Healthy Building Services for the 21st Century

Healthy Building Services for the 21st Century

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
Rector Magnificus, prof.dr.ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties in het openbaar te verdedigen
op maandag 23 maart 2009 om 16.00 uur

door

Francesco Franchimon

geboren te Voorburg

Dit proefschrift is goedgekeurd door de promotoren:

prof.dr. J.E.M.H. van Bronswijk
en
prof.dr. D.G. Bouwhuis

ISBN:	978-90-386-1542-4
Cover design:	Zwaar Water, Amsterdam
Illustration cover:	Beeldleveranciers, Amsterdam
Printed by:	Greve Offset BV, Eindhoven

The study presented in this dissertation was performed at the group Public Health Engineering for the Built Environments, Department of Architecture Building and Planning, Eindhoven University of Technology, the Netherlands.

This study was funded by the PIT, a society that aims to encourage technical, economic and scientific innovation for the Dutch Building Services Industry.

Your money or your life!

ing. W.A.M. Kuypers
September 16, 2008

Building Services as Medicine

prof. dr. J.E.M.H. van Bronswijk
September 16, 2008

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CHAPTER 1: GENERAL INTRODUCTION

Building services can be described as 'everything inside a building which makes it safe and comfortable to be in'. This is the description provided by the CIBSE (Chartered Institution of Building Services Engineers), a UK professional society. This society was established in 1976 as a fusion of the Institution of Heating and Ventilating Engineers (founded in 1897) and the Illuminating Engineering Society (founded 1909). According to CIBSE, building services engineering covers (i) energy supply (gas, electricity and renewable sources), (ii) heating and air conditioning, (iii) water, drainage and plumbing, (iv) natural and artificial lighting, and building façades, (v) escalators and lifts, (vi) refrigeration, (vii) communication lines, telephones and IT networks, (viii) security and alarm systems, and (iix) fire detection and protection. An interesting statement they make is that 'a building must do what it was designed to do - not just provide shelter, but also be an environment where people can live, work and achieve' (CIBSE 2008). Croome (1990) described the basics of building services and the innovations of the last few decades and contends that building services engineering is a totality that needs to be understood in order to support well-being.

Although the different UK building services were brought together in 1976, building services engineering dates back to inventions aimed at improving public health as devised by the ancient Greeks (2nd millennium BC). The first flush toilets and sewer systems were installed in the Minoan palace of Knossos, a village on the island of Crete, Greece (Angelakis et al. 2005). In ancient Rome, additional building services were invented, including aqueducts and central heating (Bono & Boni 1996; Fagan 1996). Building services had become an instrument for health improvement. In fact, during the 20th century, building services and nutrition were instrumental in the drastic reduction of infant and childhood mortality (Williams 1992; Wolleswinkel-van den Bosch et al. 2001).

Currently, building services may be utilised to reduce the risk of infectious diseases, to prevent chronic disease and to support autonomy. In other words, building services currently have the ability to contribute to complete health, but their emphasis has shifted over time (Figure 1.1). The World Health Organization (WHO 1946) dealt with all aspects in their health definition: 'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'.

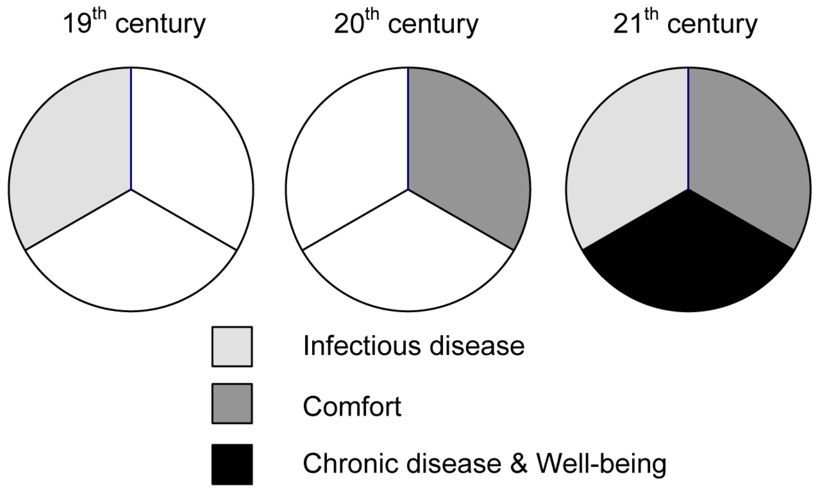

Figure 1.1: The shift in attention to the three health aims of building services that constitute complete health

1.1 The infections

In the relation between infection control and installed building services, the aim of building services shifted from health towards comfort. New and old pathogens that have emerged over the past few decades show the need for updated codes and standards that not only consider comfort, but also reduce the risk of infection.

1.1.1 Water and health

The crowded communities that resulted from the 19th century urbanisation in developed countries turned living spaces into highly polluted environments that required better infection control. Initially sewer systems were only aimed at preventing flooding and carrying storm water, but later they also became sewage systems for the disposal of faeces and other liquid waste (Cutler & Miller 2005).

Natural water from resources such as rivers and lakes had a twofold use: (i) as drinking water, and (ii) to wash away waste water. In crowded areas, the self-cleaning capacity of natural water proved insufficient (Schertenleib 2005). Consequently, centralised systems of potable water became associated with a number of epidemics of infectious disease (McGuire 2006). In 1854, about 500 deaths in 10 days were reported from London, all caused by cholera (Brody et al. 2000). The cholera bacteria were spread by centralized water systems. In the Netherlands in 1864-1866, 1% of the population (20,000 persons) died of the same disease (Weelen van & Mingelen 1868). Other European countries and the USA suffered from comparable epidemics (Kaper et al. 1995).

Soon, municipalities that used river water discovered that the disease risk decreased when the distance increased between the potable water inlet and the waste water outlet (Dawson & Sartory 2000). This had also been suggested by dr. John Snow (1813-1858), a physician, who had discovered the causative bacterium of cholera that was transmitted by drinking water (Brody et al. 2000).

Another result of centralized drinking systems was the spread of typhoid fever. Between 1860 and 1989 the death rate for 47 American cities was on the average 58 per 100,000 citizens (McGuire 2006). McQuire studied the revolutions in the history of US drinking water disinfection. The first permanent disinfection with chlorine appeared in Belgium in 1902 and later in 1908 chemical disinfection became common in the US. In 1914 limits were set for coliforms bacteria in potable water. It was recognized that filtering and disinfecting the water at the source was not sufficient to prevent transmission of pathogenic bacteria. Cleaning pipes in the distribution system became more common around 1930s. Much later, in 1974, scientists discovered the adverse effect of chlorination. The chlorination of natural organic matter produced trihalometanes, a harmful by-product. Experiments with ammonia-chlorine and ozone, at that time a typical disinfectant in Europe, resulted in a change of disinfection strategies. Secondary disinfection was therefore introduced to control the trihalometanes concentrations. In the 80s the concept of CT was adopted, a product of the concentration (C) of disinfectant and the time (T) of exposure. This concept became part of guidelines and standards.

Also in Europe disinfection became compulsory. After the 1937 outbreak of typhoid fever, chlorination of potable water became compulsory in the UK (Dawson & Sartory 2000). In the Netherlands chlorination was banned out. Kooij et al. (1999) reported that the Dutch water supplies relied on (i) good engineering practices to prevent recontamination, (ii) use of biostable materials in the distribution system, and (iii) monitoring of biostability through assessment of biofilm formation.

When the heating of entire homes and other buildings became generally accepted, a new infectious agent became prominent, *Legionella*, which causes Legionnaires' disease and Pontiac fever. These bacteria thrive at room temperature until about 60°C in both cold and hot water pipelines. People become infected by inhaling water droplets, particularly when showering. Outdoors, cooling towers represents another risk factor (Straus et al. 1996).

Legionella is sensitive to chlorine (Kool et al. 1999). Therefore, chlorination of the water supply is an effective technical means to prevent infection. In some countries, however, notably the Netherlands, the *Legionella* risk is not considered high enough and the chlorination of potable water has been

discouraged to improve the taste of drinking water and to reduce adverse effects on the environment (Gezondheidsraad 1986; Gezondheidsraad 2003). Even local epidemics such as in Bovenkarspel, a place in the north-west of the Netherlands, which left dozens dead and hundreds diseased (Boer et al. 2002), did not change chlorination policy in the Netherlands. The only change brought about by this outbreak was a risk analysis and management plan to prevent outbreaks in non-residential buildings which became compulsory (Pronk 2000). This policy has been evaluated and no evidence was found that the policy reduced the number of contaminated buildings and reported pneumonia cases caused by *Legionella* (Versteegh et al. 2007).
In our study we assessed the additional risks of modern heating systems and propose an innovative building services solution to the *Legionella* problem (Chapter 2).

1.1.2 Air and health

In 1842, the first air conditioner was installed to reduce infectious airborne disease. According to dr. John Gorrie (1802-1855), physician, scientist, inventor and humanitarian from Florida, cold air would reduce the incidence of malaria and yellow fever. At that time the relation between blood sucking insects and these diseases was not yet recognized. However, blowing cold air over ice buckets before introducing this air into sick rooms had the effect of preventing the entrance of these vectors of disease. Cooling was also applied in hospitals to prevent infections (Gladstone 1998).

The awareness of the need for ventilation requirements began earlier. In the 17th century, John Mayow (1640-1679) performed a study with animals in a confined bottle with and without a candle. An animal survived about half as long without candles. He believed that the ‘igneo-aerials’ (presumably carbon dioxide) produced by the candle was the cause of the animals’ demise. One hundred years later, French chemist Antoine Laurent Lavoisier (1743–1794) identified carbon dioxide also as cause for sensation of stuffiness and ‘bad’ air, in the study of Mayow ‘igneo-aerials’ (Janssen 1999).

Thomas Tredgold (1788-1829), an English engineer was the first who calculated the minimum ventilation requirement for mine workers. He calculated the air needed to purge the lungs from carbon dioxide, moisture, and pollutants from the miner’s candle. This resulted in a ventilation rate of 2.0 l/s. However, he ignored the amount of carbon dioxide and moisture people exhaled (Janssen, 1999).

In 1858, Max Joseph von Pettenkofer (1818-1901), a Bavarian chemist and hygienist, proposed 1000 ppm CO_2 as threshold limit to prevent ‘bad’ air. Carbon dioxide was considered a marker for volatile organic material released by humans and open fire (Pettenkofer 1858). In 1884, John Shaw

Billings (1838-1913), a librarian and surgeon, calculated a required rate of 23.5 l/s per occupant to keep carbon dioxide levels in indoor environments at 550 ppm assuming an exhaled air concentration of 200 ppm. The outdoor concentration was about 290 ppm at that time (Keeling & Stuiver 1978). Others believed 4.7 l/s was sufficient. Billings argued therefore a minimum of 14 l/s, but recommended 28 l/s. He considered not merely physiological needs based on carbon dioxide levels, but also the spread of diseases such as Tuberculosis. Shortly after the ASHVE (American Society of Heating and Ventilating Engineers, currently ASHRAE) adopted the ideas of hygienists and physiologists, they recommended an amount of 14 l/s fresh air (Janssen 1999).

