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Considerations concerning costs and benefits with application to ventilation

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Contributed Report 05

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Foreword by the AIVC

Decision makers that have to decide which type of HVAC system that has to be installed in a building, will usually base their decisions on the investment and running costs (including expected maintenance costs) and their perception of the quality of the system. In general, the energy savings will be compared to a reference (less efficient) system to calculate the benefit.

However, the choice of the building equipment has also an impact on the Indoor Environmental Quality (IEQ) and on the performance of the workers inside the building. This is frequently forgotten, probably because they do not pay attention and because the IEQ is difficult to assess and to convert into money, whereas energy can easily be converted.

For the HVAC world, it is important to increase the awareness on this problem. That's why AIVC considered that the present report, written in the framework of the IEA HYBVENT project, would be a valuable Contributed Report.

As its name indicates ("Considerations concerning costs and benefits with application to ventilation"), the report does not aim to be an exhaustive guide on the topic, but aims to give background information of the subject.

Considerations concerning costs and benefits
with application to ventilation

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26 February 2004

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Acknowledgments

Some of the information reported in the present document has been collected in the frame of the HybVent project of the International Energy Agency (IEA ECBCS Annex 35: Hybrid Ventilation in new and retrofitted office buildings and schools).

A complete description of this project can be found on http://hybvent.civil.auc.dk/.[1]

[1] The Belgian participation to HybVent has been financed by the Belgian Federal Ministry of Economic Affairs, the Government of the Flemish region, the Government of the Walloon region, the Government of the region of Brussels Capital, IVEG - intercommunale voor energie and the Belgian Building Research Institute.

1. Introduction

If someone has to design the ventilation system of a new building or to retrofit an existing building, he has to make choices among all the systems and products proposed on the market. For that, he has to fix in advance criteria he wants the system to fulfil; cost is usually regarded as one of the most important.

If it is logical and indispensable to evaluate the costs of a ventilation system, it is also very important to evaluate its costs/benefits ratio. The first task in quite straightforward and can be performed more or less easily. The second task is much more complex, as it is not easy to quantify the benefits of a ventilation system, at least in economic terms. Indeed, what is the value of a good indoor climate, in Euros?

This is an important topic for innovative ventilation systems and for hybrid ventilation systems in particular, as they could appear more expensive at first glance. It is therefore very important that the decision makers have a correct and coherent framework for discussing costs and benefits, to clearly understand the decision they have to take. This report aims to contribute to such discussion.

It is important to note that the considerations in this report can also be applied to other types of technologies. Moreover, other activities within the IEA Implementing Agreement on Energy Conservation in Buildings and Community Systems (ECBCS) are confronted with similar considerations, like for instance Annex 40 (Commissioning of Building HVAC Systems for Improved Energy Performance).

2. Philosophy of costs/benefits analysis at building level

Costs/benefits analysis is a very important decision tool to determine the chose between all the building technologies that are possible to apply in a new or renovated building. **Such analyses are unfortunately not straightforward and can be even very complex**, especially in the case of new technologies as hybrid ventilation.

Costs mainly include: investment: design, materials, installation, energy, maintenance and repairs. However, it is not always evident to quantify easily all this as aspects. For instance, as a new system can decrease some energy flows but increase others. This will be shortly discussed in § 3.

Benefits are even more complex to evaluate. In § 3, we will see that energy savings are not the only benefits that a technologies/systems provides. The impact on the indoor climate must also be assessed. This will be shortly discussed in § 5 and 6.

It is very important to note that the implementation of a new building technology or system can not be done on the basis of a costs/benefits analysis only. Indeed, if a new technology is evaluated from a costs/benefits point of view only, the energy aspects can appear not to be so important and can be neglected.

However, in the present world, energy is important. We should all try to reduce or energy consumption, not only for or own profit, but also to reduce the CO_2 emissions (Kyoto protocol), preserve the energy reserves, and reduce our dependence to our energy suppliers. These aspects should be kept in mind when selecting a building technology.

The authors believe that a costs/benefits analysis should **quantify** <u>and</u> **qualify** the advantages and disadvantages of the technology to be implemented.

The *quantitative* analysis should include:

- the costs of the building technology and its implementation,
- the reduction of the energy demand, which can be estimated for instance with non-steady state building simulation software to predict the internal temperatures and the energy demand,
- the impact of the technology on the living conditions that can be translated in monetary terms,

The *qualitative* analysis should include:

- the impact of the technology on the living conditions that can not be translated in monetary terms,
- the impact of the technology on the environment,
- other aspects (like enterprise image).

3. Considerations about costs

Considerations about costs and benefits are respectively given in the present and the next chapters.

Usually, it is much easier to determine the costs than the benefits of a building technology or service. Costs mainly include:

- investment: design, materials, installation,
- training of staff,
- energy,
- maintenance and repairs.

However, as we will see below, this analysis is not always straightforward. Different cases may be identified.

1) Some technologies have an impact on one energy flow only

Some technologies have an impact on energy efficiency which is limited to one type of energy flow, and have (almost) no impact on indoor climate. In such a case, the identification of the costs is not very difficult.

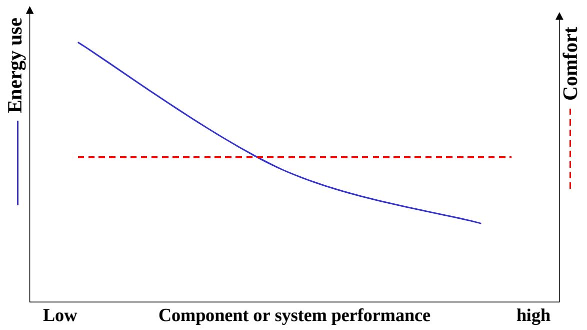


Figure 1: Impact of energy efficient fans and pumps on energy use and comfort

Example: Thermal efficiency of heating boiler

An increased efficiency of a heating boiler will automatically lead to a reduction in energy use.

Example: Specific power of fans and pumps

More efficient fans and pumps will lead to lower energy consumption. There is nearly no impact on the comfort conditions.

2) Some technologies have an impact on various energy flows

Some technologies have an impact on various energy flows, and have (almost) no impact on indoor climate. It can be that certain energy uses increase whereas other decrease. A correct costs analysis should integrate all aspects.

Example: Fans with variable fan speed:

→ lower electricity consumption for fans,

→ lower energy for conditioning (heating, cooling…) of transported air.

Example: Electronic ballast for lighting in an air conditioned building

→ lower electricity consumption for lighting,

→ increased heating demand in winter time (less internal gains),

→ lower cooling demand in summer (less internal gains).

3) Some technologies have an impact on various energy flows, as well as on comfort

Some technologies have an impact on both the energy efficiency of buildings and the indoor climate performances. If the latest decrease, this is a cost that must be included in the analysis.

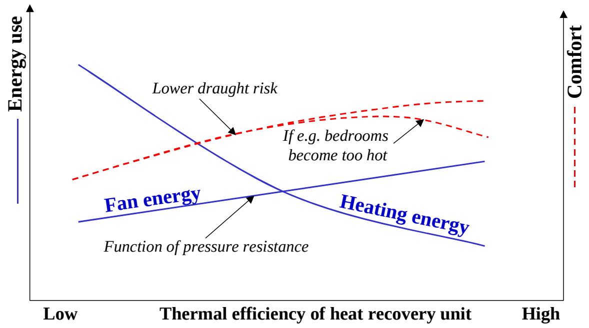


Figure 2: Impact of air-to-air heat recovery systems on energy use and thermal comfort

Example: Static heat recovery

In principle, heat recovery systems should result in a lower energy demand; there is often an improvement of the thermal comfort.

However, heat recovery systems often represent important pressure losses and therefore higher fan energy consumption. In low energy buildings (heating season has rather short duration) and non optimised heat recovery systems, it is possible that a poor performing heat recovery system is not necessarily a good choice (even without considering the investment cost).

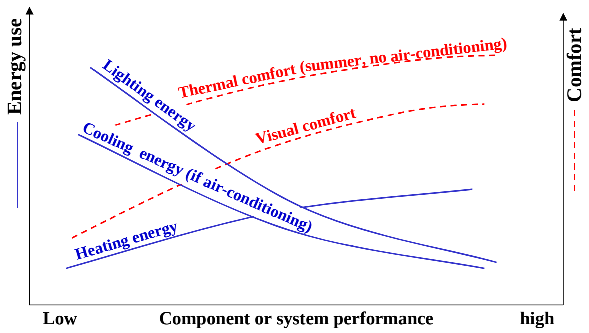


Figure 3: Possible impact of relighting on energy use and comfort

Example: Relighting

Relighting can influence the energy picture in various ways : by lowering the energy use for artificial lighting, by lowering the electrical peak power demand, by increasing the heating demand in winter (less internal gains) and by reducing the cooling demand (lower internal gains). It will surely influence the visual comfort and, in case there is no active cooling, it will also have an impact on the thermal comfort in summer.

Example: Avoidance of thermal bridges

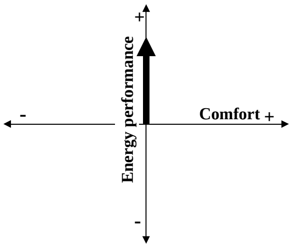
Thermal bridges result in an increased heat loss and/or an increased risk of condensation and mould growth. Avoidance of thermal bridges or solving thermal bridges in the framework of retrofitting can therefore have an impact on the energy use and the moisture problems.

4. Considerations about benefits

Hybrid ventilation systems, as well as other building technologies, aims to reduce the energy consumption and to provide more comfort. Both aspects should be included in the analysis of the benefits.

The impact of a building technology on energy and comfort will correspond to one of the following cases.

1) Some technologies only reduce the energy use

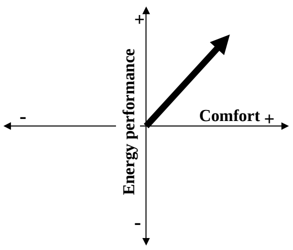


Example: Thermal efficiency of heating boiler

Example: Specific power of fans and pumps

These examples have already been discussed in the previous chapter.

2) Some technologies reduce energy use and improve indoor climate

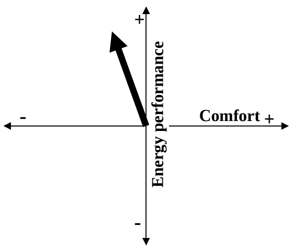


Example: Thermal insulation of opaque components.

Improved thermal insulation of the building envelope will not only reduce the energy demand for heating but will in most cases improve the thermal comfort in non-heated rooms and, if direct gains are well controlled, improve thermal comfort in summer. An example is the impact of thermal insulation on the temperature in the non-heated attic of the PLEIADE dwelling.

The application of a high insulation thickness may lead to the need of another concept for the envelope (e.g. the facades in the PLEIADE dwelling) and/or may lead to loss of useful living space.

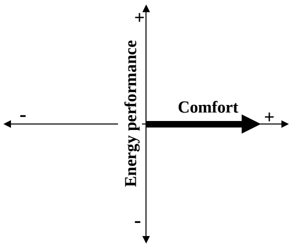
3) Some technologies reduce energy use and to a certain extent have a negative impact on the indoor climate



Example: Demand controlled ventilation.

Demand controlled ventilation aims to regulate the ventilation system in such way that the target values for the control parameter (CO_2, humidity, presence…) are reached as close as possible. Given the fact that, when compared with a classical ventilation system, a demand controlled ventilation system will in most cases give a somewhat lower IAQ level, it is clear that there is to a certain extent a negative impact on the indoor climate.

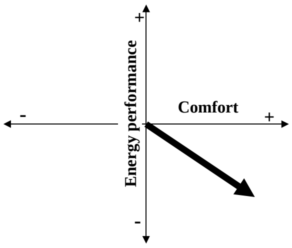
4) Some technologies are considered as only improving the indoor climate, without any energy benefit



Example: Solar control devices.

If thermal comfort is not given a certain value, the installation of solar control devices clearly gives no benefit and can even increase energy consumption in winter. If on the other hand, thermal comfort is given a priority, a solar control strategy can be compared with e.g. active cooling and a more objective cost-benefit comparison can be made.

