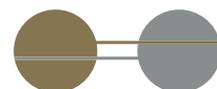


Productivity, health and energy when using natural and mixed-mode ventilation

This paper provides an overview of the scientific literature, which provides information on the association between the use of natural and mixed-mode ventilation and its effect on factors such as productivity, Sick Building Syndrome (SBS), health and indoor climate.

The literature shows that all of the independent studies around the world indicate that natural and mixed-mode

ventilation systems can contribute to some major savings, as they have a positive effect on factors such as productivity, SBS symptoms and health amongst the employees. Introducing such ventilation systems into a building would therefore have an impact on the costs of a building during its operation both energy wise and, to a greater extent, related to increased productivity gains and health cost savings for the employees.



Introduction

The various health implications associated with poor indoor air quality – from respiratory problems to infections to irritants – have been the subject of research for a long time and are well established.

Thermal comfort seems easy enough to address until one considers that individuals have drastically different temperature preferences. According to e.g. ASHRAE, thermal comfort is reached when “environmental conditions satisfy 80% of office occupants”.

Conditions affecting thermal comfort include room temperature, radiant temperature, air velocity and relative humidity, added to this, a person’s perception of thermal comfort also depends on their metabolic rate, clothing and personal preference.

It should be outlined that the user control over thermal comfort is a key factor. Where occupants are able to

adapt to their thermal environment by adjusting clothing, adjusting blinds or varying air speed across their bodies by e.g. opening windows, then wider variations in temperature can be tolerated.

Within a certain temperature range e.g. between 16 and 24 degrees C¹ there are not the same direct risks to health that poor air quality brings. Studies have shown that humans are remarkably adaptable to temperature in a way that they are not, for example to air quality². However, that does not mean that thermal comfort is not important for occupants – far from it.

Several studies suggest that moderately high temperatures are less tolerated than low³, and there is a very large body of work that demonstrates the perception of thermal comfort has a significant impact on workplace satisfaction⁴.

Focus on employees well-being is a good business

One of the more hot topics of today is the health and productivity of the employers and here the numbers clearly speak for themselves.

The World Green Building Council (GBC) published in 2015 a comprehensive report on Health, Wellbeing & Productivity in Offices.

Here it was pointed out that the staff costs, including salaries and benefits, typically account for about 90% of a business’ operating costs (Figure 1). It follows that the productivity of staff, or anything that affects their ability to be productive, should be a major concern for any organisation.

An improvement in employee health or productivity can have a huge financial implication for employers – one that is many times larger than any other financial savings associated with an efficiently designed and operated building.

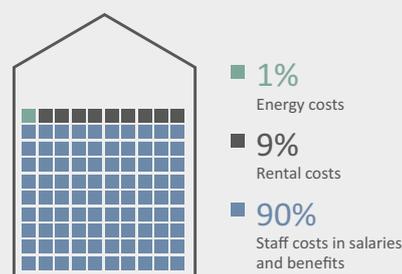


Figure 1 Typical business operating costs⁵

1. Clements-Croome DJ. (2014) Sustainable Intelligent Buildings for Better Health, Comfort and Well-Being.
2. Oh SYJ. (2005) Indoor air quality and productivity in offices in Malaysia. BSc dissertation, School of Construction Management and Engineering, University of Reading
3. Frontczak M. Schiavon S. Goins J. Arens E. Zhang H. Pawel Wargocki P. (2012) Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. Indoor Air 22, pp 119–131

4. E.g. Leaman A. and Bordass B. (2007) Are users more tolerant of ‘green’ buildings? Building Research and Information 35:6, pp 662–673.
5. Browning B. (2012) The Economics of Biophilia: Why designing with nature in mind makes sense. David Clark (2013). What Colour is your Building?: Measuring and reducing the energy and carbon footprint of buildings.



High productivity and less SBS symptoms

Several studies have been looking at the productivity gains, SBS symptoms and the health impact from natural and mixed-mode ventilation. Figure 2 illustrates the results from different studies from the last 30 years, showing an improvement ranging from the lower end of 3.2% to a massive 18.0%.

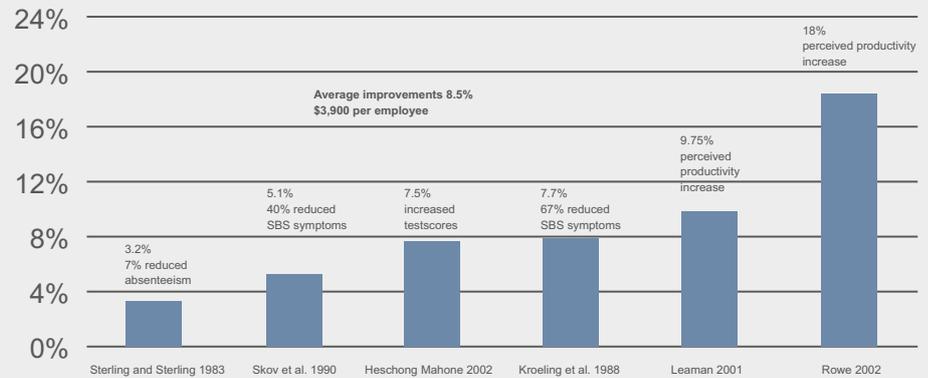


Figure 2 Annual Productivity Gains from Mixed-Mode Conditioning and Natural Ventilation⁶