1.1.3 Air and comfort

In Amsterdam, Hermans started studying the thermal effects of ventilation in 1893. He believed that bad indoor air was caused by thermal effects. Furthermore, the excessive ventilation resulted in draughts and should be avoided according to Hermans (1893). With regard to olfactory comfort, C.P. Yaglou showed in 1936 that ventilation rates could be lowered without affecting the smell of the air. This resulted in a shift from aiming at good health levels to aiming at comfort levels when designing ventilation systems. The minimum ventilation rate was reduced from 14 to 4.7 l/s (Janssen 1999) (Figure 1.2).

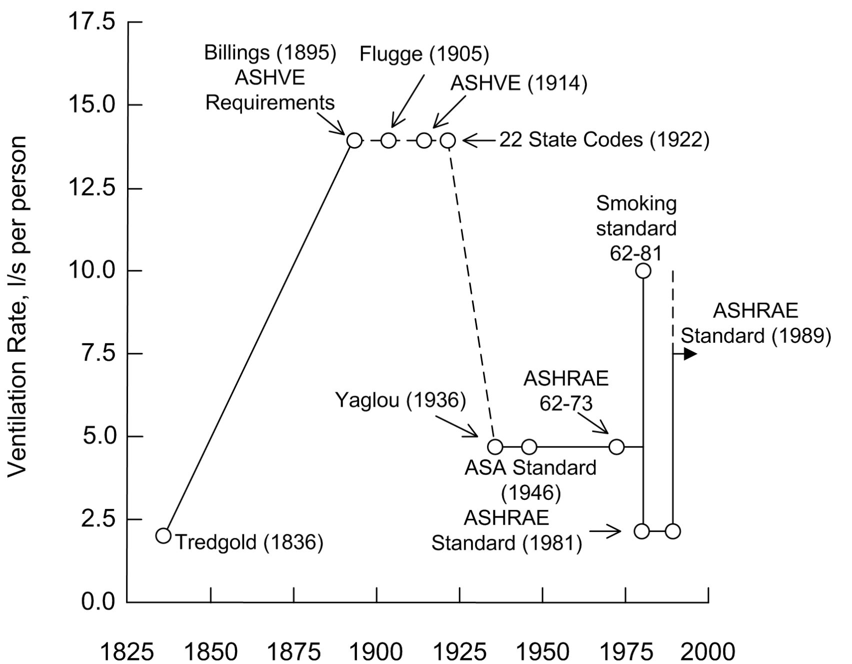

Figure 1.2: Minimum ventilation rate history (adapted from Janssen 1999)

After tobacco smoking indoors became widespread, the point was raised whether ventilation should be increased to remove the smell of smoke. In the ASHRAE standard 62-81 this increased ventilation for tobacco smoke polluting indoor spaces was not accepted by the tobacco industry and the Formaldehyde Institute. The way tobacco smoke and formaldehyde was treated in this standard, caused a conflict. Therefore, a renewed standard was developed in 1989. The findings of Fanger & Berg-Munch (1983) as well as those of Cain et al. (1983) were adopted in this new standard. Both studies were based on the dilution of pollutions to prevent odors. The minimum ventilation rate was set at 7.5 l/s per person (Janssen 1999). Although the minimum has been increased from 4.7 to 7.5 l/s per person, it still did not reach the 'health level' advised during the preceding century. European ventilation standards for residential and non-residential buildings nowadays calculate the ventilation rate considering olfactory demands, occupant density, type of indoor pollution, etc. (NEN EN 2007; CEN-TR 2006). However, these standards have not been incorporated into the Dutch national building code.

The shift from health to comfort in ventilation standards had implications for infectious diseases. The reduced ventilation rates had an adverse effect on outbreaks of Measles and Tuberculosis. Environmental measures, such as increased ventilation and UV irradiation to prevent disease, had been known since the early 1970s (Riley 1972). Riley found that UV irradiation in hospitals was successful. Recirculation of air had stimulated the spread of microorganisms. In contrast, supplying 'fresh' (outdoor) air reduced the probability of infection (Riley et al. 1957). Unfortunately, outbreaks of these diseases did not result in an increase of the prescribed ventilation rates and those infectious diseases are still present in developed countries. Recently two Measles clusters occurred in the Netherlands and both were associated with air travel. The outbreaks will most likely continue due to the low vaccination in religious confined groups and the reduced confidence in the vaccine related to alleged side effects (Binnendijk et al. 2008). Also outbreaks of Tuberculosis are still present in developed countries. Immigrants from high-prevalent countries (Borgdorff et al. 1998) and the extra risk for HIV-patients (Valadas & Antunes 2005) are in the last decade's new factors that increase the number of Tuberculosis outbreaks.

Also new infectious diseases have emerged: the Corona virus which causes SARS (Booth et al. 2005) and pandemic of avian influenza (WHO 2007); in 2003 the SARS epidemic was moving around the globe. Between November 2002 and April 2003 8,096 cases were identified in 19 different countries (WHO 2004). Li et al. (2004) studied the infection spread in a hospital in Hong Kong. They found evidence the SARS virus was transmitted by air. The sewer system appeared another transmission mode of the SARS virus (Swaffield & Jack 2004). Ventilation again appeared to play an important role in the transmission.

The lessons learnt from SARS, Tuberculosis and Measles epidemics are useful in managing an expected avian influenza pandemic. Indoor air science has recognized the airborne spread of avian influenza (Li et al. 2007). The expected pandemic is a global threat (WHO 2007). The WHO (2007) expects 7.4 million deaths globally, 233 million outpatient visits, and 5.2 million hospital admissions in developed countries alone (WHO 2005).

Another threat is manmade and related to bioterrorism. In 2001 the Anthrax attack in a US postal office with contaminated letters resulted in 5 deaths but had the potential to kill more than 500,000 individuals (Shannon 2004). It is believed that airborne transmission of Anthrax in buildings can cause new infections (Fennelly et al. 2004).

1.1.4 Infection research

This dissertation investigates the effect building services may have in our defence against biological warfare agents used by terrorists, the threat of a bird flu epidemic, and the additional risks of *Legionella* colonisation via modern heating systems and methods to mitigate risk (Chapter 2).

1.2 Chronic disease

Most infectious diseases are acute phenomena; they come and go quickly. Chronic diseases, however, are diseases of long duration and generally slow progression. Chronic diseases, such as heart disease, strokes, cancer, chronic respiratory diseases and diabetes, not only have high mortality rate, but are also very expensive in an ageing society with an increasing number of affected people (Parker & Thorslund 2007).

Building services as suppliers of air strongly influence a number of these chronic conditions, notably asthma, COPD, lung cancer and heart disease. Another result of poorly ventilated buildings is the so-called Sick Building Syndrome (SBS).

1.2.1 Asthma, COPD & SBS

One of the changes that happened in the 20th century concerns the oil-related energy problems that started in 1973. The periodic crises forced us to save energy. One of the main measures became the increase in air-tightness and thermal insulation of buildings to decrease the loss of heat in winter and cool air in summer (Hens 2007). Insulation is a measure that has a beneficial effect on human health. Higher surface temperatures of walls avoid the growth of fungi and mites (Koren 1995). The increased air-tightness of buildings results in the introduction of lower amounts of fresh air, since fresh air is supplied by both ventilation and infiltration. The reduction in infiltration left the supply of fresh air completely dependent on the ventilation rate. Unfortunately, the prescribed ventilation rate was not upgraded to compensate for the reduced infiltration.

In the Netherlands, the minimum ventilation rate was under debate in the 1980s, but the National Health Council believed that a ventilation rate of 7.0 l/s established for the prevention of odours was sufficient. Pollution sources were supposedly controlled by standards set for emissions from building and surface materials. The odourless pollution by humans was ignored and the decreased infiltration rate did not result in higher ventilation rates (Gezondheidsraad 1984).

The results of these efforts are well known. Decreased ventilation led to an increase in relative indoor humidity. House dust mites flourished as did the amounts of allergens they produced. Within a few decades the prevalence of house dust mite allergen sensitisation in atopic patients increased to 80% in both the UK and the Netherlands (Bronswijk & Pauli 1996).

Not only have allergen levels in dwellings increased due to the reduction of air exchange, but so have levels of other pollutants derived from humans, pets, hobbies, cooking, etc. This extra pollution has a detrimental effect on the health of persons with COPD, Chronic Obstructive Pulmonary Disease. This effect can partly be reversed by measures to enhance air quality (Snijders 2001).

In the 1980s, Sick Building Syndrome (SBS) became the object of numerous studies. The term pertains to office buildings in which the occupants felt increasingly sick during the working week and then (partially) recovered at the weekend (Bronswijk 1991). The complaints of the occupants may be explained by the limited amount of fresh air supplied to the indoor office environments at the time. This hypothesis is partly supported by findings by Wargocki et al. (2000). In their study, increasing the ventilation rate from 3 to 30 l/s per person resulted in a lower number of some SBS symptoms; throat dryness (27%) and mouth dryness (37%). The hygiene of ventilation systems is another factor that contributes to SBS symptoms (Seppänen & Fisk 2004). Also Seppänen & Fisk suggested a ventilation rate of 20-25 l/s to decrease the prevalence of SBS symptoms in offices.

1.2.2 Lung cancer and coronary heart disease

Although heredity is a contributing factor in both lung cancer and coronary heart disease, exposure to noxious airborne agents is considered as a culprit.

Global smoking resulted in 3 million deaths in 1990 and is expected to cause 8.4 million deaths by 2020 (Murray & Lopez 1997). Since industrial exposures are usually controlled by the Occupational Health and Safety Legislature, domestic exposure to tobacco smoke and (other) particulate matter indoors and outdoors, remain the main contributing factors (Viegi et al. 2004). The amount of extra ventilation needed to remove smoke pollution from residences exceeds normal ventilation standards by at least 500% while persons are smoking, but these measures are not considered practical for energy conservation reasons (Sistad & Bronsema 2002).

Measures against particulate matter from vehicular traffic are still under consideration. With regard to cancer, Abou Chakra et al. (2007) revealed that the genotoxicity effect was stronger for $PM_{2.5}$ than PM_{10}. Chen et al. (2005) showed an increased relative risk for $PM_{10}/PM_{2.5}$ on coronary heart disease among females in the USA. It is known that traffic-related particulate matter also penetrates into buildings through ventilation systems (Hänninen et al. 2005).

Since the technical measures against asthma, COPD and lung cancer are already known, we restricted ourselves in this dissertation to calculating the economic feasibility of implementing this knowledge in building services (Chapter 3). Only when it comes to particulate matter from traffic is the most important penetration mode unclear. We therefore studied the penetration mode of traffic-related particulate matter in a Dutch office (Chapter 3).