5) Some technologies are considered as only improving the indoor climate, with an energy penalty



Example: Ventilation systems

The installation of a ventilation system requires an investment cost and moreover a running cost (energy for heating, cooling, fan energy…). It is clear that the investment is not compensated by an energy reduction (excepted if the fact that people will possibly open their windows in winter is taken into account) However, no ventilation may result in poor IAQ conditions, mould growth and moisture problems.

6) Some technologies have a non-continuous impact on installation cost and energy use

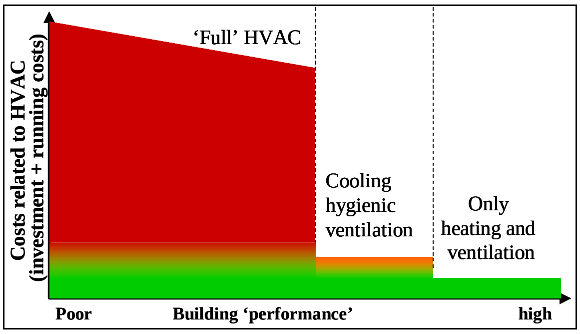


Figure 4: Relation between degree of energy efficiency and HVAC cost is not a continuous function

By an intelligent combination of various strategies (envelope design, solar control, ventilation…), it is possible to avoid e.g. active cooling for many types of buildings. This may result in important reductions in investment costs for the HVAC equipment and, directly related, in lower energy use.

As an example, various alternatives have been studied for the renovation of a building in Brussels. The investment costs and energy use of the HVAC system for various strategies have been evaluated. It was concluded that, by a combination of various measures, it was possible to avoid a full air-conditioning resulting in lower investment cost of about 150 k€ and a yearly saving in energy cost of about 25 k€.

7) It is important to note that for some technologies, the performances are very sensitive to the building characteristics.

For such technologies, very good results can be obtained in a building whereas the benefits can be very small in another building. A costs/benefits analysis must therefore be done with a lot of attention. It is not possible to extrapolate results of other projects, especially if the buildings are very different.

Example: Night ventilation for summer comfort

The efficiency depends strongly on the building characteristics (thermal mass, solar gains…) as well as the building use (density of occupation, internal gains…)

Example: CO_2 controlled ventilation

Demand controlled ventilation can be relevant if the building occupancy varies substantially and when it is not evident to predict the occupancy. CO_2 controlled ventilation, which is at present more expensive than e.g. ventilation based on presence detection, becomes more interesting if the building is leakier (which is not recommended) and if windows can be opened. Therefore, the benefits strongly depend on these boundary conditions.

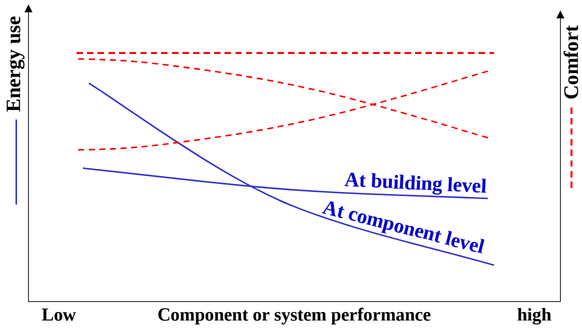


Figure 5: Energy performances of hybrid PV and possible impact on indoor comfort

Example: Hybrid PV in buildings

Hybrid PV technology can be at component level very well performing but it is not evident to find good applications at building level. The optimisation analysis may lead to the conclusion that from an energy point of view hybrid PV is in many applications not relevant.
As far as the indoor climate is concerned, the impact of hybrid PV can be an improvement (e.g. higher temperatures of supply air), a reduction of comfort (e.g. increased overheating problems in case of semi-transparent PV facades) or no impact at all.

Example: HR glazing in low energy office buildings

The glazing characteristics can have an impact on the heating and cooling demand as well as on the artificial lighting needs. In case of low energy office buildings, the heating demand can become rather marginal and the building might be during most of the year in no heating mode and even cooling mode. Therefore, the best insulating glazing may not necessarily be optimal window choice.

The costs/benefits evaluation of a building technology will be only straightforward in case **1)**, as a direct comparison between the investment costs and the energy savings can be done. In certain cases, it is important to also include indirect building costs (e.g. space use).

In all other cases, the evaluation will be much more complex.

In case **2)**, a technology that would have a relatively high investment cost compared to the energy savings only would have a too long pay-back period. Such a technology could therefore not be implemented, despite that it would also improve the indoor climate.

In case **3)**, the decision maker has clearly to balance comfort versus energy. He could simply give a higher priority to one of them - what ever the (hidden) costs. Or he could possibly identify the costs of the comfort decrease.

The situation is similar in case **4)**. The decision maker could simply decide to implement such a technology because he evaluates that it is necessary, but he could also try to identify the benefits of the comfort increase.

In case **5)**, it is logical that a costs/benefits analysis cannot be done on financial criterion only; such analysis will always prevent the technology to be implemented.

Therefore, the question is: how is it possible to transform "indoor climate" and "comfort" into "money"? The answer is: "**productivity**", as described in the next chapter.

5. Link between indoor climate and productivity

Everyone has already experienced that poor indoor climate has an impact on his work performances. Several researchers have tried to quantify this daily experience in mathematical terms. The results of their studies diverge from each others. In the literature, the productivity losses due to poor indoor climate or, more generally, poor indoor environment quality, varies as much as from 0% (no impact) to 100% (closing of the building office)! This chapter discusses that topic.

5.1 What influences productivity?

Obviously, the indoor comfort is not the only parameter that influences the worker's productivity! A very simplified model (Rohles F.H., 1994) assumes that the performance of an individual can be described by the relationship:

$$P = A.D + O$$

where P is the performance, A the ability to perform the assigned task, D the individual's drive or motivation and O an operational component. This operational component includes indoor environmental aspects (IAQ, thermal comfort, acoustic comfort, visual comfort as well as building aspect and colours, workplace and ergonomics…) as well as social aspects, enterprise culture and company image, salary and so on… The list could be lengthened ad infinitum. Figure 6 presents a schematic of factors that are known to influence productivity at work, according to (Saaty, 1972) and (Boyce et al., 2003).

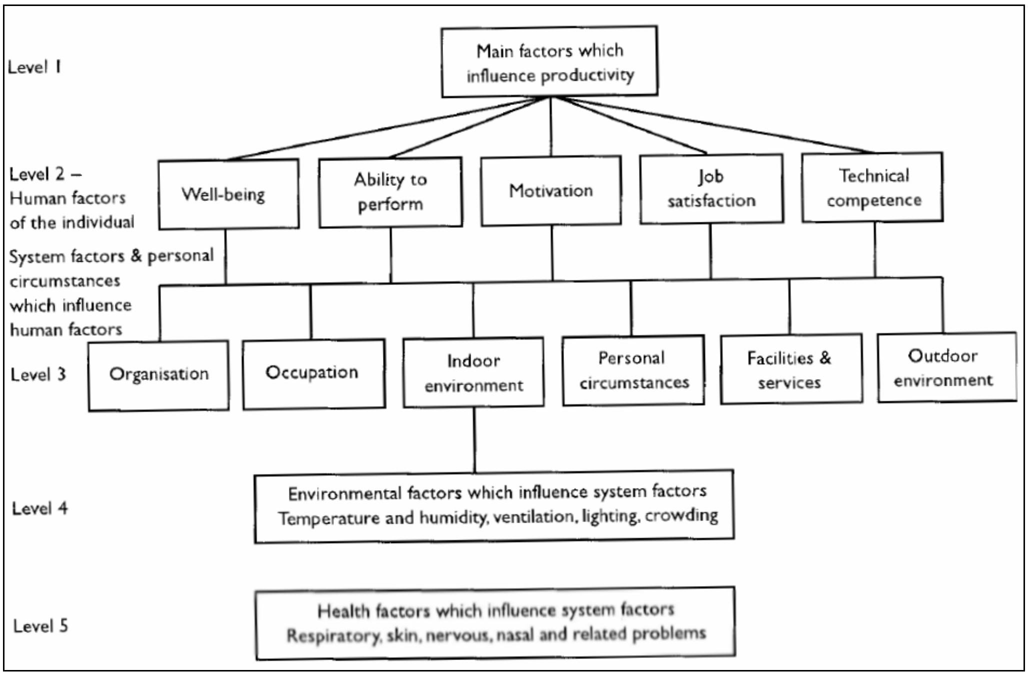


Figure 6: A schematic of actors known to influence productivity at work (source: Boyce et al., 2003)

Indoor environment quality

S.O. Hanssen has therefore developed the concept of ***indoor environment quality*** (IEQ), which comprises:

- thermal surroundings
- atmospheric environment: airborne particles, bacteria, virus, mould, VOC…
- acoustic background
- actinic background: lighting, radon and electromagnetic background
- mechanical environment: ergonomics, shape of the room and equipment…
- aesthetic surroundings: office lay-out and design, colours and walls…
- psycho-social environment: job content, work load and pace, job control…

5.2 Why the link between IEQ and productivity is not well established?

There are at least two major difficulties.

5.2.1 Difficulty to link productivity to a limited set of parameters

From 1927 to 1932, Mayo conducted experiments at the Western Electric Hawthorne Works at Chicago to analyze the relationship between working conditions and productivity. He changed the working conditions of a group of workers, and their productivity increased. After the experiments, the group of workers went back in their original workplaces, under their original poor working conditions… and the productivity was the highest ever recorded! Mayo concluded that the productivity did not increased due to the working conditions themselves but because the workers were satisfied that the management took care of them. This has been called the "Hawthorne effect".

However, the experiments conducted by Mayo were reevaluated in the 1970's by Parsons, as he has some doubts about Mayo's conclusions. He interviewed people that had participate to the experiments 50 years before, and found several lacks in the methodology. According to his findings, Parsons believes that the "Hawthorne effect" simply shows the effect of variables that experimenters are unaware of, or over which they have no control (Rice, 1982).

Whatever you believe in the "Hawthorne effect" or not, this example illustrates that the number of parameters that can influence performance and productivity is so high that it is not evident to assess the impact of one or a few of them.

5.2.2 How to measure productivity?

A second problem when analysing the link between indoor environment and productivity is how to measure productivity.

In industrial spaces, productivity can probably be more easily be measured quantitatively (e.g. number of pieces produced per worker and per period, time to perform a task) and qualitatively (number of defective pieces per worker and per period) than in non industrial spaces.

In non industrial spaces as offices, if the work is repetitive, the same techniques can be used (e.g. time to process a file or to type a text, number of typewriting errors per typewriter and per period). Otherwise, productivity is often measured by absenteeism figures or on basis of self-reported productivity and questionnaires.

5.3 Productivity and thermal comfort

Several studies have tried to determine the productivity loss due to poor thermal conditions; Figure 7 presents the results of two of them.

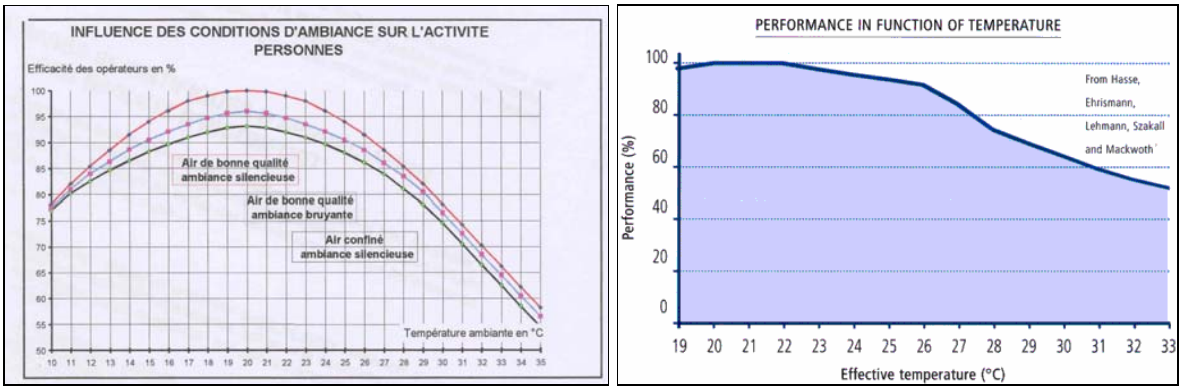


Figure 7: Productivity in function of the temperature
(Sources: left: Rio A., 2003 right: Hasse et al.)

