy, comfortable and have a good energy performance, as well as the better comfort and health shown on the average by low energy buildings shows that the apparent conflict between comfort and energy use does not, in fact, exist.

10 SOME PROBLEMS OBSERVED IN AUDITED BUILDINGS (DO'S AND DON'TS).

In the table below, problems observed in audited buildings are listed, together with their possible consequences and ways to correct them.

		Observation, problem	Resulting problems			Ways commonly used to solve the problem or avoid mistake (by order of preference)
Type[11]			Health risks	Comfort	Energy	
L	Off	Open plan office		Noise, (individual) temperature control problematic		Cellular offices
L	Off	Attached garage	Infiltration of toxic gases (Benzene, CO, NOx, etc.	Bad smells		1. Garage in a separate building 2. Airtight wall or deck (no door) between garage and living space 3. Airtight door and positive pressure difference between living space and garage 4. Ventilated lock between garage and living spaces.
E		No external solar protection		Too hot on sunny days, possible glare. Too warm: transpiration reduced performance, productivity, increase of human errors Reduced air quality (smells, humidity)	Increases the cooling load or encourages use of mechanical cooling 1. Reducing inside air temperature by improved insulation / solar protection and natural ventilation fixes comfort and energy problems. 2. Reducing inside air temperature by means of mechanical ventilation or cooling) will increase energy consumption.	1. Install external solar protection and use night cooling. 2. Mechanical cooling may improve comfort but increases energy use.
E	Res	Architect forbids the use of external solar protection, e.g. sun screens.				Good coordination during design phase of building is needed.
E	Res	External solar protection not allowed, because of too high wind pressure in high rise building, in coastal regions.				1. Use wind proof external solar protection 2. Install solar protection between glazing panels. 3. Use sun reflective glazing. This decreases daylighting, hence increases artificial lighting

.[11] Type: L: Layout problems; E: Problems linked with the building Envelope; H: Humidity problems; U: Problems with building Use; V: Ventilation problems.
"Off": observed in offices, "Res": observed in residential buildings.

		Observation, problem	Resulting problems			Ways commonly used to solve the problem or avoid mistake (by order of preference)
Type[11]			Health risks	Comfort	Energy	
E	Off	Overheating in summer of south side and upper floors of massive structure building.		Too warm: reduced performance, productivity, increase of human errors Reduced air quality (smells, humidity) Occupants: Feeling too warm, transpiration	1. Reducing inside air temperature by means of mechanical ventilation or cooling (fixed or portable air conditioning units) will increase energy consumption. 2. Trying to reduce inside air temperature by improved insulation / stores and natural ventilation will not have significant influence on energy consumption	Prevent overheating of this type of building by: 1. Installing (better) solar protection 2. Improve insulation in the roof. Consider cooling of the roof 3. Improve natural ventilation, especially at night- 4. Increase volumes of mechanically ventilated air at night 5. Change layout of office, so that as few occupants as possible have to work on the overheated places. 6. Artificial cooling with radiant panels 7. Motivate / ask occupants to start work early in the morning when building is still cool. 8. Air conditioning
E		Thermal bridges neglected; especially in well insulated buildings	Condensation or mould growth, may affect allergic occupants.	Mould smell, draughts.	The saving energy potential from thermal insulation may be strongly reduced by thermal bridges.	Insulation inside the structure leaves many thermal bridges. These become important from 5 cm insulation thickness and may be the main heat loss from 15 cm insulation thickness up. Thermal bridges shall be taken into account in the design phase, preferably by placing a continuous insulation layer outside the building structure.
E	Res	Insufficient thermal insulation of the building envelope	Condensation or mould growth, may affect allergic occupants.	Many parts of the building are too cold (and humid) in winter. Occupants complain about draughts, cold windows and walls,	High loss of energy during heating season Necessity to over-ventilate to avoid mould growth problems in cold season.	1. Increase insulation level 2. Complete renovation of building, especially insulation of walls and roof , replacement by double glazing, design of a ventilation system. 3. Installation of modern and efficient heating system
E	Res	Insufficient insulation in the roof	No serious health risks, apart from non satisfied occupants	Overheating of upper floors in summer and sometimes too cold in winter	Relatively high energy consumption for heating in winter because of insufficient thermal insulation	1. Priority: insulation of the roof and/or the floor of the attics 2. Improve insulation, including windows, of the other parts of the building.