1.2.3 Intoxication

Potable water can not only spread infectious diseases, but may also lead to intoxication. From Roman times onwards, lead was used for piping. Lead can cause irreversible neurological changes as well as renal disease, cardiovascular effects and reproductive problems. Water pipes in homes built before 1930 were usually made of lead. It took until the 2nd World War for copper or plastic piping to start replacing lead pipes. In 1998, the EU has introduced legislation concerning lead concentration levels in potable water. Fifteen years after this directive the maximum permissible lead concentration is 10 μg/l water (Prammer 1998). In the Netherlands in 2004 2.4% of 7,300 samples taken from faucets in homes exceeds the concentration of 10 μg/l water (median=0.5 μg/l, 5-percentile=0.5μg/l, 95-precentile 2.4μg/l) (Slaats et al. 2008).

1.3 Well-being

In contrast to the hygienic limits for humans with regard to indoor air and potable water, home appliances were originally not developed for complete health but to support well-being and to enhance comfort. The radio, for instance, provided social cohesion in families, the washing machine supported housewives and the telephone increased communication at a distance (Schot et al. 1998).

Home automation appliances continued this trend in the 1980s, providing even more comfort. This included automatic curtain control and access (video) control, all supplied by electrical suppliers (Franchimon et al. 2005).

Assistive technology also eventually became included in home automation and this technology slowly shifted its aim from comfort to more complete health. The additions consisted of different types of alarms with follow-up services (burglary, fire, falling and personal injury), advanced communication channels (scheduled, regular video communication with a care centre; alarm connections with next of kin; easy internet to play bridge with distant friends, etc.), as well as additional telehealth and telecare services (Šoštarič et al. 2003; Bellazzi et al. 2001). Currently, these technologies are recognised as fulfilling a number of needs for an ageing society, such as decreasing the workload of health care professionals. However, the services seem to function from a care professional point of view, not as a development that originated from the actual perceived needs of ageing individuals. Bouwhuis (2006) made a statement in his editorial that the focus of technology should be directed towards leisure instead of care (see Chapter 4 for our research on this subject).

1.4 Towards the 21st century

In this dissertation, we start from the notion that the ageing society calls for a shift in design from comfort back to complete health. We therefore structure the ‘building services’ discipline by public health function and not by the hardware used in its construction. Seen from the viewpoint of public health, building services may function in three different ways: (i) infection control (***Chapter 2***), (ii) preventing chronic conditions (***Chapter 3***) and (iii) support of well-being (***Chapter 4***). Examples, from each of these three fields will be studied in this dissertation to assess the technical and economic feasibility of increasing health in the 21st century. This will be discussed in more detail and summarised in ***Chapter 5*** in order to answer the question 'How can building services most effectively support human health in the 21st century?'.

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CHAPTER 2: INFECTION CONTROL

From a historical perspective we know that good building services reduced the incidence of infectious diseases such as cholera, typhoid fever, diarrhoea and yellow fever. With regard to infection control and building services, we chose examples related to water (*Legionella*) and air (anthrax and avian influenza).

In case of *Legionella* we studied the effect of district heating and floor heating on the increased risk of *Legionella* infection (Section 2.1), as well as the costs and benefits of chlorination as a new building service (Section 2.2). When it came to air-treatment, we modelled the effect of indoor environmental measures against the spread of avian influenza (Section 2.3) and proposed a control method for HVAC systems against bioterrorism (such as anthrax attacks) (Section 2.4).

Section 2.1[1]:

Increased *Legionella* risk due to modern heating systems

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Johanna E.M.H. van Bronswijk PhD

ABSTRACT. Modern heating systems (district heating and floor heating) increase the temperature in cold water systems and hence the growth of *Legionella*, the cause of Legionnaires' disease and Pontiac fever. We studied district heating and floor heating with actual measurements and computer simulations respectively. The aim was to assess the extra risk for *Legionella* growth in cold water systems. In both cases, the temperature of the cold water supply exceeds the 25°C limit most of the time, especially in homes occupied by the elderly, the group most susceptible to Legionnaires' disease. It is clear that chlorination or a different design of building services will be needed to reduce the risks associated with modern heating systems.

Keywords: district heating, floor heating, *Legionella* growth, homes

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[1] Submitted to *Building Services Engineering Research & Technology.*

2.1.1 Introduction

Legionella spp. is the causative organism for Legionnaires' disease and Pontiac fever (Fields et al. 2002). In the last decade district heating and floor heating are becoming more popular in newly built housing projects. District heating is a measure to save energy. District heating is an energy efficient link between waste heat from a number of sources. These could include industrial processes, electricity generation, waste incineration or renewable or sustainable energy sources. Waste heat from these processes are used to heat water, which is then transported through a pipeline system to buildings where it is used for space heating or cooling and to heat domestic hot water (IEA 2008). In 2007 approximately 280,000 Dutch households were equipped with district heating (Algemene Rekenkamer, 2007); 4% of the Dutch Housing Stock.
Where district heating is a measure to save energy, floor heating has two advantages: saving energy and improving thermal comfort (Isakssona & Karlsson 2006). Do these heating systems imply new risks with regard to *Legionella* colonisation in potable water systems in homes?

Legionella colonisations are mostly reported in cooling towers, in hot water storage tanks, in whirlpools (Shelton et al. 2000) but also on rubber components in potable water systems (Colbourne et al. 1984). Many studies were conducted in hospitals and hotels (Wright 1985). A few studies reported *Legionella* colonisation in residential potable water systems. Pedro-Botet et al. (2002) compared four studies in which *Legionella* colonisation in homes was found. The percentage of homes colonised potable water systems with *Legionella pneumophila* ranged from 6.4 to 32.7%. One study was conducted in Germany/Netherlands/Austria and reported 8% colonised homes. The same study reported also ten studies with in total 13 anecdotic cases of *Legionella* infection acquired in their home. These studies focused on hot potable water and reported the association with electrical heaters (resulting in lower temperatures). A recent study showed that more than 50% of the homes with district heating are *Legionella* contaminated, compared to 5.5 % with conventional hot water systems. Again the major cause was the lower hot water temperatures of the district heating (Mathys et al. 2008).

As to potable cold water systems, modern heating systems may also pose a new threat to health.
In case of district heating, the heat exchanger is installed in the meter cupboard where the potable water supply also enters the home. Recently Van Wolferen (2008) has conducted a study of temperatures in 23 meter cupboards. In 14 out of 23 meter cupboards the temperature exceeded 25°C incidentally.

As to floor heating, a laboratory simulation of floor heating caused accidental heating of the cold water pipeline in the same concrete floor, resulting in an increased risk of *Legionella* growth (Wolferen & Arendsen 2007).

The accidental heating of the potable cold water systems is a building services problem that has to be solved. In order to arrive at a better understanding of the risks, we measured and simulated the extent of the additional *Legionella* growth risk in homes with district or floor heating.

2.1.2 Methodology

The first modern heating system under study is district heating. Temperature measurements were taken in 3 homes with district heating located in the Rivierenwijk, a neighbourhood in the town of Utrecht, the Netherlands in January and February 2007: 2 family homes, occupied by 2 retired adults (Home 1) and 2 adults with 2 children (Home 2) respectively, and 1 apartment occupied by two retired adults (Home 3). All homes were two story buildings. Only the water distributed to the second story was considered in this study. The second story was selected since the rise pipe (going to the second story) is exposed to the temperature in the meter cupboard longer.

District heating

Water temperature was measured on the outside of the copper piping with a Grant EUS thermocouple class UU at the water meter (cold water side) and 2.2 m above the floor along the cold water piping, with a sampling time of 1 minute. The thermocouples were heat insulated from the surrounding air. In addition, the air temperature was measured in both places using a Grant CT thermocouple class UU at the same sampling time. Each measurement series took 7 days. Wireless transmitters sent recorded values to a wireless data logger (Grant Gen Eltek II series) with Eltek Darca plus software.

The tap usage of the occupants was determined by searching the data for temperature drops in the potable water system of more than 0.5°C in 1 minute. The end of each tap usage was determined as the point at which the water temperature rose 0.3°C through the district heating system in 1 minute. The time period required for a complete heating up of potable water systems after tap use was analysed during the last tap uses of the day.

Floor heating

The second type of a modern heating system is floor heating. A floor heating simulation was performed on a 5-layer concrete floor (Figure 2.1.1). We used Comsol multiphysics release 3.4. This simulation software is based on finite element method.

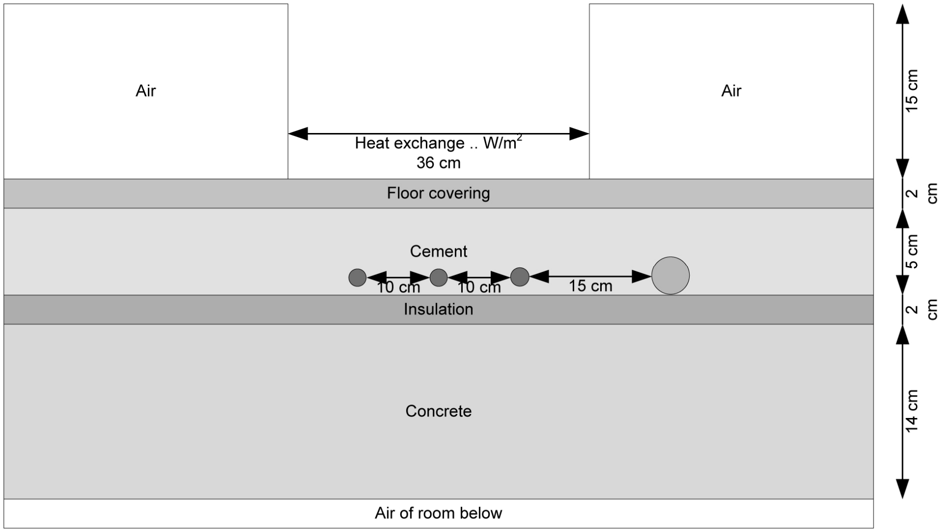

Figure 2.1.1: Scheme of floor heating (left pipes are floor heating, right pipe potable water)

The heat exchange to the surroundings was calculated in 2 steps. At first we simulated with a constant air temperature layer (I) to determine the surface temperature. The second step was simulated with a constant heat exchange in the concrete floor (Table 2.1.1). This constant, expressed in W/m^2, was calculated from the temperature differences between surface temperature and room temperature according to ISSO 49 (2002). The next layer (II) has a floor covering of 2 cm (light carpet), followed by a cover cement layer (III) of 5 cm. Three floor heating pipes were laid in this cover cement layer 10 cm apart. The cold water pipe was also laid in this layer at a distance of 15 cm (the minimum distance by Dutch Standards). Both the potable water pipe and the floor heating pipes were laid directly above the 2 cm insulation layer (IV). The last, bottom layer (IV) is a 14 cm thick layer of concrete.