Studies have conservatively estimated that improving the thermal environment in US office buildings would result in a direct increased in productivity of 0.5% to 5%, which, for the US, represents a value of $12 to $125 billion annually.

Belgian law

The legal point of view must also be addressed. For instance in Belgium, employees are (or should be) under the protection of the so-called "Règlement Général pour la Protection du Travail/Algemeen Reglement voor de Arbeidsbescherming" (that could be translated in General Regulation of Workers Protection) constitutes since 1947 the coordinated text of all regulations and prescriptions concerning health and safety of workers[2].

According to this regulation, when the wet bulb temperature exceeds a certain limit, rest time should be granted. For offices (light work), this limit is fixed at 30°C. The length of the pauses according to the wet bulb temperature is given on Figure 8. The productivity loss due to the rest time is therefore 8% at 30.1°C, 50% at 31.5°C and 92% at 33.0°C!

[2] This regulation is gradually replaced by the "Code on the wellbeing at work". This Code includes (among others) prescriptions from European directives concerning health and safety at work places.

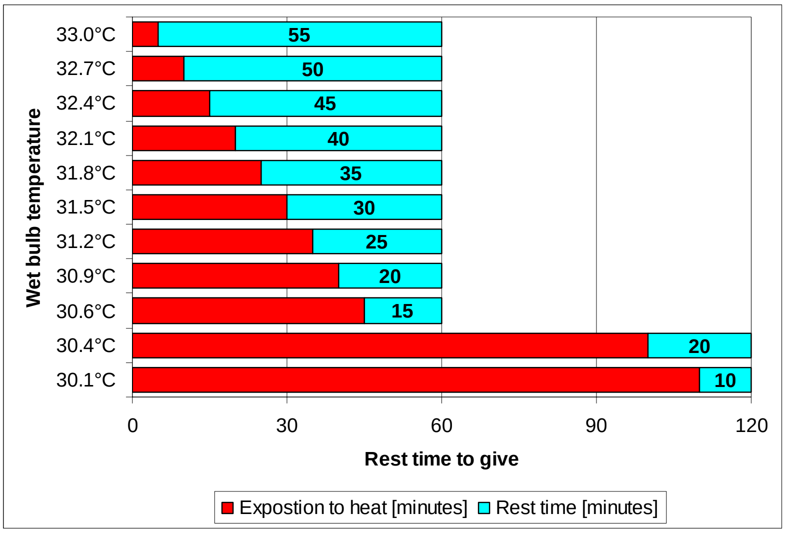


Figure 8: Rest time to be granted in function of the wet bulb temperature (RGPT/ARAB – Article 148 decies 2)

5.4 Productivity and IAQ

Several studies have shown evidences that there is a strong link between IAQ and e.g. lung cancer, allergies, respiratory infections, reduced well-being… Therefore, there must be a link between IAQ and productivity, would be this only because productivity is related to health (absenteeism for sickness) and health to IAQ.

A literature survey (Fisk W.J., 2000) reports several field studies where the health was better in buildings with better IAQ. For instance, a comparison of 40 offices has shown 35% less short term absence in the buildings that presented a higher ventilation flow rate than the normal.

Based on the available literature and analyses of statistical and economic data, (Fisk J.W., 2000) estimates that, for the US, the potential annual savings and productivity gains are $6 to $14 billion from reduced respiratory disease and $2 to $4 billion from reduced allergies and asthma.

Furthermore, several studies have shown evidences that poor IAQ decreases productivity, even if people don't get sick.

Field and laboratory studies evaluate the magnitude of productivity loss due to poor ventilation as 3% to 20%. A literature survey (Dorgan et al., 1998) has shown that a majority of the 500 studies analyzed indicate an average productivity loss of 10% due to poor IAQ.

In a laboratory study, Wargocki has compared the performances in two offices, one classified as low-polluting building, and the other as a non-low-polluting building (Wargocki P., 1998). The pollution source was a 20-year old carpet collected from an office building with a known history of poor IAQ and occupant complaints. The samples of carpet, with a total surface corresponding to the floor area of the office, were behind a screen, so that they were invisible to the occupants. The office, with and without the carpet, was occupied for 4.5 hours by female subjects, in groups of six at a time. The subjects performed three tests simulating office work: typing text on a PC, addition of numbers, and a creative thinking task. These tests were subsequently used to evaluate the subjects' productivity. Results are given in Table 1.

Test	Effect	Description	P-value
Text typing	6.5 %	Higher number of typed characters in the office without carpet	<0.003
Text typing	5.0 %	Fewer typing errors in the office without carpet	<0.10
Addition	3.8 %	Larger increase of the number of added units in the office without carpet	< 0.05
Logical reasoning	3.4 %	Larger increase of reaction time in the office without carpet	< 0.08
Serial addition	2.5 %	Larger increase of accurately added digits in the office without carpet	< 0.06
Stroop	3.1 %	Larger increase of speed in the office without carpet	< 0.10

Table 1: Productivity in a low-polluting building compared to a non-low-polluting building (Source: Wargocki P., 1998)

In a recent study, Wargocki has estimated that, if the percentage of people dissatisfied with the IAQ when entering a room is reduced by 10%, the performance increases by 1.1%. (Wargocki P., 2000)

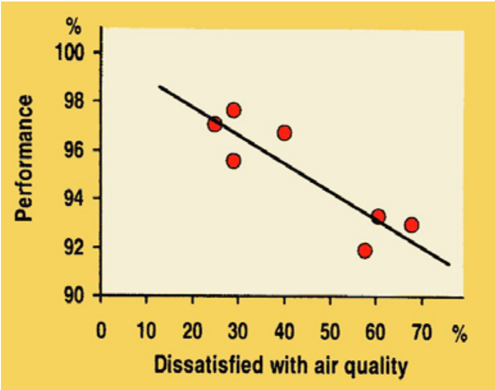


Figure 9: Performance versus % Dissatisfied (Source: Wargocki P. cited in SCANVAC Newsletter 1/2002)

5.5 Productivity and lighting

Indoor comfort (from a building physics point of view) is not only influenced by thermal comfort, but also acoustical comfort and visual comfort.

The link between productivity and lighting has been the subject of many studies. A literature review can be found in (Boyce, 2003)[3]. Several studies are reported, as the one presented in Figure 9. This figure shows that, at the same luminance contrast, performance is better at higher luminances, for all luminances contrasts. The second is that performance tends to saturate at lower luminance contrasts for higher luminances.

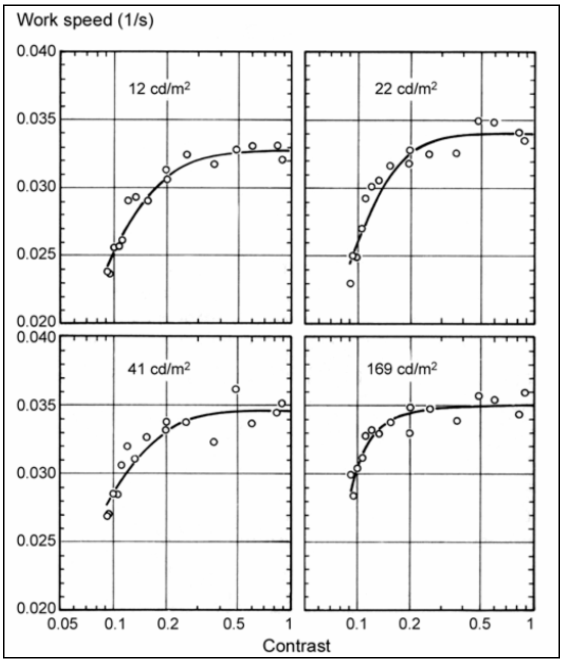


Figure 10: Mean work speed plotted against luminance contrast, for four background luminances (Rea, 1986)

5.6 Conclusions

From a literature survey, we can conclude that there are numerous evidences that improving the indoor environment decreases worker complaints and absenteeism, and increases productivity.

Despite many laboratory and field studies (mainly in Northern Europe[4] and USA[5]), it is still difficult to quantify accurately the productivity increase that can be expected by improving

[3] This literature review can be downloaded from the following website: http://www.daylightdividends.org/programs/daylightdividends/index.asp

[4] In 1998, the International Centre for Indoor Environment and Energy (http://www.ie.dtu.dk/) has been established in Denmark. The Centre's researches focus on studies of the effect of indoor air quality and thermal environment on human comfort, health and productivity. The overall purpose of this research is to develop practical design tools for use by the HVAC profession and the construction industry. The staff of the centre includes experts like e.g. Fanger P.O., Wyon D., Wargocki P.,…

the indoor climate. There are two reasons for that. Firstly, productivity depends on a wide range of parameters, and therefore it is difficult to identify the influence of a limited set of parameters. Secondly, productivity itself is difficult to measure, especially in non industrial spaces.

However, the fact that the relationship between indoor climate and productivity is not well established quantitatively should not be a barrier to promote better indoor climate. Indeed, we will see in the next chapter that a few percent of productivity increase is enough to compensate the investment and energy costs required to achieve better indoor climate.

[5] The Lawrence Berkeley National Laboratory has launched the research project "Indoor Health & Productivity" (http://www.dc.lbl.gov/IHP/), with similar objectives.

6. Introducing worker productivity in costs/benefits analysis

In this chapter, we will see that introducing worker productivity in costs/benefits analysis should definitively change the perspective of who usually does not take it into account.

As it appears on Figure 11, the main costs of workers' salaries is much higher than the cost related to rent a building, which are themselves much higher than the energy costs.

To simplify, the ratio between salaries/building/energy is about 100/10/1. This has been enlightened by several statistical analyses (mainly in USA, but the situation is expected to be similar in Belgium).

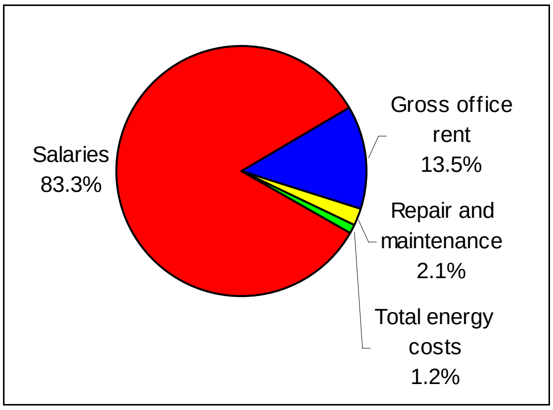


Figure 11: Typical Cost structure in an office building (source: Building Owners and Managers Association, 1999)

From that figure, it becomes clear that a productivity increase can completely offset the building's entire energy bill. The productivity increase can economically justify an increase of the total building construction cost; this will be illustrated with the following simplified example.

A hybrid ventilation system is applied in a new building.

→ Assumption on cost: staff: 90%, building: 10%

→ Assumption on potential increase in productivity: from 0 till 6 %

→ Assumption on increase in building cost due to hybrid ventilation: from 0 till 10%

→ Assumption on energy: same as traditional ventilation system

The results are presented in Figure 12. It clearly appears that the impact of the additional investment cost is probably relatively small if an improvement in productivity of more than 1% can be achieved (due to better thermal comfort, better indoor air quality and more global satisfaction of users). An increase of 10% of the total construction cost can be economically rentable, if it increases the productivity by 1%, or 18 hour a year, of 5 minutes a day (without considering energy costs).