		Observation, problem	Resulting problems			Ways commonly used to solve the problem or avoid mistake (by order of preference)
Type[11]			Health risks	Comfort	Energy	
E	Res	Poor design of a sun wall for preheating the supply air. The air inlet duct was in the living room and provided air into the occupied zone.	Indirect problem: Too low base-ventilation may lead to health risks: If it is not working correctly occupants often close the air inlet valve.	Direct problem: Draft problems and supply of too cold air in the occupied zone	Was not designed to function under all weather conditions. Sometime it supplies air and sometimes air goes through it in the wrong direction (i.e. out). Little or no energy saving potential.	A sunwall should be designed so that it can operate independently of the weather (wind) conditions. Furthermore, the inlet from the sunwall should be placed so that it does not give draft problems.
E	Res	Preheating of supply air in glazed gallery		Too high supply air temperatures, resulting in high temperatures indoor	May increase cooling energy use when installed.	Design such system so that supply air can be controlled according to the needs.
H		Noisy humidity-controlled ventilation, leading to misuse.	The relative humidity was too high especially in the bathroom	Too noisy		The noise from the humidity-controlled ventilation in the bathroom shall be sufficiently low so that people do not switch it off due to noise. Therefore, use silent fans or external fans (e.g. on the roof) instead of noisy fans mounted in the bathroom.
H	Res	Presence of mould growth and condensation problems in bathrooms	Probably few health risks from this type of mould, but may harm allergic people.	• Smell of moulds • Gives an unhygienic impression (visually)	Effect on energy use depends on the cause: • Lack of ventilation decreases energy use • Lack of thermal insulation increases energy use. And on ways to fix the problem: • Additional thermal insulation decreases energy use • Increased ventilation or temperature or air dryer will increases energy use.	1. Reduce thermal bridges (additional insulation) 2. Increase natural (windows open, keep door open) and/or mechanical (extraction fan in window/wall) ventilation in bathroom 3. Keep bathroom warmer than other parts of the apartment 4. Install a dehumidifier 5. Remove mould with chemical products and treat surfaces with e.g. paint or coating that is less sensitive to mould growth

Type[11]		Observation, problem	Resulting problems: Health risks	Resulting problems: Comfort	Resulting problems: Energy	Ways commonly used to solve the problem or avoid mistake (by order of preference)
H	Res	Condensation problems in kitchens	Lead to mould growth that may harm allergic people	• Smell of mould • Inconvenient to live in a humid environment (humid walls, ceiling, windows)	Effect on energy use depends on the cause: • Lack of ventilation decreases energy use • Lack of thermal insulation increases energy use. And on ways to fix the problem: • Additional thermal insulation decreases energy use • Increased ventilation or temperature or air dryer will increases energy use.	1. Reduce thermal bridges (additional insulation) 2. Install hoods that evacuate the air (no recirculation!) 3. If already installed, increase ventilated volumes by the hood 4. Open windows (if present) when cooking 5. Use a dehumidifier
H	Res	Condensation problems in apartments	Lead to mould growth and proliferation of dust mites that may harm allergic people	• Smell of humidity • Inconvenient to live in a humid environment (humid walls, ceiling, floor, windows, furniture)	Effect on energy use depends on the cause: • Lack of ventilation decreases energy use • Lack of thermal insulation increases energy use. And on ways to fix the problem: • Additional thermal insulation decreases energy use Increased ventilation or temperature or air dryer will increases energy use.	1. Reduce thermal bridges (additional insulation) 2. Increase ventilation 3. Keep indoor temperature above 20°C. 4. Open windows when producing water vapour 5. Use a dehumidifier (uses energy)
S	Res	Hot water (sanitary and heating purposes) from central heating plant is delivered by insulated pipes (underground) to semi-individual houses over relatively long distance (tot. 2 km of ducts).	Risk of developing Legionella if hot water delivered at too low temperatures (< 55 °C)	Circulation of hot water in the whole circuit is required to ensure fast delivery.	High energy losses because of length of ducts	1. Use the central heating plant only for heating purposes (in the cold season) 2. Do not use the central heating plant for “sanitary hot water” production; especially in summer when heat flow through pipes is small 3. Produce sanitary hot water locally e.g by means of solar energy and local boiler.