Table 2.1.1: Material properties used in simulation model

Layer/Material		Density (ρ) (kg/m^3)	Thermal conductivity (λ) (W/m·K)	Heat capacity (C) (J/kg·K)
Layer I:	Air	1.3	0.024	720
Layer II:	Floor covering	1,900	5	800
Layer III:	Cover cement	100	0.95	840
Layer IV:	Insulation	40	0.04	1,470
Layer V:	Concrete	2,300	1.8	840

To simulate the heat transfer, Comsol multiphyics rendered a mesh grid automatically. The total mesh consisted of 29,580 elements (Figure 2.1.2).

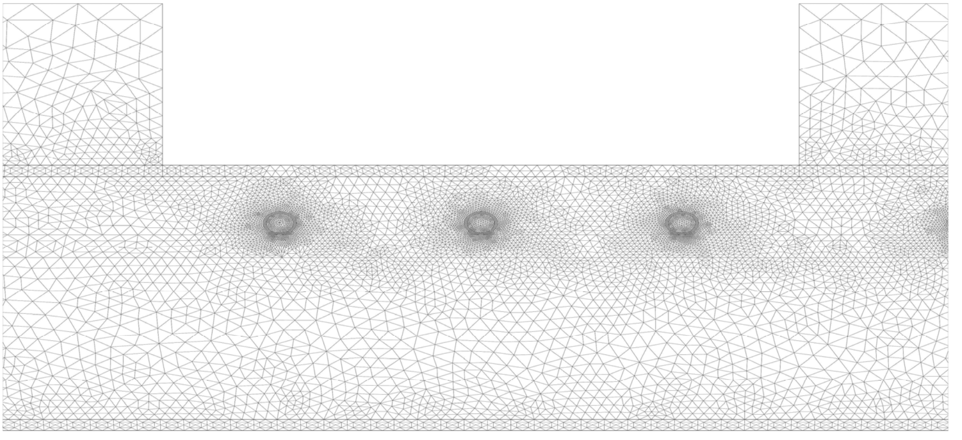

Figure 2.1.2: Mesh grid of floor heating simulation

To calculate the cooling down of the construction caused by tap use, the final temperature of the floor heating of the stationary analysis and the potable water temperature set at a constant temperature of 12°C were taken. Since the average tap usage for a shower takes at least 7.7 minutes (Foekema et al. 2008), the cooling down of the floor was simulated for 8 minutes.

To simulate the reheating of the floor structure, the end results of cooling down simulation were used, in which the stagnant potable water temperature was assumed to be constant.

The simulation used the tap usage patterns of the three homes measured in order to predict the amount of time per temperature range. The problem was that only a single temperature can be assigned to the tap water as opposed to a varying temperature such as measured in the district heating experiment. Therefore, after every tap use we assumed a temperature of 12°C. If the tap was used for longer than two minutes this assumption corresponds with the supply temperature of the water utility. However, in our measurements this supply temperature ranged between 11.5°C and 14°C.

Data analysis

All data derived from the physical measurements (district heating) and the simulation (floor heating) was grouped into 5 temperature ranges: <20°C, 20-25°C, 25-27°C, 27-30°C and >30°C. The correlation between cold water temperatures and air temperature has been computed with the Spearman two tailed rank correlation test (SPSS release 16.0).

Assumptions

It should be said that the supply of potable water could be at a higher temperature than normal. Outdoors the district heating pipes are laying adjacent to the potable water supply about 0.8 m under street level, making heat exchange possible.

Another possible fault is the effect of furniture. We did not configure furniture which reduces the heat transfer of the floor to the room. If we change the air layer in our model into oak (a common material for furniture) layer, the temperature rises to 34.5°C (supply temperature 50°C). This is 4°C higher than the air layer.

2.1.3 Results

District heating

In homes with district heating, weekdays and weekends revealed a different temperature pattern. At weekends, the taps are used more frequently during the day than on weekdays, resulting in lower frequencies in the temperature ranges above 25°C. It is clear that stagnant cold water is above 25°C at least 84% of the time (Table 2.1.2).

Table 2.1.2: Cold water temperature distribution at the entrance to the homes connected to district heating during weekdays and at the weekend; Highest recorded water temperature was 29.6°C and lowest 11.5°C

Temperature Range °C	% of time					
	Home 1		Home 2		Home 3	
	weekdays	weekend	weekdays	weekend	weekdays	weekend
$\theta < 20$	4	8	16	13	7	8
$20 < \theta < 25$	9	8	9	14	11	11
$25 < \theta < 27$	87	84	12	29	81	53
$27 < \theta < 30$	0	0	63	43	0	0
$\theta > 30$	0	0	0	0	0	0

The air temperature at 2.2 m rose to 32.2°C (recorded on a weekday, Home 3), but the highest recorded surface temperature of the copper pipe did not exceed 29.6°C. Fluctuations in air temperature at 2.2 m above the floor in the meter cupboard correlated with the water temperature ($p<0.05$) and ranged from 0.17 (Home 3 at the weekend) to 0.78 (Home 1 on weekdays). The correlation between air and water temperature for Home 3 was lower. This had to do with an improperly installed thermocouple. The thermocouple used to measure air temperature was installed too close to the hot water pipe.

The tapping pattern was calculated from the district-heated dwelling measurements. It consisted of a regular pattern between 06.00 – 09.00 H and 18.00 H – 21.00 H during weekdays and only one peak (12.00 H – 15.00 H) in weekends (Figure 2.1.3). Dwelling 3 had more short taps, most likely caused by the different configuration of the home (apartment). The kitchen and living room are on the second story instead of the bathroom (as was the case in dwelling 1 and 2).

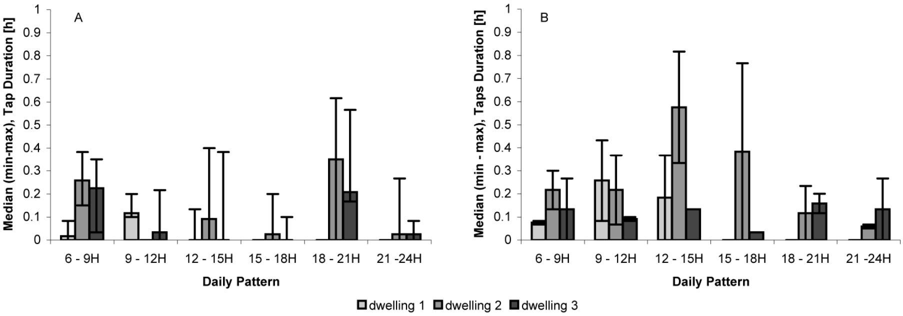

Figure 2.1.3: Number of taps in the different dwellings during workdays (A) and weekend (B)

Tapping cold water results in a drop in the water temperature since the outdoor supply temperature ranges between 12-14°C during our measurements. The temperature rise after the last tap of the day shows that it takes 40-75 minutes before 25°C level is reached (Figure 2.1.4).

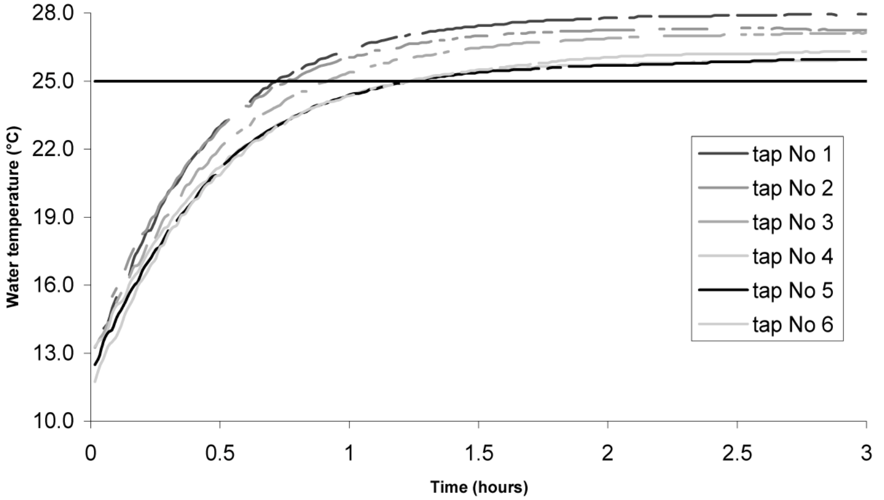

Figure 2.1.4: Heating up of the potable water through district heating after one tap for six different taps

Floor heating

The simulation showed different final temperatures of the potable water for the different floor heating supply temperatures (Figure 2.1.5).

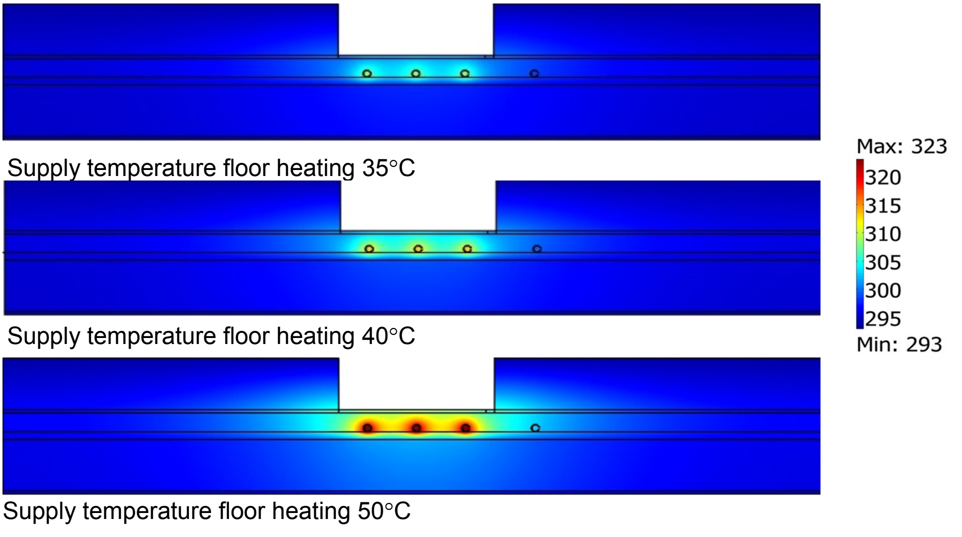

Figure 2.1.5: Temperature (K) distribution in the floor

The cold potable water from the water utilities that flows through the floor during a tap cools down the floor. After this tap it takes about 22 to 34 minutes before the potable water reaches 25°C again (Figure 2.1.6).
After applying the tap pattern of the homes measured in the district heating situation, the distribution of the temperatures for week and weekends in case of floor heating is obtained (Table 2.1.3).

The cold water temperature increases when the supply temperature of the floor heating increases. Another variable is the air temperature in the room. In this study 21°C was used as room temperature. When the room temperature is set on 22°C instead of 21°C, however, the temperature of the cold water will rise 0.5°C.