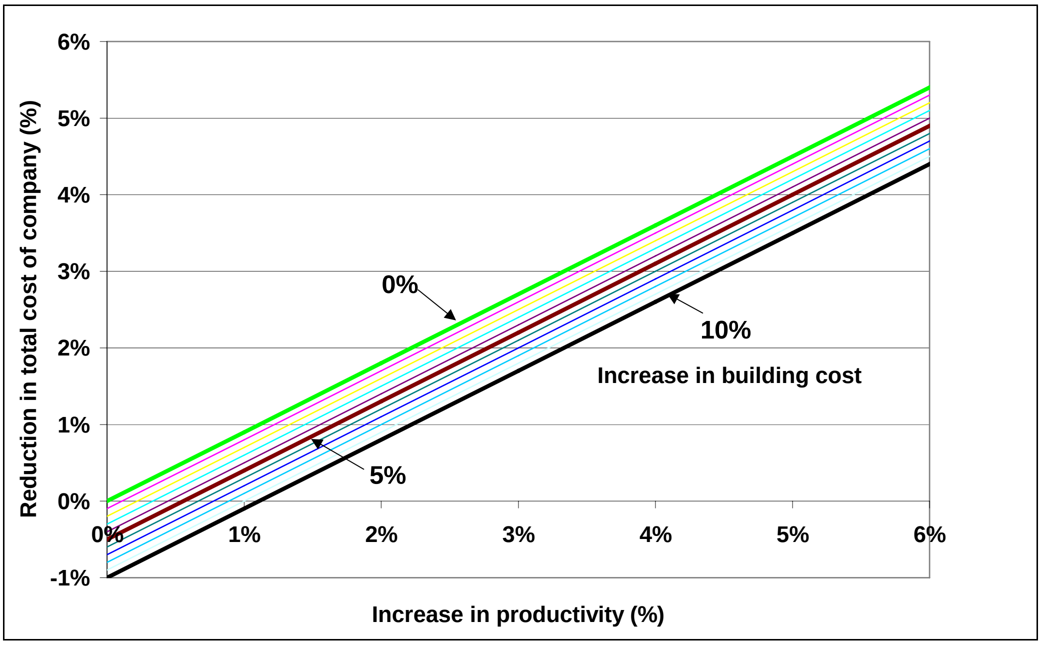


Figure 12: Simplified relation between increase in building cost, increase in productivity and reduction in total company cost (assumption: staff cost = 90% of total company cost)

Does the fact that the ratio between salaries/building/energy is about 100/10/1 mean that energy is not important anymore? Certainly not! Productivity and energy savings are not mutually exclusive objectives.

For instance, it is not necessary to provide too high airflows, as:

- productivity is not only related to airflow, as we have seen earlier,
- the relation between airflows and productivity is not linear and moreover, there is a limit with the increase in the realizable productivity,
- if the airflows are unnecessarily increased, it can cause negative side effects such as acoustic problems and draughts, as well as an increase in the investment costs (see e.g. § 3, case 6),
- it is possible to select technologies that provide better indoor climate with less energy; hybrid ventilation should have that as primary objective,
- energy costs can be small compared to the salary costs… but important compared to the company benefits; in such case, a reduction of the energy costs can increase the benefits considerably,
- low energy buildings can improve the image of the company,
- **and last but not the least, environmental impact must also be taken into account.**

7. Example: the PROBE building

7.1 Description of the building

Although the PROBE building was built just after the first oil crisis (1975), no energy conservation measures were taken: no insulation, single glass, simple heating installation, no energy management, no ventilation, and no control of summer comfort... The indoor conditions were not optimal at all: poor regulation of the heating for thermal comfort in winter, poor performance of the lighting equipment, poor indoor air quality, overheating in summer (which was maybe the more severe problem). For these reasons, the PROBE building needed to be renovated[6].

Figure 13 : The PROBE building

The main objectives were: to improve the thermal comfort (winter comfort as summer comfort) and the visual comfort, to guarantee a good IAQ, to limit the energy use… The main retrofitting works were:

- Replacement of old fuel boilers by high efficiency fuel boilers;
- Introduction of thermostatic valves and energy management system for heating;
- Relighting with energy-efficient luminaires with daylight control;
- Addition of thermal insulation layer onto the flat roof when replacing roofing;
- Replacement of single glazing by high efficiency double glazing;
- Replacement of part of the existing frames by new, well insulated frames;
- Integration of automatically controlled solar protection systems to reduce solar heat gains during the summer;
- Integration of a fully natural, intensive night ventilation for free cooling in summertime;
- Installation of a demand controlled mechanical ventilation system for indoor air quality;
- Replacement of leaky ventilation ducts by more airtight ductwork.

[6] As it was estimated that the situation occurred in many office buildings in Belgium, it was decided not only to renovate this single building, but also to evaluate the benefits of the renovation (both in terms of energy savings and indoor conditions improvements) and to promote this renovation approach. PROBE stands for *Pragmatic Renovation of Office Buildings for a Better Environment.* The project has been financed by several industrial partners and by the Ministry of the Walloon Region (DGTRE).

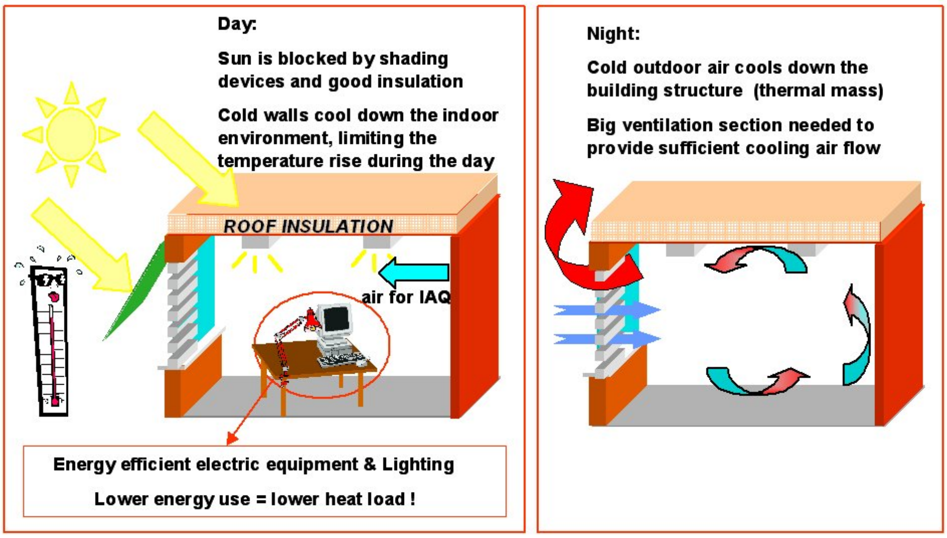


Figure 14 : The strategy to improve indoor conditions

The ventilation strategy of the PROBE building can be considered as hybrid as there are two ventilation systems that have each ones its own goal:

- a *mechanical ventilation system* for IAQ, controlled by presence detection;
- a *natural ventilation system* for thermal control in summer by intensive night cooling, controlled by the users.

The two-storey building was designed for 53 persons. There are 10 small offices for 1 person and 8 big offices for 2 persons per floor. Nowadays, the occupancy is higher.
In at least one of the small office, meetings of 2 to 8 persons are frequently held.

Costs/benefits analysis

The costs/benefits analysis of some aspects is quite obvious; for instance, the replacement of the fuel boilers and the introduction of the energy management system. The costs are indeed easy to determine and the benefits can be calculated in terms of energy savings only.

Figure 15: Elements of the hybrid ventilation strategy

The costs/benefits analysis of the hybrid ventilation system or strategy is not straightforward at all.

Which are the costs of the strategy? Are they limited to the costs of the mechanical and ventilation systems only? Or must other aspects be included, such as efficient lighting and equipment, solar protections, access to thermal mass, thermal insulation of the envelope… All those aspects are indeed indispensable for the good working of the night cooling strategy!

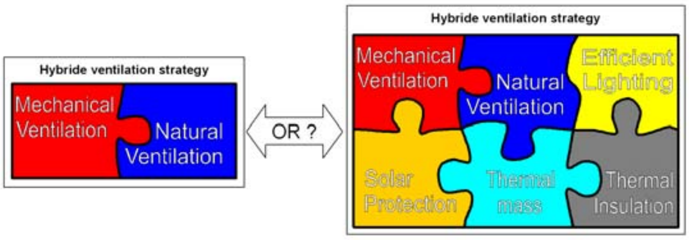


Figure 16: What costs should be included in the costs/analysis of the hybrid ventilation strategy?

Which are the benefits of the strategy? It depends on the system that is chosen as reference.

If we compare to a situation with a full air-conditioning system, the hybrid strategy can prevent to install air-conditioning. The benefits are the investment costs and energy consumption.

If we compare to a situation without any ventilation system and consider that energy savings are the only benefits, there is no gain at all. The mechanical ventilation system increases the energy consumption – but it increases the IAQ. The natural ventilation system reduces the overheating during summer. Both aspects increase the worker productivity.

If we compare the presence detection system with a constant airflow system, energy is saved (depending on the occupancy). IAQ is (slightly) reduced (when someone enters a room).

7.2 Development of a new hybrid strategy

The main problem with the hybrid strategy as it is now implemented is that the opening of the louvres is manual. This has many disadvantages. The occupants and guards must be trained. The outdoor temperature can still be very high when the people leave their office at 5 p.m.; during the first ours of the evening, the building is warmed up if the windows are open. The strategy can only be applied from Monday to Thursday, thus 4 nights a week. Therefore, it was decided to apply an automatic strategy in two offices of the PROBE building. This system automatically opens or closes the window, not only according to the temperature but also to the IAQ, measured by a CO_2 sensor.

This new strategy was applied in two offices for 1 person, including the one where small meetings are frequently held.

Costs

As the components installed are not standards components for room ventilation, the cost are difficult to evaluate. However, a rough approximation of the costs of the system is given below.

Item	Cost – 1 unit	Cost – 36 units	Notes
CO_2 sensors	370 €	11.320 €	1, 2
Temperature sensors	30 €	1.020 €	1, 40 units
Screen for outdoor temperature	105 €	420 €	4 units
Presence sensors	30 €	1.020 €	1
VAV	170 €	5.200 €	1
Motors	140 €	4.280 €	1, 3
Installation (including cabling)		6.760 €	5
Control unit		12.500 € → 2.500 €	4
Development of the strategy		25.000 € → 5.000 €	4
TOTAL		**71.300 € → 41.300 €**	

Table 2: Estimated cost of the new hybrid ventilation strategy

This should be compared with the cost of the IR-controlled ventilation devices.

Item	Cost – 1 unit	Cost – 36 units	Note
IR-controlled ventilation device	110 €	**3.366 €**	1

Table 3: Estimated cost of the old ventilation strategy

Notes:

1. It is assumed that the price is reduced by 15% when the order size is higher than 10 units.
2. According to (van der Aa A., 2002), prices today vary between 214 € and 530 €. 370 € is an average value, which correspond also to the price of a similar sensor that the one used in the PROBE building. According to this market survey, the price of CO_2 sensors is expected to decrease in the coming years.
3. This price comes from another project. The price of the motor actually installed in the PROBE building was higher (320 €), due to the geometry of the windows. Furthermore, as only four pieces were needed, no much attention has been paid to find cheaper ones.
4. The first guess is based on experiences from other projects → this price could be strongly reduced if the system is commercialised on a wider scale, and so become a standard product.
5. The installation costs are evaluated as 25% of the other costs, excepted control unit and development of the strategy.

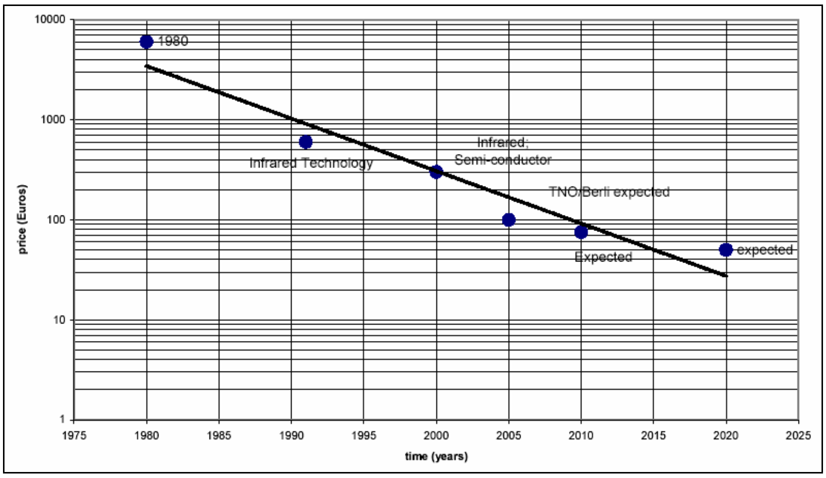


Figure 17 : Price of CO_2 sensors
(Source: van der Aa A., 2002)

Benefits

In the frame of the HybVent project, a monitoring took place in order to evaluate the benefits of the new strategy.