Type[11]		Observation, problem	Resulting problems: Health risks	Resulting problems: Comfort	Resulting problems: Energy	Ways commonly used to solve the problem or avoid mistake (by order of preference)
S	Res	Solar collector is not working properly.		Either lack of hot water , or …	…energy savings are less than predicted.	Make sure that you have a good, professional firm for design, building, commissioning and maintenance of the technical installations.
S	Res	Solar collector is mounted vertically, integrated in facade.		Possible lack of hot water even in summer.	Solar gains for this orientation is slightly larger than the other in winter, but much smaller than a tilted orientation during all other seasons..	Mounting of hot water solar collectors preferably tilted towards SE to SW., at an angle = latitude ± 25°
U		Technical solutions/systems that require special knowledge from occupants	Systems may not be used as intended and therefore problems may occur.	Systems may not be used as intended and therefore problems may occur.	Systems may not be used as intended and therefore problems may occur.	Technical solutions/systems that require special knowledge from occupants only work when people are committed. This means that caution should be taken for flats that are rented out/sold. Such flats need to have systems that do not strongly depend on occupant behaviour.
U		Smoking allowed in office	Smoking and passive smoking concerning all occupants	Poor air quality; Smells / odour. Symptoms (dry throat, headaches, etc.	Increased ventilation loss to reduce ETS	Separate smoking room with its own exhaust system and a tight construction that prevent polluted air to enter office.
U	Off	Smoking is allowed in a building designed for non-smoking				1. Prohibit smoking in buildings that are designed as non smoking building. 2. Design all buildings for possible smoking.
U	Off	Smoking in (mechanically ventilated) office is only allowed in separately ventilated rooms, but 52% of occupants say being surrounded by smokers	Smoking and passive smoking concerning many occupants, possibly resulting in illnesses and reduced productivity	Poor air quality; Smells / odour. Symptoms (dry throat, headaches, etc.	No significant influence on energy consumption (Separately ventilated rooms may be higher in energy consumption compared to an overall ventilation system. However, an overall ventilation system will require larger volume of ventilated air because of smokers, thus increasing energy consumption)	1. Enforce and control that smoking is only allowed in the separately ventilated rooms 2. Keep doors and windows closed between smoking and non-smoking rooms 3. Create overpressure in non-smoking rooms 4. Do not recirculate air from smoking rooms 5. Check if exhaust air from smoking rooms is not mixed with air taken by other ventilation systems, e.g. via RHE