Table 2.1.3: Calculated cold water temperatures in case of floor heating with different supply temperatures as resulting from the computer simulation at a room temperature of 21°C

Temperature range °C	% of time					
	Dwelling 1		Dwelling 2		Dwelling 3	
	weekdays	weekend	weekdays	weekend	weekdays	weekend
	supply temperature 35°C					
θ < 20	2	5	7	13	6	7
20 < θ < 25	5	6	12	16	12	16
25 < θ < 27	93	89	81	71	82	77
27 < θ< 30	0	0	0	0	0	0
θ > 30	0	0	0	0	0	0
	supply temperature 40°C					
θ < 20	2	4	8	12	6	6
20 < θ < 25	3	5	9	11	9	11
25 < θ < 27	95	91	84	77	86	83
27 < θ< 30	0	0	0	0	0	0
θ > 30	0	0	0	0	0	0
	supply temperature 50°C					
θ < 20	1	3	6	9	4	5
20 < θ < 25	1	2	3	5	3	4
25 < θ < 27	2	3	6	7	6	7
27 < θ< 30	14	12	26	36	25	33
> 30	81	80	59	43	62	51

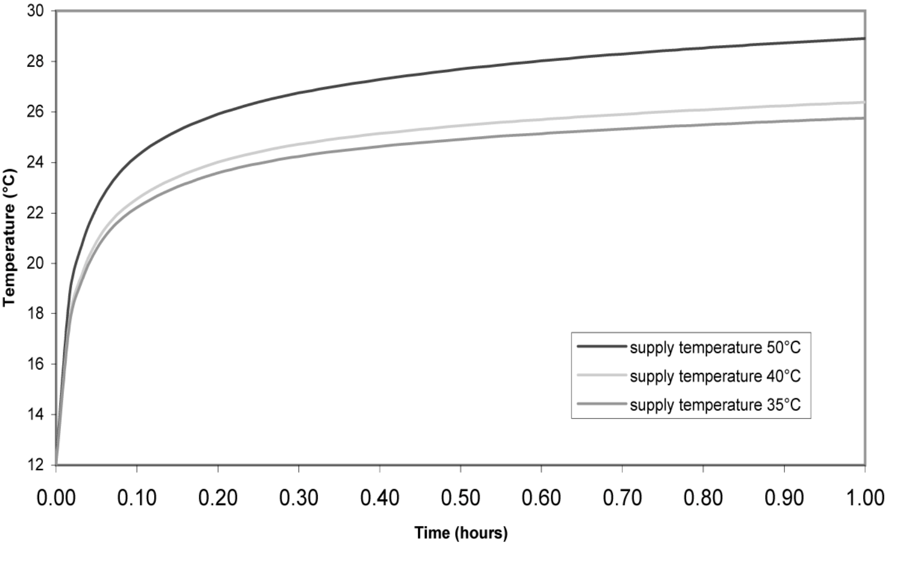

Figure 2.1.6: Heating up of the potable water through floor heating after one tap

The temperature will be above 25°C 71-93% of the time at a supply water temperature of floor heating of 35°C. The percentage of temperatures above 25°C rises to 86-97% at a supply water temperature of 50°C. Moreover, 43-81% of the time the temperature will be above 30°C. Heating up of the cold potable water to levels above 25 °C occurs within 34 minutes for supply temperatures of 35°C, 23 minutes for 40°C and 11 for a supply temperature of 50°C. Furthermore, at 50°C of the floor heating 27°C has been reached after 21 minutes. The temperature of the potable water system rises faster than it did in the situation of the district heating. The faster rise means the water is remaining longer in a higher temperature range where more *Legionella* might grow. On weekdays at least 81% of the day the temperature is above 25°C given various supply temperatures of the floor heating system. In the weekend, taps are more likely to be spread over the day with the result that the cold potable water pipes are spooled more frequently with 'cold' potable water from the water utility.

2.1.4 Discussion

Legionella can grow between 20-50°C (Rogers et al. 1994) with a maximum growth rate at 37°C (Yee & Wadowski 1982). The various species of *Legionella* grow in different temperature ranges. *Legionella spp.* can grow at lower temperatures (Lee & West 1991). The reported doubling time of *Legionella* is 36 hours at 25°C and 16.8 hours at 32°C (Wadowski et al. 1985). Since during weekdays the cold water temperature exceeds 25°C 71-93% of the day, as simulated for floor heating, and up to 87%, as measured for district heating, both types of heating will result in a considerably higher risk of massive *Legionella* growth. This is especially the case in homes inhabited by retired people (Home 1 and 3) that used the taps less frequently than a family with children (Home 2).
Since these high temperatures occur due to district heating and floor heating, it would be of interest to collect *Legionella* samples in homes with district heating and/or floor heating. Also in the two studies of Van Wolferen (2007, 2008) no *Legionella* samples were collected. Most of the previous studies in which *Legionella* samples were taken in homes, were focused on potable hot water.

This difference in tap usage patterns had been reported earlier (Foekema et al. 2008). An increased risk is the age of retired people, since the risk of developing Legionnaires' disease from *Legionella* infections increases sharply with age (Helms 1980). The *Legionella* attack rate of Pontiac fever surmounts 90%, while Legionnaires' disease is only 0.1-4.0% (Fliermans 1996). In existing dwellings measures against this infection risk should be implemented. Disinfection such as chlorination with monochlorimanes will fight the *Legionella* colonisation effectively (Campos et al. 2003). In new dwellings heating systems such as floor heating and district heating require better attention to prevent *Legionella* colonisation.

Both floor heating and district heating pose an increased risk of *Legionella* growth that may lead to extra cases of Legionnaires' disease or Pontiac fever. These increased risks are due to the longer time periods that stagnant water in cold potable water is exposed to temperatures that support *Legionella* colonisation.

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Section 2.2[1]

The economic acceptability of monochloramine treatment of potable water in the Netherlands

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ABSTRACT. Monochloramines are considered one of the most effective and safe disinfectants for potable water. In the Netherlands, however, chlorination is not regularly practised, but the reported number of cases of Legionnaires' disease is one of the highest in Europe. We therefore studied the costs and health gains of this water treatment as an innovative building service for the prevention of Legionnaires' disease.
In total, 1,360 DALYs (healthy life years) may be gained each year at a maximum cost of € 35 - €100 per household depreciated over 5 years if monochloramination is applied in residential areas. In countries where central chlorination is prohibited, local chlorination as an innovative building service seems promising.

Key words: Legionnaires' disease, potable water, economic assessment, households, monochloramines

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1 Prepared for *Water Research*

2.2.1 Introduction

Many disinfectants have been studied in an attempt to control *Legionella* growth, the cause of Legionnaires' disease and Pontiac fever. A review by Campos et al. (2003) compared inorganic disinfectants (chlorination, ozone and hydrogen peroxide), thermal treatment, Copper/Silver ionisation and ultraviolet light radiation. The study identified the various advantages of continuous monochloramination: (i) more effective in preventing recolonisation than other disinfectants because of greater biofilm penetration, (ii) less corrosive than free chlorine and (iii) a lower number of disinfection by-products. A disadvantage is its nitrification. The monochloramines release ammonia that oxidizes to nitrite or nitrate. Many drinking water utilities in the US already apply monochloramines as secondary disinfectants. They tend to manage the nitrification with the proper control of the chlorine and ammonia ratio (Seidel et al. 2005).

From an economic point of view, it is interesting question as to whether monochloramination in homes is socially acceptable. The WHO developed a model to calculate the Disability Adjusted Life Years (DALYs) (Lopez 2006). It is based on egalitarian principles. These are explicitly built into the Disability Adjusted Live Year (DALY) metric. Furthermore, it uses the "ideal" life expectancy for all population subgroups and excludes all non-health characteristics (such as race, socioeconomic status or occupation) apart from age and sex, from consideration in calculating lost years of healthy life. Most importantly, it uses the same "disability weight" for everyone living a year in a specified health state (WHO 2008).
According to the WHO, it is socially acceptable to invest 1 to 3 times the Gross National Product to gain one DALY (Sachs 2001).

This study aims to assess the maximum investment required to gain one healthy life year through chlorination with monochloramines in potable water systems in homes in the Netherlands. No central chlorination of potable water is available in this country. Since the intervention would only be applied in residential areas, it targets community acquired Legionnaires' disease.

2.2.2 Methodology

To compute the gained healthy life years (DALYs), the efficacy of monochloramination on *Legionella* spp. in potable water systems in homes (Reduction Factor) and the attribution of Legionnaires' disease in community acquired pneumonia (Attributable Factor) have been established. Multiplication of the Reduction Factor (RF) and the Attributable Factor (AF) result in the reduction of community acquired pneumonia (Figure 2.2.1).

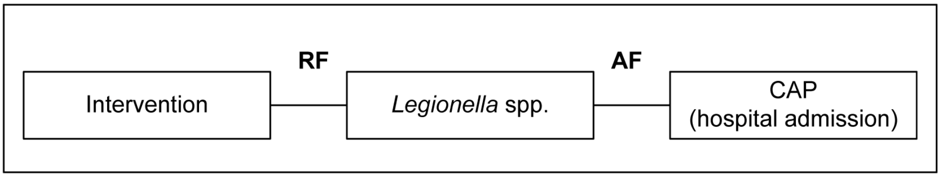

Figure 2.2.1: The Reduction Factor (RF) is the estimated reduction in exposure as a result of the monochlorination; The Attributable Factor (AF) is the estimated community acquired pneumonia (CAP) attributable to Legionella spp

The DALY load for Pneumonia is reported by the Dutch Institute for Public Health and Environment (Poos & Gommer 2007). The gained DALYs through monochloramination determine the maximum economic acceptability of investing in this intervention.

Reduction Factor

We established the RF of chloramines in potable water systems through a literature survey in Web-of-Science with the following keywords 'legionellosis', '*Legionella*' 'legionnaires' disease' in combination with 'monochloramine', '(mono)chloramine(s)', 'control', 'decontamination', 'disinfection', 'intervention', 'prevention', 'reduction (factor)'. This search resulted in 72 papers. Only three papers remained after excluding secondary papers and those concerned with (i) more than one control measure, (ii) effect of chloramines on bacteria/viruses in general, (iii) chloramines added to waste water, sewer water, and pool water, (iv) biofilm experiments and (v) in vitro tests. The RF was established from these three papers (Moore et al. 2006; Kool et al. 1999; Flannery et al. 2006).

Attributable Factor

To establish the AF of Legionnaires' disease in community acquired pneumonia (CAP) we performed a literature survey in Web-of-Science with the following keywords, 'Attributable Factor (AF)', 'attributable risk (AR)', 'etiology' in combination with '*Legionella*', 'legionellosis', 'legionnaires' disease', 'pneumophila', 'community acquired' and 'pneumonia'. This search resulted in 174 papers. Only 15 papers remained after removing: secondary papers, studies from outside Europe and North America and those not pertaining to CAP or when patients showed co-morbidities such as cancer, HIV or patients received chemotherapy. The AF of *Legionella* was established from the data of the following 15 papers (Rello et al. 1993; Schneeberger et al. 2004; Sopena et al. 1999; Almirall et al. 1995; Bates et al. 1992; El-Solh et al. 2001; Falco et al. 1991; Park et al. 2001; Fernandez-Sabe et al. 2003; Ruiz et al. 1999; Gutierrez et al. 1993; Socan et al. 1999; Ostergaard et al. 1993; Almirall et al. 1999; Lagerstrom et al. 2003).