- **Thermal comfort**

The hybrid ventilation strategy was developed to maximise the use of natural ventilation, including intensive night ventilation, in order to reduce the risk of overheating.

The monitoring was not able to evaluate quantitatively the benefits of the new system, because the temperature in the two equipped offices is too highly dependent on the temperatures in the whole building.

However, in order to have a rough estimation of the benefits that were achieved, we can compare the number of hours above a certain temperature in the two offices equipped with the hybrid ventilation system with the other offices for one person.

Based on the estimated productivity in function of the temperature (see Figure 7), we have:

T°	Number of office hours above a temperature		Estimated productivity (see Figure 7)	Productivity loss [hours]	
	Office with hybrid ventilation	Others offices for 1 person		Office with hybrid ventilation	Others offices for 1 person
20°C - 21°C	872	325	100.0% - 100.0%	0.0 h - 0.0 h	0.0 h - 0.0 h
21°C - 22°C	583	669	100.0% - 100.0%	0.0 h - 0.0 h	0.0 h - 0.0 h
22°C - 23°C	423	718	99.3% - 98.1%	3.0 h - 8.0 h	5.0 h - 13.6 h
23°C - 24°C	225	453	97.4% - 96.1%	5.8 h - 8.8 h	11.8 h - 17.7 h
24°C - 25°C	151	181	95.0% - 92.7%	7.5 h - 11.0 h	9.1 h - 13.2 h
25°C - 26°C	66	116	93.3% - 88.4%	4.4 h - 7.7 h	7.7 h - 13.4 h
26°C - 27°C	28	55	91.8% - 83.1%	2.3 h - 4.6 h	4.5 h - 9.3 h
27°C - 28°C	0	18	83.8% - 77.4%	0.0 h - 0.0 h	2.9 h - 4.0 h
28°C - 29°C	0	6	74.4% - 71.0%	0.0 h - 0.0 h	1.6 h - 1.9 h
29°C - 30°C	0	1	69.4% - 64.7%	0.0 h - 0.0 h	0.4 h - 0.5 h
30°C - 31°C	0	0	64.1% - 56.7%	0.0 h - 0.0 h	0.1 h - 0.1 h
> 31°C	0	0	59.1% - 48.6%	0.0 h - 0.0 h	0.0 h - 0.0 h
TOTAL				**23.0 h - 40.1 h**	**43.2 h - 73.7 h**

Table 4: Rough estimation of the productivity loss due to overheating

Remarks:

1. The offices are not occupied during every office hours. The average occupancy of an office for 1 person is about 52% of the time. This is not taken into account here; it is assumed that the temperature in the office is higher when it is occupied.
2. Furthermore, the hybrid ventilation system has not given its full efficiency regarding to thermal comfort, as the temperature in two offices is too much influenced by the temperature in the other offices.

We have, with the following assumptions:

- → The productivity loss is roughly estimated to 20 - 33 hours per person and per year.
- → The office building is occupied by 52 persons.
- → The cost of labour is ± 50.000 € per person and per year or 25€/hour/person/year.

➔ The productivity loss due to overheating only, compared to the reference system, can be roughly evaluated to 26000€ - 43000€.

➔ The pay-back period of the system is therefore 0.9 to 2.6 years only.

A more conservative estimation would consider a productivity loss only if temperature is higher than 25°C. In such case, the number of hours that are lost is between 12 h and 19h, which corresponds to 15830€ - 24875€. The pay-back period becomes 1.5 to 4.3 years (when only thermal comfort is taken into account).

- **Indoor Air Quality**

The hybrid strategy was not designed to provide better IAQ than the standard system, excepted in the office were meeting of 2 to 8 persons were frequently held. The aim was to adapt the IAQ target to the climatic conditions and to provide a better IAQ when there was no energy penalty due to low outdoor temperature or overheating risk due to high outdoor temperature.

8. Economic aspects at macro-scale

In the previous chapters, we have analysed the economic aspects from the building owner's or building occupant's point-of-view. In other words, at micro-scale.

However, building technologies have clearly an environmental impact. Therefore, an economical analysis should also be performed at macro-scale.

8.1 Macro-scale cost of poor IEQ

Several studies have tried to estimate the cost of poor/bad Indoor Environment Quality. We have already mentioned an estimation done by (Fisk W.J., 2000). Based on the available literature and analyses of statistical and economic data, the potential annual savings and productivity gains for the US are estimated \$6 - \$14 billion from reduced respiratory disease, \$2 to \$4 billion from reduced allergies and asthma, \$10 - \$30 billion from reduced sick building syndrome symptoms, and \$20 - \$160 billion from direct improvements in worker performance that are unrelated to health. The total benefit would be between \$38 and \$208 billion per year.

Studies in Sweden and Norway have clearly shown that the economic impact of sub-standard IEQ is very substantial:

- Sweden : 0.6 Billion €/year (Institutet för hälso- och sjukvardseconomi, 1994)
- Sweden : 1.1 Billion €/year (Alprosen nr 3.96 ref AAF/Högskolan I Växjö, 1996)
- Norway : 1 Billion €/year (Faktarapport, del II, SHD, BF, KUF, MD, KRD, SD, OED, 1998)
- Norway, 1.1 – 1.6 Billion €/year (BE-nytt nr 2, Statens Bygningstekniske Etat, 1991)

Estimations concerning the yearly loss due to poor IEQ are available for several countries:

- Norway : 300€/inhabitant (S.O. Hanssen)
- USA : 400 €/inhabitant (B. Fisk)
- Finland : 600 €/inhabitant (O. Seppanen)

8.2 The government's point-of-view

At political level, a comparison with other investments in environmental measures is appropriate.

In a simplified approach, one can make a distinction between different actors at the investment side as well as at the benefit side (see Figure 18):

⇒ Investments :
- By public authorities
- By the individual

⇒ Benefits :
- For public authorities
- For the society
- For the individual

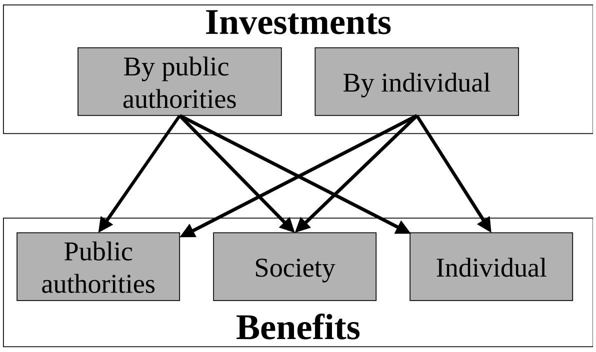


Figure 18 : Who pays and benefits from investments Source : BBRI(1997)

As an illustration, two examples are briefly described:

⇒ Investment in catalytic converter for cars (Figure 19).

These investments must be financed by the car owners. The benefits are mainly for the society (lower environmental pollution) but also the government has some benefits (taxation…). There are no direct benefits for the car owner; the consumption of the car may even increase.

⇒ Investments in new public transportation systems.

The investments must be covered by the government, whereas the individuals and the society have the benefits (Figure 20).

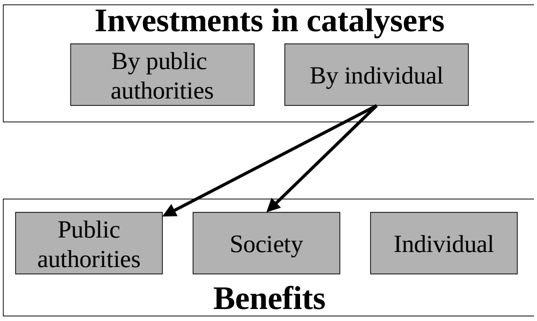


Figure 19 : Car owners invest in catalytic converters but no direct benefits

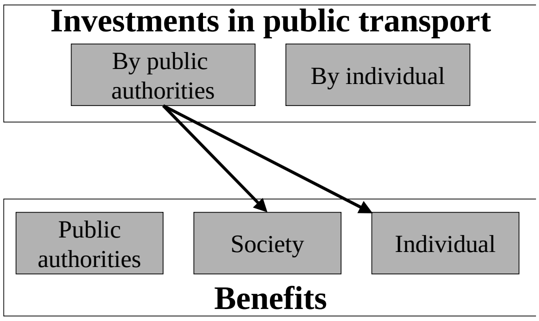


Figure 20 : Investments in public transport systems

A completely different situation is found when analysing investments in energy efficiency measures in buildings (Figure 21). A number of investments in energy efficiency in new buildings result in energy savings allowing to recover during the lifetime of the investment more than the investment costs. Pay-back periods of a few years to less than 10 years are often reported. In such circumstances, it seems justified that regulations are made which strongly stimulate or even oblige people to invest in more energy efficient buildings (e.g. through an EP regulation).

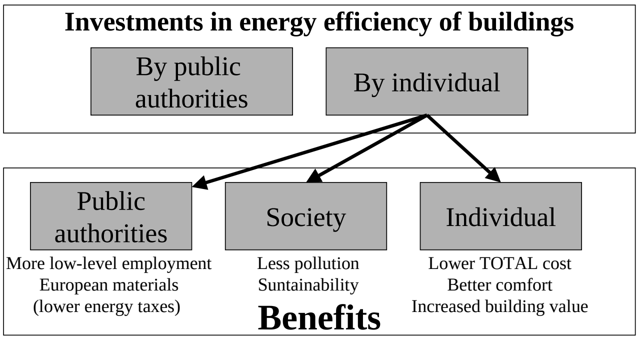


Figure 21 : Investments in energy efficient measures are financed by owners with benefits for everyone

The advantages are important and numerous:

⇒ for the building owners and/or renters :

- the investment cost is fully recovered during the lifetime of the investment and often results in important financial savings;
- the value of the building is increased;
- there are often improvements in indoor climate resulting in a better comfort for the occupants.

⇒ for the whole society :

- a more energy efficient built environment will result in lower environmental pollution. This is a very important benefit for the whole society;
- increased energy efficiency in the building sector is an important contribution in the development of a sustainable society.

⇒ for the government :

- investments in energy efficiency in the building sector can be fully financed by the owners since they have a positive net present value. The governments are therefore not obliged to invest money in this kind of measures;
- the required labour forces for achieving increased energy efficiency in buildings (material production, transportation, installation…) are to a large extent low skilled jobs and often from relatively short distance. As such, it can contribute in job creation without requiring huge investments from the various governments.

9. Potential technical and economic barriers

Nowadays, a whole range of suitable technical solutions exist for achieving energy efficient buildings with a good indoor climate. Moreover, knowledge and technology (e.g. software) exist to predict quite well most performances in relation to indoor climate and energy efficiency. In this context, the following questions are important.

- What are the technical barriers to apply new technologies, as hybrid ventilation?
- What are the non-technical barriers?

An overview of various barriers is given in Table 5.

		Description
Technical barriers	1.	Increased complexity for the designer
	2.	Increased complexity for the product manufacturer
	3.	Increased complexity for the building contractor
	4.	10 years warrantee period
Non-technical barriers	1.	Low energy prices
	2.	Energy cost is a marginal part of a company budget and even of the building cost
	3.	Different priorities for building investor and building user
	4.	Payment schemes for designers and consultants
	5.	Lack of performance oriented standards and regulations
	6.	Limited attention for indoor environment and energy efficiency in project specific requirements
	7.	Lack of clear and consistent messages towards decision makers
	8.	Lack of control and/or need for more refined control
	9.	Difficulties for detecting lack of quality

Table 5: Overview of technical and non-technical barriers

The splitting between technical and non-technical barriers is for most issues rather logical. However, for a number of them, the classification is less evident.