Productivity and energy benefits

A comprehensive analysis in 2004 by Carnegie Mellon⁷ concluded that natural ventilation or mixed-mode conditioning could achieve 0.8 - 1.3% savings on health costs, 3 - 18% productivity gains and 47 - 79% in HVAC energy savings, for an average ROI (Return Of Investment) of at least 120%. The more in depth numbers can be found below.

Eight studies have shown that natural ventilation and mixed-mode systems can pay for themselves in less than one year due to energy and productivity benefits.

- Natural ventilation and mixed-mode systems yield;
 - annual energy cost savings of \$110 per employee
 - health cost savings of \$60 per employee
 - annual productivity gains of \$3,900 per employee
 - total savings of \$4,070 per employee annually
- The average ROI for an investment in natural ventilation or mixed-mode conditioning is 407% for new construction and 120% for retrofits.

- In the US office sector this would mean more than \$6.4 billion in energy savings each year. If only half of those buildings used natural ventilation or mixed-mode conditioning, over 40 billion kWh would be saved each year.
- Given the average productivity and health benefits of \$3,900 and \$60 per employee, respectively, the total savings achieved by providing half of the U.S. workforce with mixed-mode conditioning or natural ventilation is over \$118.9 billion annually (equivalent to 1% of the U.S. GDP in 2003).

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studies have shown that natural ventilation and mixed-mode systems can pay for themselves in less than **one year**

6. <http://cbpd.arc.cmu.edu/ebids>

7. Carnegie Mellon (2004), Guidelines for High Performance Buildings – Ventilation and Productivity



Occupant's perceptions, symptoms prevalence and perceived control opportunities

A study in 2009 by J. Toftum⁸ compared occupant perceptions, symptom prevalence, and perceived control opportunities in Danish office buildings with natural and mechanical ventilation. The survey includes responses from almost 1300 people in 15 building with mechanical ventilation and 9 with natural ventilation.

Figure 3 indicates that more occupants in buildings with natural ventilation perceived their control opportunities as being better than in buildings with mechanical ventilation, which was confirmed by a statistically test.

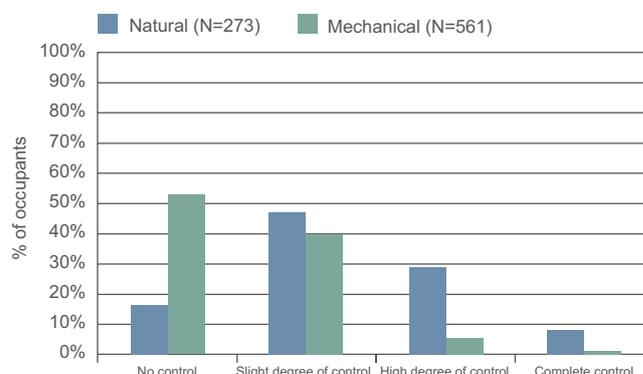


Figure 3: Distribution of occupants' perception of control opportunities in buildings with natural and with mechanical ventilation.

The same study also looked in to the prevalence of adverse perceptions and the prevalence of reported symptoms for the buildings using natural and mechanical ventilation. The results are displayed in Table 1 and 2.

Table 1 shows the distribution of the prevalence of adverse perceptions experienced in the two building categories. The table indicates that adverse perceptions generally appeared more often in buildings with mechanical ventilation.

Table 2 lists the prevalence of six of the most prevalent symptoms experienced among occupants in natural- and mechanically ventilated buildings. Four of these were general symptoms and two were specific symptoms related to the eyes and the nose. From the table, it appears that the percent of occupants experiencing a certain symptom generally was higher in buildings with mechanical ventilation.

This comparison between naturally and mechanically ventilated building shows clearly a difference in the building occupants regarding their perception of control, adverse perceptions and symptoms – all in favor of natural ventilation.

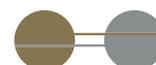
8. J. Toftum (2009), Building and Environment 45 (2010) 23–28, Central automatic control or distributed occupant control for better indoor environment quality in the future.