DALY calculation

The Dutch health statistics under the authority of the National Institute for Health and Environment does not distinguish between community, hospital and travel acquired pneumonia. They report pneumonia incidences and pneumonia incidences requiring hospital admission. Since our intervention is directed at monochloramine disinfection of potable water in residential areas, there is only a reduction in CAP. Therefore, the statistics from the Eurosurveillance System for Legionnaires' disease (Ricketts & Joseph 2005) were applied. It distinguishes between hospital, community and travel acquired Legionnaires' disease. For the number of mortalities, we adopted the mortality rate of Fine et al. (1996). They performed a meta-analysis that included 127 cohort studies with different etiologic agents.

The costs per 1 DALY follows from the Incremental Cost-Effectiveness Ratio (*ICER*). When the total annual extra costs (ΔC_{net}) of the intervention and the number of gained DALYs ($\Delta DALYs$) are known, the extra costs for 1 *DALY* gained can be easily calculated as follows:

$$ICER = \frac{\Delta C_{net}}{\Delta N_{DALYs}} \quad (1)$$

The *ICER* is the amount of money needed to produce 1 *DALY*, in our study the required investment to disinfect potable water systems in homes. Such a result can easily be compared with the *ICERs* of other socially investments.

Since no systems exist that disinfects potable water in homes with monochloramines, we established the maximum investment required to earn one DALY. This is based on the assumption that the cost of an intervention in the range between one to three times the Gross National Product is socially acceptable. Both the Gross National Products (based on International Monetary Fund statistics) and the number of homes (based on national statistics agency Statline's data) were obtained for 2007, but the derived DALYs concern 2003.

2.2.3 Results

Reduction Factor

The reported RFs ranged from 0.68 to 0.98 (Table 2.2.1). The study of Kool et al. (1999) measured the reduction of Legionnaires' disease immediately in hospitals. No samples were taken from potable water systems to determine the reduction of colonised potable water systems in hospitals. The studies of Moore et al. (2006) and Flannery et al. (2006) sampled the buildings before and after the intervention to measure the efficacy of monochloramines disinfection on colonisation with *Legionella* spp. We took the average of Moore et al. (2006) and Flannery et al. (2006) of 0.8 as the RF.

Attributable Factor

The reported AF ranged from 0.00 to 0.14, an enormous level of variability: in Spain 0.02 to 0.14 and more stable factor in USA 0.08 to 0.09 (Table 2.2.2). The method of diagnosis (serology, urine, sputum) and included species in these studies varies significantly. This might affect the AF. We therefore used the value reported for the Netherlands: 0.13 (Figure 2.2.2).

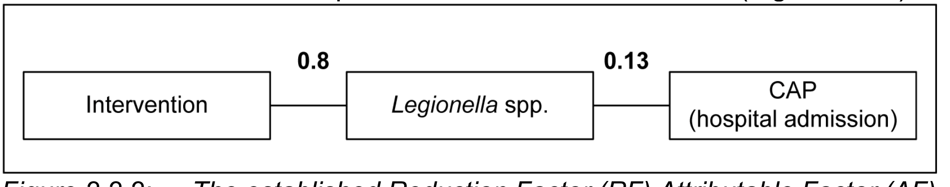

Figure 2.2.2: The established Reduction Factor (RF) Attributable Factor (AF)

DALYs

The incidence of pneumonia in the Netherlands in 2003 is estimated at 135,000 with a mortality of 5,500 persons (4%). Almost 30,000 cases needed hospital admission. We assume a mortality of 1,200 (4%) (Poos 2007).

Applying statistics from the European Surveillance System for Legionnaires' disease (Ricketts & Joseph 2005), 12,000 of the 30,000 cases were acquired in communities (41.1 % community acquired). The mortality rate for Legionnaires' disease was assessed by Fine et al. (1996). They reviewed 20 cohort studies included 272 patients and found a mortality rate of 14.7%.

The established AF of 13% resulted in an incidence of Legionnaires disease of about 1,600. The established mortality rate of 14.7% which equals 230 deaths. Combining the incidence and mortality of Legionnaires disease, leads to a DALY load of 1,700. Based on the RF of 80%, 1,360 DALYs may be gained with monochloramine disinfection.

Table 2.2.1: Reduction Factor (RF) of monochloramination

Type of Study	Sample size	RF	Comments	References
Prospective intervention study	41 hotels	0.68		Moore et al. 2006
	35 governmental buildings		Reduction of colonised buildings	
	20 single-family homes			
Case-control study	32 case hospitals	0.90	Reduction of hospital acquired Legionnaires' disease incidence	Kool et al. 1999
	48 control hospitals			
Prospective intervention study	24 public buildings	0.93	Reduction of colonised buildings	Flannery et al. 2006
	29 commercial buildings			

Table 2.2.2: Attributable Factor (AF) of Legionnaires' disease

Country	Reported CAP (indentified etiology)		AF	Causative organism	Reference
ES	58*	(35)	0.14*	*L. pneumophila*	Rello et al. 1993
ES	389	(228)	0.12	*L. pneumophila*	Sopena et al. 1999
ES	58	(24)	0.09	*L. pneumophila*	Almirall et al. 1995
ES	400	(165)	0.08	*L. pneumophila*	Falco et al. 1991
ES	1474	(728)	0.07	*L. pneumophila*	Fernandez-Sabe
ES	395	(182)	0.04	*L. pneumophila*	et al. 2003
ES	493	(243)	0.04	*L. pneumophila*	Ruiz et al. 1999
ES	205	(88)	0.02	*L. pneumophila*	Gutierrez et al. 1993
USA	151	(79)	0.09	*L. pneumophila* *L. micdadei*	Almirall et al. 1999
USA	104	(55)	0.09	*L. pneumophila*	Bates et al. 1992
USA	410	(220)	0.08	*Legionella* spp	El-Solh et al. 2001
	72*	(48)	0.06*	*Legionella* spp	Park et al. 2001
NL	125	(35)	0.13	*L. pneumophila* *L.* non– pneumophila	Schneeberger et al.2004
SL	211	(85)	0.03	*L. pneumophila* *L. micdadei*	Socan et al. 1999
DK	254	(83)	0.03	*L. pneumophila*	Ostergaard et al. 1993
S	177	(62)	0.00	*Legionella* spp	Lagerstrom et al. 2003

Economical acceptability

The acceptable value in the Netherlands for a healthy year ranges from €33,750 to €105,000 per year, bringing the maximum allowable investment for building services with an onsite decontamination device to € 7 - 20 / household per year.
The cost of chlorination in hospitals was assessed by Campos et al. (2003) and amounted to € 45 per bed. Assuming 500 litres of potable water used for each bed position per day (Samenwerkende Drinkwaterbedrijven 2004), this results in € 0.09 per litre of potable water. Each person in a household uses 127 litres per day (Foekema et al 2008). On the average, each home is occupied by 2.2 persons which means every household uses 280 litres of potable water per day. The cost per household amounts to € 25 per year.

2.2.4 Discussion

The Netherlands belongs to the top five European countries for the incidence of Legionnaires' disease. Almost 13.7 (2003) and 14.8 (2004) cases per million inhabitants are reported by the European Surveillance system (Ricketts & Joseph 2005). The Dutch Health Council estimated 50 cases per million inhabitants (Gezondheidsraad 2003). The reported incidence of Legionnaires' disease is almost four times lower than estimated by the Dutch Health Council. Our established incidence of Legionnaires' disease is also underestimated. We excluded the cases without etiologically identified organisms and only included hospital admitted patients. This means that the real incidence of Legionnaires' disease is higher.

The life years lost due to Legionnaires' disease is limited compared to other diseases (Melse et al. 2000). The severity of the pneumonia was determined to be low; resulting in a low number of Years Lost due to Disability (YLL). Heart diseases, lung cancer and chronic non-specific lung disease have higher disease weight (DW). On the other hand, modern heating systems can increase *Legionalla* colonisation in cold water systems in homes, especially those occupied by - more susceptible - older people (Helms 1980).

In 1994, the cost of CAP was estimated. An episode of care was $264 for outpatients and $7500 for inpatients (including hospital and physician care, and follow-up care) in the US. The total costs associated with treating CAP were about $10 billion for that year (Lave et al. 1999). After correction, based on the dollar's value in 1994, this amounts to € 6,750 for inpatients. Multiplying the RF for the established incidence of Legionnaires' disease (1,200 cases) health expenditure can be reduced by € 8.1 million Euros. This is negligible in comparison to the value of the gained DALYs (€ 142.8 million).

At first sight, the maximum investment required to supply monochloramine disinfection as a building service appears unrealistic. However, the DALY gained through this intervention is yearly, considering the technical lifespan of monochloramine disinfection building services is about 5 years, the investment can be depreciated over those 5 years. This results in a maximum investment of € 35 - 100/household. The costs for local chlorination are, however, only available for hospitals. In the Netherlands, the average hospital has approximately 300 beds (Deuning 2006) and consumes 150,000 litres of potable water. This is comparable to a residential area consisting of 540 homes. The cost of intervention in a residential area is assumed to be equal to a hospital, thus amounts to € 25 per household per year. Considering the yearly DALY gains and the technical lifespan of monochloramine disinfection building services, the intervention is below the socially acceptable level and therefore economically feasible.

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Section 2.3[1]

Indoor air-related measures against avian Influenza virus

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ABSTRACT. The threat of a new pandemic of Avian Influenza has forced the WHO to publish preparedness plans. Although the WHO has recognised the effect of airborne transmission of the causative agent, they did not attempt to include measures for indoor environmental control. We studied indoor humidity control in comparison to other air related measures such as ultraviolet irradiation, portable HEPA filtering and increased ventilation rates aimed at slowing down the spread of the infection in a population. This study was limited to homes. A combination of the Wells-Riley equation and the Nazaroff equation was used to compute the effect of each infection risk decreasing measure. An increase in ventilation and the use of portable HEPA filters were not effective. Although ultraviolet radiation appeared more effective than humidification control, the latter is most feasible.

Keywords: avian influenza, filtration and ventilation, ultraviolet radiation, humidity control

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[1] A previous version has been published in The Proceedings of the 11th International Conference on Indoor Air Quality and Climate, August 2008, Copenhagen, Denmark.

2.3.1 Introduction

From 2003 to December 2008, a total of 391 cases of bird flu were reported that resulted in 247 deaths (WHO, 2008). These are incidental cases. A pandemic of avian influenza could result in an estimated 7.4 million deaths globally. In developed countries this would amount to 233 million outpatient visits and 5.2 million hospital admissions (WHO 2005a).