9.1 Potential technical barriers to apply innovative systems

9.1.1 Increased complexity for the designer

The building design community (architects, consultants…) mainly consists of thousands of SME's, with the majority of them having less than 10 employees. During the last decades, they have been confronted with a lot of new building technologies and a lot of new challenges. One of these challenges to be achieved is energy efficiency and good indoor climate conditions in buildings.

For a number of reasons, a large majority of the actors in the building sector are rather conservative in the application of such new materials and concepts:

- The use of new materials or concepts often requires a learning ('trial and error') period and can increase the risk of failures and related responsibility problems.
- A number of projects, where new materials and/or concepts have been applied, have been confronted with sometimes serious problems with major economic consequences. Perhaps the most relevant example is the occurrence of moisture and mould growth problems in the seventies and eighties in dwellings with (poorly designed and/or installed) thermal insulation. These problems have been important with sometimes very substantial financial consequences. In the case of thermal insulation, the problem is at present well understood and technically managed, but still a part of the building professionals is afraid of applying thermal insulation.
- Application of new issues as optimal solar control, intelligent use of daylight, hybrid ventilation… requires a good understanding of the global context and a correct technical knowledge. This is not obvious. Moreover, application in daily practice requires the <u>integration</u> of these concepts in the overall building challenge. This is not evident and surely not for small architectural offices.
- The designers are the last decades also confronted with an increased number of regulations or recommendations concerning the indoor climate and energy efficiency of buildings. Practice shows that the application in daily practice of these approaches (e.g. ventilation and acoustical requirements, energy performance regulation…) is not at all evident for small design offices, which often are unable to have specialists in their teams. On the other hand, the lack of generally accepted guidance and evaluation tools (e.g. for the assessment of thermal comfort in summer) is in many countries also a technical barrier since it requires from the designers that they must handle the challenges themselves.

9.1.2 Increased complexity for the product manufacturer

The increased demand on indoor climate performances and energy efficiency means that product manufacturers are confronted with an increased number of critical boundary conditions. In the future, the integration of environmental concerns will further complicate the issue. Examples are the trend for limiting the emission of VOC's from building materials, the maintainability of ventilation systems, the development of hybrid ventilation systems, the increased complexity of European standards for product characterisation (e.g. characterisation of the thermal conductivity of thermal insulation materials),….

In the case of hybrid ventilation, the manufacturers often have to deal with technical areas in which they had before little or no experience, e.g. control strategies…

9.1.3 Increased complexity for the building contractor

The sometimes financially very serious problems encountered with the (wrong) application of thermal insulation in the 70s and 80s have clearly shown the increased risk for the building contractors. New technological concepts in relation to indoor climate and energy efficiency may represent substantial risks for the building contractors and it requires from them more technical skills. Examples of potential problems are e.g. double façade concepts for which the building contractor has large responsibilities, the use of domotic systems in buildings…

In the case of hybrid ventilation, contractors will in most cases be confronted with new challenges, e.g. rather complex electronic systems, the need to have a global view on supply and exhaust devices…

9.1.4 Ten years warrantee period

Building activities involve substantial financial resources. Lack of performance may result in the need of repair or high damage claims. Moreover, and in contrast with other commercial goods, the responsibility is often not ending after a period of a few years. As an example, there is in Belgium for major parts of the works a legal obligation to give a warrantee of ten years:

- Civil Code, Article 1792:

  In case a building, which is established for a fixed price, fully or partly perishes due to a deficiency in the building, even due to the unsuitability of the ground, then the architect and building contractor are liable for a period of 10 years.

- Civil Code, Article 2270:

  After a period of 10 years, architects and building contractors are discharged from liability with respect to the major works they have executed or directed.

It is clear those innovative systems as hybrid ventilation may have during the first years some maintenance and/or reliability problems.

9.2 Potential non-technical barriers to apply innovative systems

Besides technical reasons for a lack of appropriate performances, there is often also a range of non-technical barriers. In this paragraph, a number of these specific barriers are discussed.

9.2.1 Low energy prices

The low energy prices substantially reduce the economic advantages of investments in energy efficiency measures. Moreover, the fact that the cost of energy has substantially dropped during the last decade is an additional psychological factor since it gives many decision makers the false impression that the energy problem is not longer a real one.

9.2.2 Energy cost is a marginal part of a company budget and even of building cost

Even if the energy prices would be twice as high, the energy cost for an office building is in a typical company only a marginal part of the annual company budget, with the majority of the expenditure related to salaries (see §6).

9.2.3 Different priorities for building investor and building users

A substantial part of the office stock is for selling or renting. As long as the running cost of the building and/or the indoor climate is not an element in the negotiations between promoter and possible renter or buyer, it is clear that investors are not strongly motivated for investing in energy efficient buildings. Indeed, the investor must pay for the investments whereas the renter has the benefit without paying an increased rent.

Appropriate assessment schemes, refined project specific requirements by the clients, an EP regulation… are probably essential for a substantial change.

9.2.4 Payment schemes for designers and consultants

Architects and consultants on building physics and indoor climate are professionals which are assumed to be paid for their work. In practice, one observes that the payment schemes are often not at all stimulating to achieve the general quality objective.

Usually in Belgium, architects are paid based on a percentage of the total building cost (architect) and engineer consultants are paid based on a percentage of the installation cost (consulting engineer).

A consultant, who is willing to achieve an energy efficient building, will often propose solutions requiring technical installations of reduced size and cost. However, he is then obliged to carry out additional actions (e.g. dynamic simulations) and he shall have to assume increased technical responsibilities and this for a lower income. This is not an evident framework. Therefore, alternative payment schemes for consultants are justified and even essential. A fixed price concept or a percentage of the total building cost may be more suitable.

9.2.5 Lack of performance oriented standards and regulations

In many countries, there is a lack of performance oriented standards and regulations. This barrier can be considered as a result of a technical barrier but also as a non-technical barrier.

- From the point of view of the developers of standards and regulations, it is not evident to develop for all issues concerning the indoor climate and energy efficiency performance oriented standards and regulations.
  Examples: appropriate procedures (sufficient reliable but also sufficiently simple) for assessing thermal comfort in summer, correct characterisation of the performances of advanced artificial lighting systems (daylight compensation, presence detection…)
- From the point of view of the need of a more efficient building stock with a better indoor climate, the fact that standards and regulations are not available is a non-technical barrier. On the one hand, there is no guidance for the decision makers. On the other hand, it makes it more difficult to impose certain performance levels.

9.2.6 Limited attention for indoor environment and energy efficiency in project specific requirements

fcAn alternative for standards and regulations is the use of project specific requirements. At present, it seems that in many countries, and surely in Belgium, there is often a lack of attention for including in the programme of requirements performance based requirements regarding indoor climate and energy efficiency of buildings.

9.2.7 Lack of clear and consistent messages towards decision makers

Convincing the decision makers is essential. As far as the indoor climate and energy use of buildings is concerned, there are often opposing or at least confusing signals towards the decision maker. Moreover, one bad application often receives much more attention than hundred successful achievements.

In countries with only a relatively small portion of non-professional builders (e.g. the Netherlands) or in countries which have already a long tradition (e.g. the Scandinavian countries as far as energy efficiency is concerned), the impact of confusing or contradictory messages is smaller than in countries with little tradition and/or with many individual builders which have a limited technical background. As an example, many Belgian decision makers have difficulties to understand that a correct thermal insulation is not in contradiction with a ventilation system in a building.

9.2.8 Lack of control and/or need for more refined control

The competition in the building sector is often very sharp. As a result, many professional building investors, building contractors… try to reduce their costs to meet just the stated needs of the client. In case of no control or a very superficial check, it is evident that there are companies which are not respecting the requirements in the building regulations or the technical prescriptions.

Other building contractors, investors or product suppliers, which may have the intention to achieve a correct performance, might be too expensive. In case of lack of control, they may be driven to quality reduction. As mentioned before, lack of quality in relation to indoor climate and energy efficiency is often not leading to visible problems (exception are condensation and mould growth problems) and legal complaints, so a supplier may consider a certain lack of quality as acceptable.

Therefore, a coherent control scheme is essential.

9.2.9 Difficulties for detecting lack of quality

For most activities in the building sector, there is by the supplier a high attention for auto-control of quality: non-quality can result in structural and/or visual problems, e.g.:

- Stability: cracks in building components…
- Painting: adhesion problems, visual quality…
- Floors: cracks in flooring materials, colouring problems, durability problems…
- Roof structures: water infiltration, wind resistance…
- Sanitary installations: water infiltration problems, odour problems…

These problems are for most customers unacceptable and will oblige the suppliers (designers and building contractors) to repair the situation and/or to cover the damages.

In relation to indoor climate and energy efficiency, this is often not the case. A major exception is condensation and mould growth problems for which there is a great awareness among most customers. However, there is little awareness for many other aspects: energy efficiency of the building envelope, airtightness of ductwork… This can be explained by several reasons:

- the difficulty in most cases to detect if there is a lack of quality (e.g. with respect to the execution of the thermal insulation, the building and duct airtightness…),
- in many cases the lack of a very clear reference context for deciding whether a certain performance is acceptable or not (e.g. overheating),
- often not well defined expectations of the customers (What is a correct energy performance level? What is an acceptable indoor climate? …),
- the large tolerance by many customers (e.g. noise from ventilation system, overheating in summer…).

10. How to specify the indoor climate needs of users?

As we have seen earlier, indoor climate performances are too often not included in the programme of requirements, as well as in the costs/benefits analysis. However, this is of first importance, as buildings which are suffering from indoor climate problems (e.g. poor indoor air quality and overheating in summertime) are clearly not desirable. Further more, it is not possible to speak of an energy efficient building if there are major indoor climate problems.

This paragraph discusses the expression of the needs with respect to the indoor climate conditions.

10.1 Thermal comfort in summer

The way these needs are expressed is very important and it may have major cost implications.

- **Strict comfort requirements**

  The comfort theory as described in e.g. NBN EN ISO 7730 is in practice often translated into rather straightforward design criteria, e.g.:

  → Maximum conditions : 26 °C and 60% relative humidity

  Such criteria can only be achieved by use of a full air-conditioning system. This leads to major investments costs as well as in most cases an important increase in the energy use.

- **Probabilistic criteria concerning thermal comfort**

  Since the beginning of the nineties, more flexible criteria have been developed, whereby the following elements play an important role:

  - The fact that energy use and investments costs are taken into consideration. Lowering of the comfort need may allow (in many cases) to avoid the use of an active cooling system and therefore an important energy reduction.

    → *This can be seen as increasing the expectations concerning the energy efficiency needs.*

  - The fact that it is considered by these decision makers that one can accept on very hot days and during a rather limited number of hours higher temperatures.

    → *This can be seen as a lowering of the expectations concerning thermal comfort needs.*

  - The fact that the available simulation programs seem to allow a rather reliable prediction of the thermal conditions.

    → *This is important: new technology (= simulation capabilities) has an important impact on the possibilities for expression of the needs.*

  As an example, the Rijksgebouwendienst (= organisation in charge of the Dutch public buildings) in the Netherlands has adopted the following criteria:

  → Indoor temperature not more than 5% of the office hours above 25 °C <u>and</u>

  → Indoor temperature not more than 1% of the office hours above 28 °C.

  Assuming 2000 office hours a year, we have:

  → Indoor temperature not more than 100 office hours above 25 °C <u>and</u>

→ Indoor temperature not more than 20 office hours above 28 °C.

In a later phase, these requirements have been expressed in equivalent PPD hours.

Another interesting, but with respect to the philosophy rather different, approach is found in Switzerland in the canton of Zurich. The use of active cooling is only allowed if one can prove by simulation that it is not possible to achieve thermal comfort without such air-conditioning.

The impact of such new criteria goes far beyond the level of thermal comfort in buildings and their energy use. Such new approaches have a major impact on the design process (e.g. the need that architects and mechanical engineers work close together) and on the market potential for certain technologies (e.g. solar control techniques, passive cooling strategies…). Therefore, they have a direct impact on the investment and operation costs of buildings.