Type[11]		Observation, problem	Resulting problems			Ways commonly used to solve the problem or avoid mistake (by order of preference)
			Health risks	Comfort	Energy	
U	Off	High amount of electrical office equipment and solar gains in building	Risk of overheating and inhaling of ozone and possibly other pollutants	Too warm: reduced performance, productivity, increase of human errors Possible odours.	• In case of presence of cooling units: high energy deman d for cooling purposes. • High energy demand by electrical equipment • Reduced energy demand for heating	1. Use low electricity consumption office equipment and only switch on when needed 2. Improve solar protection (thermal mass/thermal inertia) 3. Improve cooling / (natural) ventilation capacity
U	Off	Offices are difficult to clean (Also floor cover often is carpet)	Various health risks, but mainly related to accumulating dust (and related bacteria, fungi and mites)	Smells, possible cause of SBS.	Increased ventilation rate to improve IAQ Possible clogging up of ventilation systems, increasing energy to move the air	1. Change layout of the office, so it is easier to clean 2. Avoid dust accumulating materials (such as carpets and curtains) 3. Use appropriate cleaning gear and products
U	Off	High levels of noise in the office from inside (machines in basement) and outside (city centre, railway station)	ABove 85 dB(A): permanent damages to audition.	Annoying for occupants; reduced performance and productivity	No significant influence on energy consumption (inside office: replacement of old or used noise producing equipment by modern less noise producing - low energy equipment, will decrease energy consumption)	1. Reduce noise level from outside by insulation of windows (double, triple glazing) 2. Reduce noise level from outside by keeping windows closed, however provide good alternative for ventilation (mechanical or natural) 3. Reduce noise level from inside by insulating noise producing equipment, and changing, repairing or adjusting of noisy equipment in order to decrease produced noise. 4. Reduce noise level from inside by insulating floors, doors and walls
U	Res	Problems with the apartments and IEQ - especially concerning heating and ventilation- are not tackled or solved sufficiently by the owner/management		• Various, but mainly: • Too hot in summer, too cold in winter • Unwanted differences in temperature in the building • Ventilation flow rates oto high or low during certain periods of the day	Probably actual energy consumption is higher than necessary.	• More "problem solving" action and efficiency required from the management company.

		Observation, problem	Resulting problems			Ways commonly used to solve the problem or avoid mistake (by order of preference)
Type[11]			Health risks	Comfort	Energy	
V		Too low base-ventilation in apartment	Too high relative humidity	Poor air quality		Install natural, controllable ventilation openings Install a mechanical system that provides base-ventilation.
V		Ventilation system is designed so that the ventilation rate is lowered (probably to save energy) and even stopped when the temperature in the room is lower than the set-point.	Higher concentration of pollutants	Poor air quality		It is recommended to design ventilation and heating systems so that the temperature can be regulated without reducing the supply rate of fresh air.
V		Air grilles give draught in the occupied zone. Typically, this will make occupants to block the grilles. This reduces the air supply.	Higher concentration of pollutants	Draughts, or poor air quality		Design units and locate grilles so that draught is prevented.
V		Ventilation dependent on temperature control (VAV)	Sometimes too small ventilation rates or…		…sometimes energy spill	Temperature control independent from ventilation (e.g. separate systems for heating, cooling and ventilation)
V	Off	100% mechanical ventilation and sealed windows		Occupants have feeling of lack of control on their environment	No natural ventilation. All mechanical ventilation (incl heating /cooling) takes energy	Increase occupants' control over living environment: Give possibility to influence temperature, lighting, ventilation. (e.g. demand-control switches, some operable windows)
V	Off	Ventilation intake on ground level next to busy road and building construction activities	Dust, particles, contaminants, exhaust fumes enter ventilation system and are circulated through building	Smells/odour, inhaling of particles and contaminants.	No influence on energy consumption (unless tighter filters (higher class) that require higher pressure for suction)	1. Change location of ventilation intake, away from polluting sources 2. Install higher class filters (minimal F7)in ventilation intake 3. Remove polluting sources (in this case building construction is finished, and traffic is limited in street, and installation of more filters is planned.
V	Off	Noise from mechanical ventilation (induction units and jets)	No particular health risk	Annoying for occupants and loss of concentration	No significant influence on energy consumption, except pressure loss at unit.	Check whether modifications of airflow rate and type of induction units reduce the noise level. Clean nozzles in induction units.