No environmental measures have currently been proposed to fight the outbreak of a pandemic (WHO 2005b) although Rudnick and Milton (2003) mentioned that infectiousness depends on temperature and humidity. Influenza A virus is vulnerable to a relative air humidity (RH) above 50% (Harper 1963). The efficacy of other measures, such as ultraviolet irradiation to inactivate virus particles, and the effect of increasing ventilation rate in order to remove infectious particles has been studied (Riley et al. 1977). Portable HEPA filters in living rooms and bedrooms are mostly used to remove allergens from mites and cockroaches (Eggleston 2005) and may also be useful. The effect of high humidity in indoor environments has not been studied before. High humidity might have its effect on health through a stimulating effect on other organisms such as house dust mites and fungi.

We have learned from the spread of Tuberculosis and Measles over the past century and more recently the spread of SARS (Booth et al. 2005) that airborne transmission is a major actor in spreading these diseases (Riley et al. 1957; Bloch et al. 1985; Tong & Liang 2004). This is also important in case of avian influenza (Li et al. 2007).

The spread and airborne transmission of pathogens has been the subject of experimentation and deduction since the late 1920s. Soper (1929) developed a mathematical model to investigate the transmission of Measles in Glasgow based on forty years of epidemiological data. Wells developed an infection risk model in 1955 (Wells 1955), which was modified by Riley et al. (1978), the so called Wells-Riley equation. This model was applied to the airborne spread of Measles at a primary school. The Wells-Riley equation constitutes the basis for the simplified model of Nazaroff (1998). Nazaroff simplified the model and incorporated parameters to calculate the efficacy of measures such as wearing a mask and increasing the ventilation rate.

This study aims to determine the feasibility of raising the relatieve humidity (RH) in comparison to other environmental measures such as ultraviolet irradiation, portable filtration and increased ventilation in order to delay the spread of avian influenza within households.

2.3.2 Methodology

Efficacy of measures

To prevent infection, a virus may be inactivated (decay of virus viability) or removed (filter efficiency). The efficacy of humid air (RH > 50%), ultraviolet irradiation, portable HEPA filtering and an increased ventilation rate have been retrieved from scientific literature.

Indoor air humidity control

To raise the humidity to the 50% level needed for viral particle deactivation (Harper, 1963), we calculated the amount of water that would need to be evaporated using the HAMBASE model (Wit 2006). HAMBASE has been validated in the International Energy Agency (IEA) annex 41 working group. The hygric model fitted the measurements well.

A 100 m^2 home (volume 250 m^3) was simulated by using typical finishing materials on surfaces (soft board, plasterboard) (Table 2.3.1).

Table 2.3.1: Physical properties of the finishing materials used in dwelling simulation (A: surface area, μ: vapour resistance, ξ: specific differential moisture storage coefficient, ρ: density and c: specific heath)

Material	A (m^2)	μ (-)	ξ (kg/m^3)	ρ (kg/m^3)	c (J/kg.K)
softboard (ceiling)	100	4	40	275	2100
plaster board (inner wall)	75	6	40	1300	810
plaster (wall)	84	6	20	1300	840
tiles (half of the floor)	50	28	8	2000	840
carpet (half of the floor)	50	1.5	1	50	840

Other input parameters include a threshold indoor temperature of 21°C, air exchange rate of 0.5 and 1.0 respectively, a constant outdoor climate of -5, 0 and 5 °C respectively, an outdoor RH of 60%, no sun, a wind speed of 7 m/s from southwest, the prevailing wind characteristics in the Netherlands (KNMI 2002). The ACH of 1 equals the Dutch building code (0.7 $l/s/m^2$ or 7.0 l/s per person) but in the study of Emenius et al. (1998) the ACH was much lower. In 22 mechanical ventilated Swedish homes the mean ACH was 0.59 and in 29 homes with mechanical exhaust only the ACH was 0.27. Tracer gas was used to measure the ventilation rate. It should be noted that the Swedish building codes prescribes a minimum of 0.5 ACH. Although the Dutch building codes has more severe requirements, it appears, however, that in 84% of mechanically ventilated Dutch homes the capacity was below

21 l/s (only sufficient when occupied by three or less persons) (Dongen & Vos 2007).

Moisture was produced by evaporating 4 litres of water per hour, four times a day starting at 7.00 am, 11.00 am, 3.00 pm and 7.00 pm. The 24 hour average is therefore 0.67 kg/h. Sources such as showers or cooking were excluded in this study. For persons, a moisture production of 0.05 kg/h was assumed. The simulation time was 10 days to establish the mean indoor relative humidity. We have simulated with a constant outdoor temperature and relative humidity to gain the worst case.

Infection risk model

The model of Wells-Riley (Riley et al. 1978) was used (Equation 1). The mean risk of infection was calculated using a logarithmic function.

$$P = 1 - e^{\frac{-I \cdot q \cdot p \cdot t}{Q}} \tag{1}$$

Where P is the probability of infection for susceptible persons, I the number of infectors, q the quantum (number of particles exhaled by infector) of airborne infectious particles per infector (h^{-1}), p the volume of inhalation rate (m^3/h), t the exposure time (h) and Q the ventilation rate (m^3/h).

Nazaroff et al. (1998) simplified the expression of P for those cases in which the exponent of the equation is much smaller than 1. In this case, using $e^{-x} \approx (1 - x)$, the infection risk P then becomes $P = I \cdot q \cdot p \cdot t / Q$.
However, in our case the ventilation rate (0.5 and 1.0 air changes per hour), and the quantum (67 per hour according to Liao et al. 2005) differs significantly from Nazaroff's study, which meant we could not use Nazaroff's simplified model. The volume of inhalation p was set at 0.6 m^3/h (Nardell et al. 1991).

The Well-Riley equation accounts for the effectiveness of ventilation as the only control measure (Q in the denominator). Nazaroff et al. (1998) added other control options such as recirculation ventilation in order to remove viable particles and ultraviolet radiation in order to inactivate particles. In the Wells-Riley equation this means that the denominator will be replaced by:

$$Q + \lambda \cdot V + Q_r \cdot \eta_r \tag{2}$$

Where λ is the decay rate of the viable particles due to specific measures, V is the volume of the room (m^3), Q_r is the recirculation rate (m^3/h) and η_r is the efficiency of the removal of the viable particles.

For the probability of infection risk *P* we can now write:

$$P = 1 - e^{-\frac{I.q.p.t}{Q + \lambda \cdot V + Q_r \cdot \eta_r}} \qquad (3)$$

The time before the infection of the next member of the household was calculated for each measure in case of full social isolation (no physical contact with persons outside the home). We computed probability-of-infection risk for 48 and 72 hours. These exposure times were taken because the incubation time of the influenza A ranges between two and three days (Kowalski 2002).

2.3.3 Results

Efficacy of the measures

The efficacy in terms of the decay rate λ in decreasing the viability of virus particles and the efficacy in removing infectious virus particles were estimated from scientific literature (Table 2.3.2).

The viable particles of the influenza virus are below 0.0001 when they are exposed to a humidity between 50-60% and below 0.1 between 30-40% after 30 minutes (Hemmes et al. 1959). In the study of Harper (1961) the decay with a relative humidity of 50-51% after one hour is 5 times lower. In the same study the decay rate for a relative humidity of 34-36% (typical indoor humidity in heating season) was established, after one hour the concentration was 1.5 times lower. We assume that the difference between both is caused by the higher relative humidity. Since the degree of exposure to infection can be described as $I \cdot q \cdot p \cdot t$ and the reduction by $Q + \lambda \cdot V + Q_r \cdot \eta_r$ (equation 2 and 3) and the ventilation rate in the experiment of Harper was zero, this means the concentration due to a higher relative humidity is 3.5 times lower. The decay rate λ is therefore set at 3.5. The experiments were performed under a temperature that ranged from 20.5 to 24.0°C.

As to the UV irradiation, Riley & Nardell (1989) reported an equivalent ACH of about 20 for bacillus Calmette-Guérin. This was obtained in a room of $18 m^2$ with 30 Watt suspended UV fixtures. More recently, a study by First et al. (2007) showed much higher equivalent ACH for Vaccinia viruses (belong to dsDNA group). Here equivalent ACH of 19 and 42.8 were reported. In this study the total installed capacity of the lamps was higher (144-150 Watt) and the air was perfectly mixed by a ceiling fan. The highest reported equivalent ACH (42.8) was caused by a modern louvered fixture and four fixtures mounted on the walls (150 Watt) while in case of the lower reported ACH, only four fixtures were mounted in the corners (144 Watt). Influenza A belongs to another group of viruses (ssRNA); Tseng & Li (2005) found that this category is even more susceptible to UV irradiation. Therefore we set the decay λ rate at 20.

Table 2.3.2: Input parameters to calculate reduced infection risks

Description	Parameter	Value	Reference
Increased ACH	Q	250	-
HEPA Filter	η_r	0.99	Rutala et al 1995
	Q_r	500	Shaughnessy & Sextro 2006
Humidity Control	λ	3.5	Harper 1961
	V	250	
UV Irradiation	λ	20	Riley & Nardell 1989
	V	250	

Raising indoor humidity

The amount of evaporated water required to maintain a relative humidity of above 50%, mainly depends on the ventilation rate, outdoor humidity and outdoor temperature. Due to the high ventilation rates, the number of people in the home has a limited effect (Table 2.3.3), e.g. four people in the home effects the mean relative humidity over a day less than 3 %.
If the ventilation rate is 1.0 ACH the indoor relative humidity is below the required 50%. This means that more water should be evaporated. Calculations show that the amount of water to be evaporated for -5°C, 0°C, and 5°C is 10, 8.6, and 6.8 litres respectively at four times a day.

Table 2.3.3: Daily mean and standard deviation (SD) of indoor RH when 4 litres of water have been evaporated in a two hour four time a day (at 7 am, 11 pm, 3 pm and 7 pm)

ACH [h^{-1}]	RH daily mean, (SD) [%]	RH daily mean (SD) [%]
	2 persons at home	4 persons at home
	Outdoor temperature -5 °C	
0.5	52 (6)	55 (6)
1.0	35 (5)	37 (5)
	Outdoor temperature 0 °C	
0.5	56 (6)	59 (6)
1.0	39 (5)	41 (5)
	Outdoor temperature 5 °C	
0.5	60 (6)	63 (6)
1.0	45 (5)	46 (5)

Infection risks

Ultraviolet irradiation appears to be the most effective measure regarding the infection risk probability. The probability drops to approximately 0.3 in case of 48 hours exposure. Raising the humidity shows a probability of 0.82-0.85. Thus the probability risk has been reduced with 0.15-0.18. The use of portable HEPA filters is less effective; a reduction of 0.06-0.07. Increasing only the ventilation rate has no effect. In case of an exposure of 72 hours, only ultraviolet irradiation appears effective (Figure 2.3.1).