Application on hybrid ventilation (and innovative ventilation systems in general)

For the promotion of hybrid ventilation systems, it is important to pay explicit attention to the improvement of indoor climate conditions (indoor air quality and thermal comfort). However, the use of strict comfort criteria (maximum temperature …) is not recommended since it may be a barrier instead of a stimulation.

10.2 Indoor air quality

10.2.1 General

The translation of indoor air quality needs into requirements is far from evident.

A schematic representation concerning the procedure used to express the ventilation needs is given in Figure 22.

As far as the expression of needs is concerned, the following issues are important:

- It is not possible to define optimal ventilation conditions (see NBN EN ISO 7730);
- Very large variation in practice with respect to IAQ and related air flow specifications for occupancy related pollution;
- Various approaches in standards for defining ventilation needs in relation to non-occupancy related pollution (§10.2.4);
- Expression of ventilation needs varies substantially (§10.2.5);
- Need for reliable product data on pollution sources (§0);
- Specific difficulties for characterisation of pollution sources which are related to building operation (§10.2.6)

Each of them is further explained in the next pages.

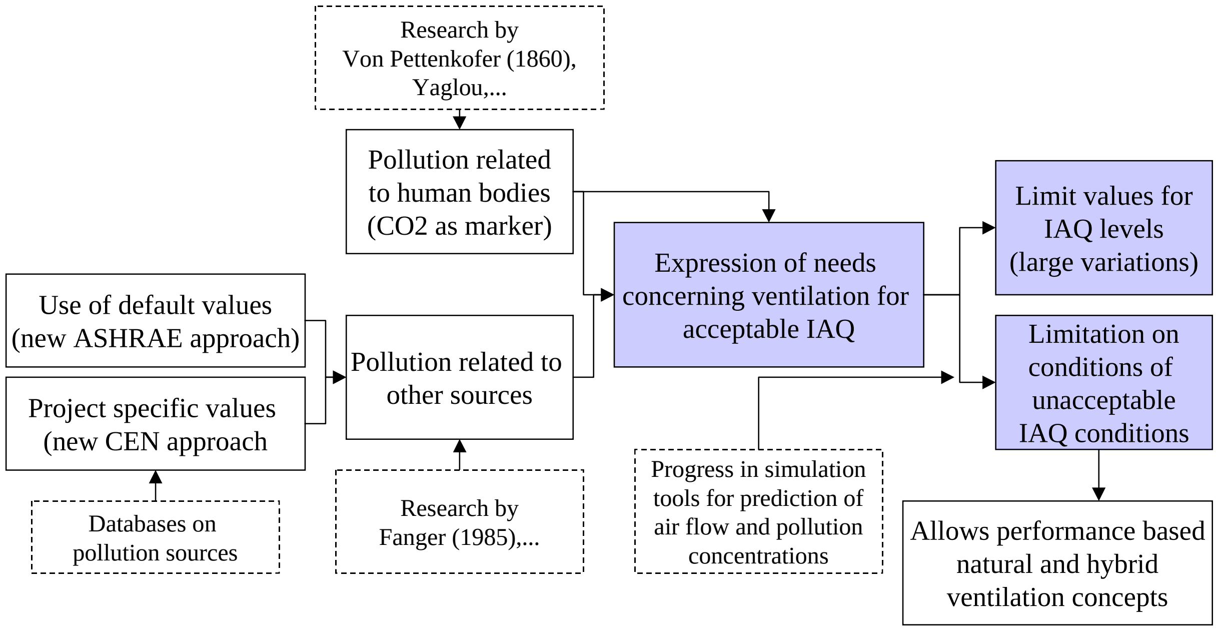


Figure 22 : Schematic representation of various approaches for expressing ventilation needs

10.2.2 It is not possible to define optimal ventilation conditions

In contrast with the thermal comfort needs, where rather clear boundaries exist with respect to the temperature level outside which the comfort is decreasing, there is not such range for IAQ. In general, the more one is ventilating with outdoor air of good quality, the better the indoor air quality becomes. This is illustrated in Figure 23.

Given the fact that an increase in air flow rate in most circumstances results in an increase in energy use, a judgement has to be made by the customer. It is evident that a variation in the ventilation requirements has major cost consequences.

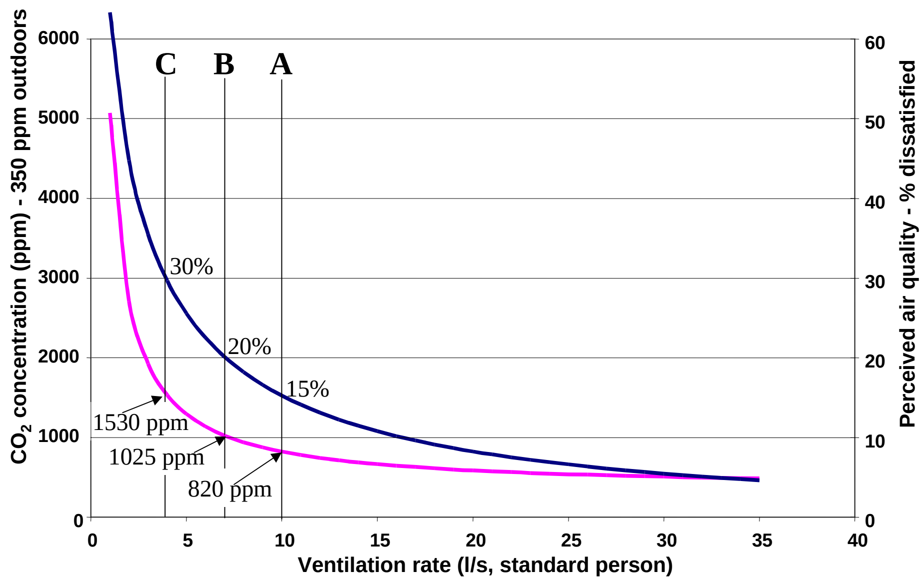


Figure 23 : Relation between air flow rate and CO_2-concentration Source: CEN (1998)

10.2.3 Very large variation in practice with respect to IAQ and related air flow specifications for occupancy related pollution

The classical approach for expressing the IAQ needs in relation to occupancy related pollution is to impose limit values on the CO_2-level.

When only considering the ventilation needs in relation to the occupants related pollution, a wide range of performance levels exist. As is illustrated in Table 6, CEN CR1752 considers three classes for indoor air quality. Even without considering ventilation needs for other pollution sources than the occupants, a difference in air flow rate of 250 % is found (4 l/s versus 10 l/s). Although such a very large difference, there have not been major discussions in CEN TC 156 ‘Ventilation in buildings’ concerning the levels adopted for the three classes.

	Perceived air quality		Required ventilation rate (l/s.olf)
Category	**% dissatisfied**	**Decipol**	
A	15	1.0	10
B	20	1.4	7
C	30	2.5	4

Table 6 : Perceived indoor air quality and required air flow rates   Source: CEN (1999)

The concept of strict limit values may eliminate the use of ventilation concepts which make use of natural ventilation. Mainly for this reason, an alternative approach has been developed, whereby it is allowed that the limit values are not met during a certain period of time.

This approach is especially relevant in relation to natural or hybrid ventilation systems. In practice, the achieved IAQ performances are quite similar to those obtained with the classical requirements but it has as major advantage that a wider range of systems can be considered and it probably allows the application of certain energy efficient concepts.

This new approach is possible due to the availability of powerful simulation tools. It can therefore be considered as an illustration that new technology allows new ways for expressing the needs.

10.2.4 Various approaches in standards for defining ventilation needs in relation to non-occupancy related pollution

At present, the dimensioning of a ventilation system according a ventilation standard is normally done based on an assumed nominal occupancy level and a certain air flow rate per person. A variation of the air flow rate is often allowed, e.g. as function of the occupancy profile, air quality related parameters (CO_2, presence detection…).

This air flow rate approach has been adopted in the PLEIADE project and is in line with the approach used in the Belgian standard NBN D50-001. However, research during the last decade indicates that occupants are in many buildings not the only pollution sources: building materials, cleaning products, HVAC installations… emit often also pollutants which reduce the indoor air quality.

If non-occupancy related pollution sources are also considered, a coherent procedure for dimensioning a ventilation system is less evident:

- Whereas there is no major problem to identify the nominal occupancy level (buildings are made for persons), it is not evident to precisely quantify the non-occupancy related pollution sources since these are not intended to be there.
- Adaptation of the air flow rate as function of the pollution load by non-occupancy related sources is not evident, since there is not yet a straightforward monitoring procedure.

In practice, two approaches are considered in proposals for new standards:

- ❑ The assumption of a default pollution load, which can be translated into e.g. a certain additional air flow rate requirement per m² of floor area. This approach is adopted in the draft proposals for the revision of ASHRAE 62.
    - → If the assumed pollution loads are high enough, this approach is appropriate with respect to the need for limiting the pollution levels. Moreover, it is for the designer an easy approach. However, it is not a good translation of the need for minimising the pollution sources. Moreover, it is not optimal in relation to the energy needs.
    - → This approach is not a strong driving force for applying low-emission materials and therefore it probably has limited cost consequences.
- ❑ A rather detailed estimation of the pollution sources and the estimation of the pollution load. This approach is used in CEN CR 1752.
    - → This approach is a good translation of the need for minimising the pollution sources and, moreover, allows an optimal combination of IAQ needs and energy needs. However, a major problem is its application in daily practice. This issue is further discussed in the next paragraphs.
    - → This approach, as far as applicable in daily practice, can be a very strong motivation for using low-emission materials. At present, there is no clear picture of the cost consequences.

10.2.5 Expression of ventilation needs varies substantially

As indicated before, there is a clear tendency in standardisation for taking into account pollution from non-occupancy related activities (building materials, HVAC systems...).

In Figure 24, requirements on air flow rates for individual offices are compared for the 3 CEN classes and for 2 situations:

- Low value : assumption of no pollution emission by the building (as assumed in many existing standards);
- High value: assumption of average pollution level as was measured in a range of European buildings over the last 5 years. The assumptions concerning the conditions are listed in Table 7. The units used are dp (decipol) and olf/m².

	Low value	High value	Comments
Outdoor air quality	0.0 dp	0.3 dp	0.3 dp is average value reported in JOULE IAQ-Office project
Building emission	0.1 olf/m²	0.3 olf/m²	
Ventilation efficiency	0.7	1.0	

Table 7 : Assumptions with respect to air quality related parameters   Source: Wouters (1996)

As shown in Table 8 and Figure 24, one observes a variation in the air flow rate requirements with a factor of about 10.