Type[11]		Observation, problem	Resulting problems			Ways commonly used to solve the problem or avoid mistake (by order of preference)
			Health risks	Comfort	Energy	
V	Off	Dual duct system			High energy use	Separate systems for heating or cooling from the ventilation system
V	Off	Improper air supply (low inducing grilles with too cold air)		Draught		High inducing grilles Supply warmer air
V	Off	Dysfunction of natural ventilation due to lower driving forces than anticipated	Insufficient ventilation	Too high temperatures		Appropriate design of natural ventilation openings Use hybrid system; despite energy 'penalty'
V	Off	Natural ventilation system (opening of grilles) to be activated by occupants.	Insufficient or inappropriate ventilation			Install automatic moisture-controlled grilles Use central control (grilles default open during office hours), possibility of overruling by occupants
V	Res	Heat recovery using rotating heat exchanger on every space, including kitchen.	Recirculation of contaminants	Propagation of odours	RHE have a better efficiency than other types.	Use airtight heat exchangers for air from polluting rooms Extract air from kitchens, toilets and bathrooms separately Install active charcoal filters in supplied air.
V	Res	Ground heat exchangers under the building	No particular health risks	In winter the ground exchangers withdraw energy from under the building	It is possible that the positive effects of ground heat exchangers with regard to energy consumption (cooled air in building in summer and warmed up air in building in winter) are (partly) compensated by higher energy needs for heating of basement levels in winter.	Do not place Canadian wells directly under the building. Better is to place them deep enough to prevent from energy withdrawal from under the basement or to put them next to / around the building
V	Res	Ground heat exchangers ducts partly filled with water	No particular health risks as long as kept dark, but increased humidity of supply air		Reduced section of ducts.	Prevent the ground heat exchangers from being under ground water level. Drain the ducts.

		Observation, problem	Resulting problems			Ways commonly used to solve the problem or avoid mistake (by order of preference)
Type[11]			Health risks	Comfort	Energy	
V	Res	Air intake on the roof for mechanical ventilation is close (few meters) to chimneys of apartments' fireplaces. If wind comes from wrong direction smoke is sucked into air intake.	Smoke is reintroduced in the buildings: Inhalation by occupants. Health risks depend on concentration of smoke and smoke chemical composition.	Reduced air quality (odours) Possible symptoms (irritated eyes and respiratory system)	The problem as such does not have an influence on energy consumption. However reducing the impact may do: occupants may try to increase the ventilation rate or open windows: increase of energy consumption	1. Change the position of and increase the distance between air inlet and chimneys. 2. Do not use the fireplaces when supply air is taken next to the chimneys. 3. Installing additional filters, such as active charcoal filters in the supply duct will partly solve the problem.
V	Res	Air in the room supplied partly through slits placed in the floor under two windows, resulting in in dust lifting.	Exposure to particles	May cause occupants to occasionaly sneeze		Do not install high velocity grills close to the floor Prefer low velocity grills, or install grills higher.
V	Res	Central air supply in high rise building via central stairway. Air is presumed to pass by an opening under the front door, which is often blocked to prevent sound entering the apartment.	Not enough fresh air entering the apartment. Air polluted by the staircase Air quantity per apartment not controlled.	Fresh air needs to enter the apartment directly through the windows, which increases the risk of draught.	In the winter little more energy then necessary is spent. Supply system is working in under pressure situation. More energy loss is caused by direct air supply through window/facade openings.	Don't apply this kind of supply air system or if used make sure that air can freely enter the apartment by using air grilles with sufficient low air resistance. This system is not compatible with some fire safety rules. Better is to apply separate air ducts for air supply systems.
V	Res	Mechanical exhaust system 24 hours per day in same air quantity.			Energy savings during the nights by using speed control on the exhaust fan should be possible.	Use speed or demand control systems for mechanical exhaust.
V	Res	Occupants do not know that balanced ventilation system can be switched from winter to summer settings. Some occupants have ventilation system switched off.	Too little ventilation	Insufficient or too much preheating of supply air	Misuse of the heat recovery.	Easy understandable instruction provided to occupants Occupant's proof set-up of system.
V		Dirty ventilation grilles, becoming clogged	Poor hygiene, insufficient ventilation	Reduce ventilation rate, stuffy air	Increases pressure drop in air handling unit	Periodically clean grilles Instructions to occupants fro cleaning grilles

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