Perception	Natural ventilation (% voting "every day" or "every week")	Mechanical ventilation (% voting "every day" or "every week")
Temperature too high	18	30
Temperature too low	11	27
Varying temperature	13	36
Draught	16	24
Stuffy air	22	43
Dry air	20	39
Noise	25	46

Table 1: Distribution of the prevalence of adverse perceptions experienced in naturally and in mechanically ventilated buildings

Perception	Natural ventilation (% voting "at least weekly")	Mechanical ventilation (% voting "at least weekly")
Fatigue	21	30
Heavy head	18	24
Headache	11	11
Difficult to concentrate	8	15
Irritated nose	10	15
Irritated eyes	8	17

Table 2: Prevalence of symptoms experienced at least weekly among occupants in buildings with natural and with mechanical ventilation



Perception of thermal comfort and perceived control

A study⁹ was carried out in order to identify differences in the perception of thermal comfort of office workers in naturally ventilated and air-conditioned buildings. Six of the buildings are naturally ventilated, eight of them have air-conditioning systems a total 14 buildings including 4500 interviewed persons.

The analysis of the interviews shows that occupants of naturally ventilated office buildings are significantly more satisfied with their thermal environment than occupants in air-conditioned buildings.

Figure 4 shows for each of the investigated buildings the percentage of occupants who were satisfied with

indoor temperature. The mean value of satisfaction for all buildings is 61%. In air-conditioned buildings, only 50% of the occupants are satisfied whereas in naturally ventilated buildings 77% of the occupants are satisfied with indoor temperature.

Figure 5 shows the mean value of perceived control for each building. The mean value of perceived control in air-conditioned buildings is 0.32. It is significantly lower than the value for buildings with natural ventilation (0.87).

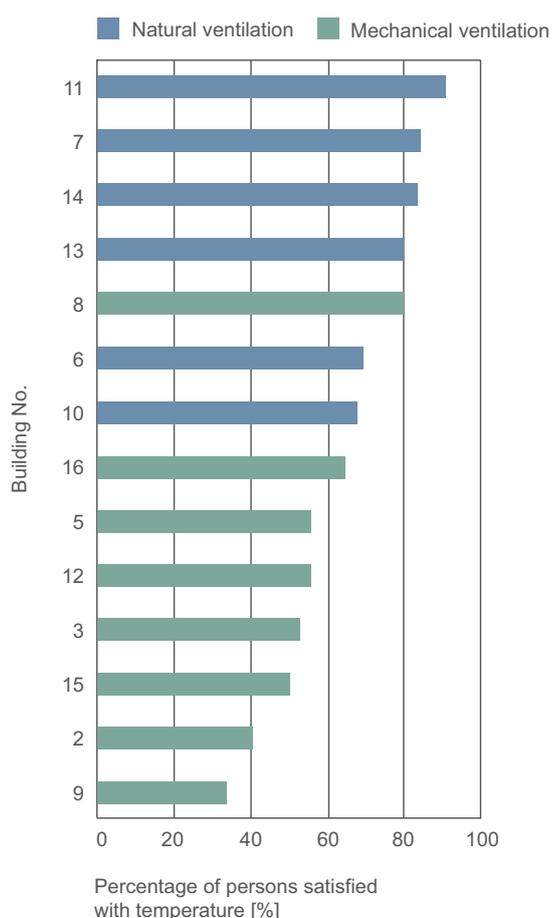


Figure 4 Percentage of persons satisfied with indoor temperature for each building (n = 4400).

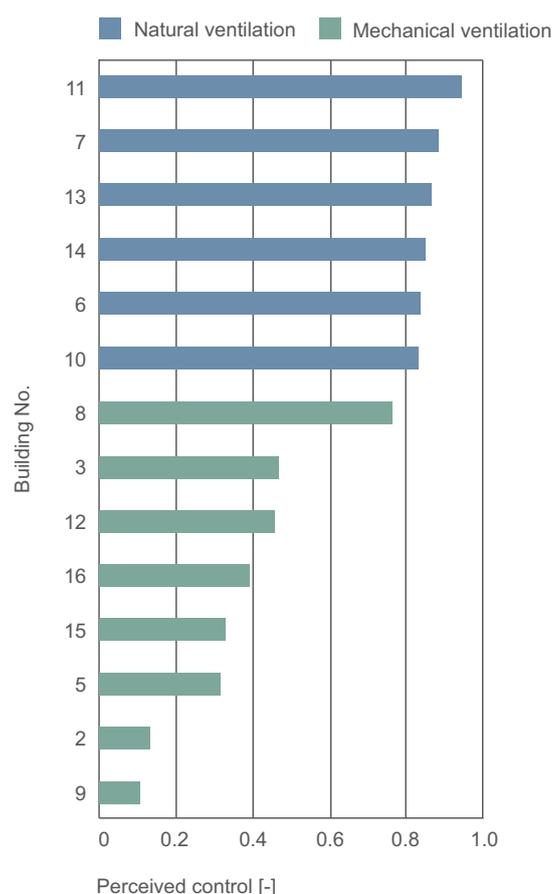
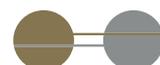


Figure 5 Mean value of perceived control for each of the investigated buildings (n = 4492).