		A High	A Moderate	B High	B Moderate	C High	C Moderate
[1]	Building pollution	0.3 olf/m²	0.1 olf/m²	0.3 olf/m²	0.1 olf/m²	0.3 olf/m²	0.1 olf/m²
[2]	Nominal occupation	0.1 person/m²	0.1 person/m²	0.1 person/m²	0.1 person/m²	0.1 person/m²	0.1 person/m²
[3]	Human pollution = [2]	0.1 olf/m²	0.1 olf/m²	0.1 olf/m²	0.1 olf/m²	0.1 olf/m²	0.1 olf/m²
[4]	*Total pollution = [1]+[3]*	*0.4 olf/m²*	*0.2 olf/m²*	*0.4 olf/m²*	*0.2 olf/m²*	*0.4 olf/m²*	*0.2 olf/m²*
[5]	Perceived pollution allowed	1.0 dp	1.0 dp	1.4 dp	1.4 dp	2.5 dp	2.5 dp
[6]	Outdoor pollution	0.3 dp	0.0 dp	0.3 dp	0.0 dp	0.3 dp	0.3 dp
[7]	*Difference = [5]-[6]*	*0.7 dp*	*1.0 dp*	*1.1 dp*	*1.4 dp*	*2.2 dp*	*2.2 dp*
[8]	*Airflow if $\varepsilon_v = 1$ = 10*[4]/[7]*	*5.7 l/s.m²*	*2.0 l/s.m²*	*3.6 l/s.m²*	*1.4 l/s.m²*	*1.8 l/s.m²*	*0.8 l/s.m²*
[9]	Ventilation efficiency ε_v	0.7	1.0	0.7	1.0	0.7	1.0
[10]	***Airflow = [10] / [8]***	***8.2 l/s.m²***	***2.0 l/s.m²***	***5.2 l/s.m²***	***1.4 l/s.m²***	***2.6 l/s.m²***	***0.8 l/s.m²***

Table 8 : Variation in possible requirement levels in the context of CEN standardisation for single offices (l/s.m²)

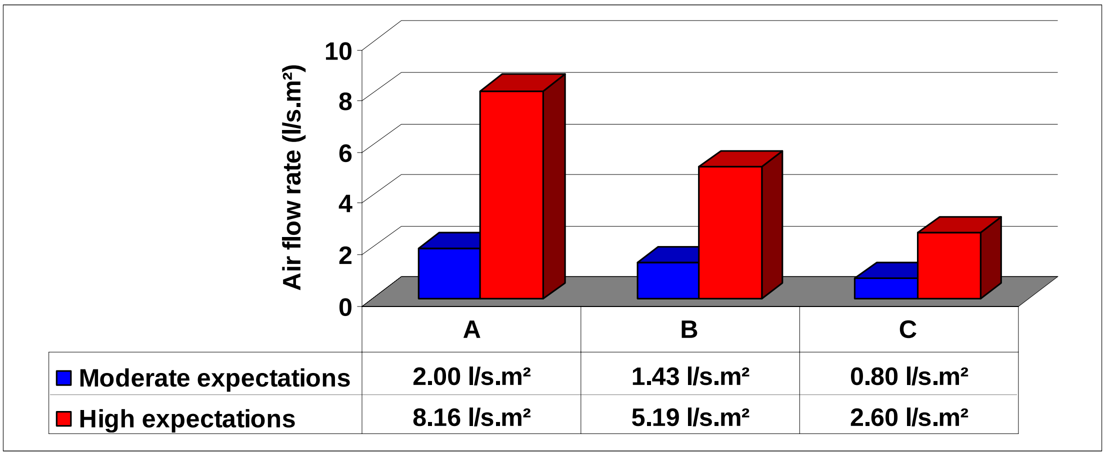


Figure 24 : Air flow rate requirements in cellular office according approach of CEN CR 1752 and for 2 boundary conditions Source: Wouters (1996)

Collection of reliable product data on pollution sources requires major efforts and investments

The application of ventilation specifications which take into account emission of buildings materials and other pollution sources is in practice only possible if sufficient and reliable product and system data are available. Indeed, it is essential but not sufficient to have a well defined procedure for expressing the needs in relation to non-occupancy related pollution sources.

There clearly is a need for reliable product data. At present, concepts for such data bases at a European level are still under development, e.g. the database SOPHIE (**SO**urces of **P**ollution for a **H**ealthy and Comfortable **I**ndoor **E**nvironment) (Bluyssen, 1999). Examples of databases which are already operational at national level are the FiSIAQ classification procedure in Finland (Seppänen, 1998) and the ICL procedure developed in Denmark (Larsen, 1999).

10.2.6 Specific difficulties for characterisation of pollution sources which are related to building operation

At the design stage of a ventilation system, one has to make assumptions concerning the status of the pollution sources in a building. For certain pollution sources, the boundary conditions may be more or less evident (e.g. for the emission of carpets at the moment of installations, the procedure developed by ECA may be relevant). However, for many other sources, this is not evident. A few examples: the impact of ageing and dirt in carpets, dirt in HVAC systems, dirty filters…). The HVAC designer has often no control about these pollution sources. Application in practice of a detailed estimation of the pollution sources seems therefore very difficult, unless clear guidelines are established.

11. References and literature review

11.1 References

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11.2 Short literature review

Here is a short review of papers dealing with relationship between the indoor environment (including indoor air quality and thermal comfort) and productivity (some of them can be found on internet). **This review is far to be exhaustive**.

Dorgan C., Kanarek M., Willman A. ***Health and productivity benefits of improved indoor air quality*** **ASHRAE Transactions 1998, vol. 104, Part 1A, p. 658-666**
In a literature survey, the authors have found that a majority of studies indicate an average productivity loss of 10% due to poor IAQ. If the standards ASHRAE 62 and ASHRAE 55 were met in every non-industrial building, the total productivity and health benefits for the US would be $62.7 billion per year, or $910 per worker and per year.

Sensharma N.P., Woods J.E., Goodwin W.J. ***Relationships between the indoor environment and productivity: a literature review*** **ASHRAE Transactions 1998, vol. 104, part 1A, pp 686-701**
One of the objectives was to identify commonly used to measure occupant performance and productivity. The authors have analysed 262 references, 53 of which were found to be relevant to their task. Techniques commonly used include absenteeism, self-reported productivity, typewriting errors, time to process a file, time to perform a task, average number of mistakes per worker per hour… The authors also identified commonly analysed factors that have an impact on the productivity. They can be grouped in four types: HVAC system performance, exposure, human response and exogenous factors. Results reported in the 53 references were found to be often divergent. This divergence may be attributed to inappropriate measure of productivity and/or inadequate identification or assessment of the factors that influence the productivity.

Fisk W.J. ***Review of health and productivity gains from better IEQ*** **Proceedings of Healthy Buildings 2000, vol. 4**
Based on the available literature and analyses of statistical and economic data, the author estimates that, for the US, the potential annual savings and productivity gains are $6 to $14 billion from reduced respiratory disease, $2 to $4 billion from reduced allergies and asthma, $10 to $30 billion from reduced sick building syndrome symptoms, and $20 to $160 billion from direct improvements in worker performance that are unrelated to health. The total benefit would be between $38 and $208 billion per year

Wargocki P., Sundell, J, Bischof, W, Brundrett, G., Fanger, P.O., Gyntelberg, F., Hanssen, S.O., Harrison, P., Pickering, A., Seppänen, O., Wouters, P. ***Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN)*** **Indoor Air, vol. 12, no. 2, pp. 113-128**
Scientific literature survey on the effects of ventilation on health, comfort, and productivity in non-industrial environments. The main conclusions are that there is a link between ventilation and productivity, that outdoor air supply rates below 25 l/s.person increase the risk of SBS symptoms, increase short-term sick leave and decrease productivity and that in buildings with AC there might be an increased risk of SBS symptoms compared with naturally or mechanically ventilated buildings.

Fisk W.J., Price P.N., Faulkner D., Sullivan D.P., Dibartolomeo D.L. ***Worker performance and ventilation: analysis of time-series data for a group of call-center workers*** **Proceedings Indoor of Air 2002 Conference, vol. 1, pp 790-795**
Field study. Analyse of the influence of the ventilation rate on the productivity of advice nurses in a call-centre. The impact was found to be nil or very small (<2%), excepted maybe for excellent IAQ (ΔCO_2 < 75 ppm).

Djukanovic R., Wargocki P., Fanger P.O. ***Cost-benefit analysis of improved air quality in an office building*** **Proceedings Indoor of Air 2002 Conference, vol. 1, pp 808-813**
Costs-benefits analysis of improvements of HVAC systems of an existing air-conditioned office building (according to energy simulations) based on the assumptions that every 10% reduction in the proportion of occupant entering a space whoa are dissatisfied with the air quality gives a 1.1% increase in productivity. According to is this study, the payback time of the HVAC first costs is lower than 4 months!

Tuomainen M., Smolander J., Palonen J., Seppänee O. ***Modeling of the cost effects of the indoor environment*** **Proceedings Indoor of Air 2002 Conference, vol. 1, pp 814-819**
This team is currently developing a model to estimate the cost-effectiveness of various measures and strategies to improve the indoor environment.

Fang L., Wyon D.P., Clausen G., Fanger P.O. ***Sick building syndrome symptoms and performance in a field laboratory study at different levels of temperature and humidity*** **Proceedings Indoor of Air 2002 Conference, vol. 3, pp 466-471**
Laboratory study. Results from this study show that decreasing the indoor air temperature and humidity significantly improved both the immediate and the adapted perception of indoor air acceptability during a 280-minute exposure, and that the impact of a decrement in the ventilation rate from 36 to 13 m³/h. person on perceived air quality could be counteracted by a decrement of temperature and humidity from 23°C/50% RH to 20°C/40% RH. This study has not shown any significant effect of temperature and humidity on performance, presumably because subjects succeeded as intended in remaining in a state of thermal comfort by adapting their clothes. However, in the real world, office workers do not succeed in remaining in thermal comfort over the range 20-26°C; therefore, it would be a mistake to conclude that temperature and humidity have no influence on the productivity.

Nilsen S.K., Blom P., Rydock J., Nersveen J., Fostervold K.I. ***An intervention study of the relationships between indoor air-related health problems, productivity and cleanliness in an office setting*** **Proceedings Indoor of Air 2002 Conference, vol. 3, pp 472-477**
Field study. Results from this study indicate that improved cleaning quality may reduce SBS symptoms, improve productivity and reduce short time sickness absence.

Damiano L., Dougan D. ***Productivity and energy conservation are NOT mutually exclusive objectives*** **Online magazine http://www.automatedbuildings.com/, April 2003**
The authors believes that only a few percent of productivity increase is sufficient to justify the increased energy, maintenance and any additional equipment or construction costs and that energy cost savings are still possible, even with increased ventilation rates, if energy conservation measure are applied.

Rio A. ***Maîtrise des conditions d'ambiance : gains de productivité et rentabilité des investissements*** **CVC (Chauffage Ventilation Conditionnement d'air), France, March/April 2003**
According to the author, the productivity of workers in industrial buildings decreases by 38% if the indoor temperature increases from 25°C to 35°C; the productivity decreases further by a few % if IAQ is poor and/or in noisy environment. According to his experience, the payback period of improvements of the indoor comfort in industrial buildings is 2 to 2.5 years.

Other references include[7] :

Menzies D., Pasztor J., Nunes F., Leduc J., Chan C.-H. ***Effect of a new ventilation system on health and well-being of office workers*** **Archives of Environmental Health, 1997, vol. 52, n°5, pp 360-367**
Examines the effect of a new, individually controlled ventilation system on employee symptoms. Two groups of employees were studied in one office building with mechanical ventilation, with one group the control. Individual control of the workspace ventilation was given to the intervention group. The new system gave higher air velocities, more variable temperatures, and higher concentration of airborne dust and fungal spores. Nevertheless, after four months, employees reported fewer symptoms. After sixteen months, employees reported increased productivity (11%) in contrast to a reduction in the control group (4%).

Wargocki P., Sundell J., Bischof W., Brundrett G., et al. ***Ventilation and health in nonindustrial indoor environments. Report from a European multidisciplinary scientific consensus meeting*** **Proceedings of the 7th REHVA World Congress and Clima 2000 Naples 2001**
Literature review. According to this literature review, ventilation is strongly associated with comfort and health, and that an association between ventilation and productivity is possible; there is evidence that increasing outdoor air supply rates in non-industrial environments improves perceived air quality; outdoor air supply rates below 90 m^3/h.person increase the risk of sick building syndrome symptoms, and lead to an increase in short-term sick leave and a decrease in productivity among occupants of office buildings ; buildings with air conditioning systems may have an increased risk of SBS symptoms compared with naturally or mechanically ventilated buildings, which implies that improper maintenance, design and functioning of air conditioning systems contributes to an increased prevalence of SBS symptoms.

Wargocki P. ***Making the case for IAQ*** **ASHRAE IAQ applications, Fall 2002, vol. 3, n°4, pp 20-21**
The article summarizes the results of three recent Danish studies showing that the improvement of air quality in offices increases productivity by 5% or more. It also mentions a recent Danish study about the annual benefit of improved air quality, which was found as being at least ten times higher than the increase in costs.

von Kempski D. ***Increasing the value of a building by addressing well being – the principal tools: thermal and olfactory comfort*** **Proceedings Indoor of Air 2002 Conference, vol. 3, pp 678-683**
Field study.

[7] Only the abstracts of those references were read by the authors.

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