9. R.T. Hellwig, S. Brasche, W. Bischof, Thermal Comfort in Offices – Natural Ventilation vs. Air Conditioning, Healthy Buildings 2006



Prevalence in symptoms in schools

Doctor Harald W. Meyer et al.¹⁰ conducted a study on the symptoms of poor indoor climate, for example irritation of the eyes, headaches, fatigue and concentration problems in dependence of mould and ventilation type on boys in 8th and 9th grade.

The study clearly shows that the boys have more symptoms in rooms with mechanical ventilation than in rooms with natural ventilation.

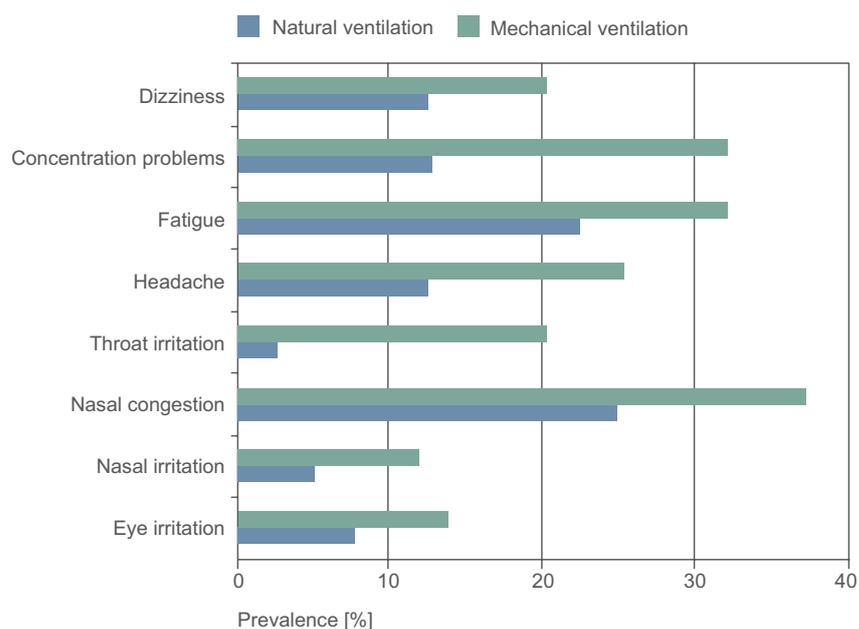


Figure 6: Prevalence in symptoms in the schools depending on the type of ventilation

Summary

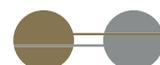
This paper provides an overview of the scientific literature, which provides information on the association between the use of natural and mixed-mode ventilation and its effect on factors such as productivity, SBS symptoms, health and indoor climate.

Independent studies around the world indicate that natural and mixed-mode ventilation can contribute to some major savings and hereby a positive effect on all the mentioned factors. A short summary in bullets gives a clear overview.

- Based on increased productivity gains and health costs savings for the employees and additional energy savings, the total annual savings of \$4,070 per employee can be achieved for an office building utilizing the benefits of natural and mixed-mode ventilation. The total savings achieved by providing half of the U.S. workforce with natural or mixed-mode ventilation is more than \$110 billion annually (equivalent to 1% of the U.S. GDP in 2003).

- The average return on investment for an investment in a natural ventilation or mixed-mode conditioning system is 407% for new construction. Meaning that these system can pay for themselves in less than one year due to energy and productivity benefits.
- Utilizing natural or mixed-mode ventilation can decrease the SBS symptoms by more than 65% and reduce the absenteeism leading to more satisfied employees with an increased productivity.

¹⁰ Meyer HW, Würtz H, Suadicani P, Sigsgaard T, Nielsen PA, Gyntelberg F and the Danish Moulds in Buildings-group. Are high levels of moulds in dust a greater problem in mechanically ventilated rooms? Proceedings of the 11th International Conference on Indoor Air Quality and Climate 2008, Copenhagen, Denmark, 17-22 August 2008.



WindowMaster aspires to protect people and the environment by creating a healthy and safe indoor climate, automatically ventilating spaces with fresh air through facade and roof windows in buildings. We offer the construction industry foresighted, flexible and intelligent window actuators and control systems for natural ventilation, mixed-mode ventilation, and smoke ventilation – of the highest quality.

WindowMaster employs around 150 highly experienced cleantech specialists in Denmark, Norway, Germany, United Kingdom, Ireland, Switzerland, and the United States of America. In addition, we work with a vast network of certified partners. With our extensive expertise built up since 1990, WindowMaster is ready to help the construction industry meet its green obligations and achieve their architectural and technical ambitions.

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