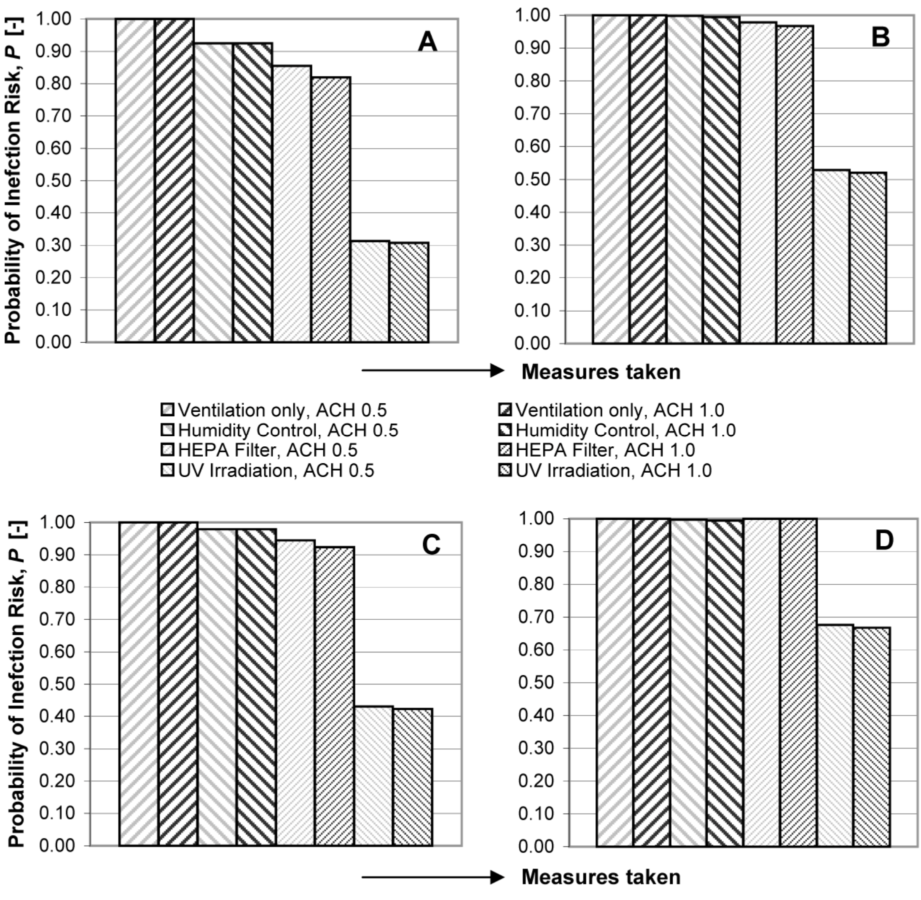

Figure 2.3.1: Infection-risk probability after 48 and 72 hours in a household (A=48 hours and 1 infector, B=48 hours and 2 infectors, C=72 hours and 1 infector, D=72 hours and 2 infectors)

Analysis of sensitivity

In our calculation we used a constant outdoor relative humidity of 60%. When we use 40% as constant outdoor humidity at an outdoor temperature of 0°C, a ventilation rate of 0.5 ACH and a 4-persons household, the calculated mean indoor relative humidity is 55% (SD=6%). If the ventilation rate is 1.0 ACH then the mean indoor relative humidity is 37% (SD=5%). In both cases, this is 4% lower compared to the results with an outdoor relative humidity of 60%. For our analysis this is acceptable.
We simulated with a constant outdoor temperature and relative humidity to establish the required evaporation. Simulations with a dynamic outdoor temperature and relative humidity were performed during a winter period of 60 days. This resulted in a mean indoor relative humidity of 65% (SD=7).

No moisture sources were included except for the persons. This could imply that a lower evaporation level could be used. For instance, in case a single family house is occupied by 4 persons who are all taking a shower in the morning hours about 1.2 kg moisture will be produced (Peeters 2007). Another example is cooking, this produces about 0.5 – 2 kg moisture (depends on the presence and operation of a cooking hood) (Peeters 2007).

The used infection model (equation 3) is more sensitive when the exponent is smaller than 4 (Riley & Nardell 1989). This occurs for all measures except the increased ventilation rate from 0.5 ACH to 1.0 ACH. A deviation of the exponent of ± 10% result in a deviation of ± 8% for the ultraviolet irradiation. The other measures have a deviation below 2%. If the deviation of the exponent is ± 20% then the calculated probability is ± 18% for ultraviolet irradiation and below ± 6% for the other measures. The ultraviolet irradiation causes the lowest exponent in equation 3 as compared to the other measures.

In our study we calculated with an inhalation rate of 0.6, typical for mature persons according Riley & Nadell (1989). Factors such as age and activity level are, however, ignored in our study. Recently Allen et al (2008) performed a study to identify the inhalation rates for different cohorts and activity levels. Their results showed that the mean inhalation rates ranges from 0.09 m^3/h (2.18 m^3/day) for infants to 0.69 m^3/h (16.57 m^3/day) for adults (20-59 years). For children and seniors this mean inhalation rate is 0.61 m^3/h (14.52 m^3/day) and 0.63 m^3/h (15.02 m^3/day). The deviation for infants lies between 0.1 and 0.6. The inhalation rate of infants is a factor 6 lower than for other cohorts.

The highest deviations were retrieved, as expected, for ultraviolet irradiation. The deviation of the exponent is through the lower inhalation rate for infants (more than six times lower). This implies the gained results are not valid for infants. Allen et al (2008) reported 0.69 for mature adults, this is approximately 10% lower than in the initial calculation. As already shown, a deviation of 10% results in a 8% deviation on the probability for ultraviolet irradiation.

We took 67 particles per hour as quantum for influenza A infection. This is the geometric mean in the study of Liao et al. (2005). They used the school based surveillance weekly reports during the period from 2003 to 2004 of the Taiwanese Center for Disease Control to establish the quantum for Influenza A. The quanta varies among different epidemics (Nardell et al. 1991). A factor of almost ten is also reported (Riley et al. 1978) caused by primary and secondary infection. Applying this to our model, results in a deviation of more than 80% for all measures. The variance of the quantum is very important for the end-results. The quantum we have used is based on a two year surveillance database where the study of Riley et al. (1978) reported a single epidemic in an elementary school. We therefore suggest that the quantum of Liao et al. (2005) is more reliable.

2.3.4 Discussion

Our calculations do not take into account the typical ID_{50}, the number of micro-organisms that will cause infections in 50% of an exposed population. The model we have used incorporates environmental and human factors such as volume of space and inhalation rate of susceptible persons. The ID_{50} for Influenza A is 20 (Kowalski 2002). According to Fennelly et al. (2005) a quantum produces infection in 63% of uniform by exposed animals or 1.25 times the median infection dose (ID_{50}). If the ID50 is 20 than the quantum will be 25. This is almost three times lower than the quantum reported by Liao et al (2005). This implies that our results are overestimated.

An assumption in the equations is an equal infection risk for all household members, although Woods & Abramson (2005) showed different risks for children and adults.

Airborne transmission of influenza A is still under debate. Evidence based studies are lacking. On the other hand, epidemiological studies cannot rule out airborne transmission (Brankston et al. 2007). More recently, Sze et al. (2008) performed an experiment in a hospital ward that showed the effect of ventilation design and coughing orientation on the transport of viral pathogens. Furthermore, Fabian et al. (2008) suggested that influenza A virus may be contained in fine particles generated during tidal breathing.

The reduced infection probability of the raised humidity in our calculations might be an underestimation since the decay rate of 3.5 h^{-1} in humid air is a conservative estimation. Hemmes (1959) found recovery rates as low as 0.1% after 30 minutes. Furthermore, the ventilation rate of 1.0 ACH has a detrimental effect on the amount of water to be evaporated in order to keep the humidity level at 50%. We therefore suggest a decrease in the ventilation rate during an outbreak.

A high RH not only has a detrimental effect on influenza A virus, it also supports the growth of allergenic mites and fungi in the home (Bronswijk 1981). However, preventing viral death and illnesses due to a pandemic takes priority over preventing chronic conditions such as allergies. We suggest that raising air humidity levels could be used as a temporary measure when a pandemic is feared.

2.3.5 Conclusion

Although ultraviolet is the most effective measure, supplying millions of households with ultraviolet irradiation devices for each indoor living space, seems unrealistic. Supplying mobile HEPA filters to each household seems also unrealistic. Evaporating tap water to reach 50% RH appears to be a feasible alternative in homes. Every home can evaporate 4 litres of water four times a day using an electric kettle or cooking implements. If a pandemic should approach the borders, the national government should advise the population to use domestic cookers to temporarily increase indoor humidity and lower the ventilation.

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Section 2.4[1]

Health-proofing HVAC systems

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ABSTRACT. Heating, Ventilation and Air-Conditioning (HVAC) systems are designed to increase comfort and protect health and vitality, but also pose health hazards, including recognised threats such as bioterrorism. A number of stakeholders and regulations influence the design, maintenance and usage of HVAC systems, but health and safety are seldom an integral part of their planning and design. HVAC systems deliver air to be inhaled. For food consumption, the life cycle of food is addressed using the Hazard Analysis of Critical Control Points (HACCP) methodology, to perform integral quality control on food. This contribution extends this methodology to indoor air and the risk of Anthrax attacks as biological hazard. An attempt is made to apply the HACCP methodology to a HVAC system controlled by an agent-driven building management system. Applying an integral control system such as the HACCP method to HVAC systems appears to be a solution for coping with the health and safety risks posed by terrorist attacks on buildings.

Keywords: HACCP, HVAC, health risk, safety, bioterrorism

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[1] A previous version was published in the Proceedings of the 10th International Conference on Indoor Air Quality and Climate, September 2005, Beijing, China.

2.4.1 Introduction

In the 1980s, the term Sick Building Syndrome (SBS) was introduced: a phenomenon whereby the users of buildings with mechanical ventilation experience decreased health. Some explanations for this phenomenon included the presence of biological agents (anon 2003) such as fungi and bacteria, or chemical agents (e.g. formaldehyde, radon, ozone) (Su 1996; Zummo & Karol 1996) inside HVAC systems (Clausen 2004; Wargocki 2004). Other influential aspects appeared to be ventilation (Seppanen & Fisk 2002) and maintenance strategies. In spite of this rich knowledge, current maintenance strategies are not directed towards health risks, but mainly towards comfort and energy aspects. Khan & Haddara (2003) studied a maintenance planning method based on risk analysis to minimise the probability of system failure and its consequences with regard to safety, the economy and the environment, but without including bio-terrorist attacks.

In this contribution, air, which is vital to human beings, is considered the result of treatment by HVAC systems. This air can be polluted by three different sources: (i) the outdoor environment (Grievink et al. 2000), (ii) the HVAC system itself or (iii) the indoor environment. Following the air routing, critical points may be identified from primary source to actual inhaled air. To prevent damage to health, a strategic approach should focus on these critical points.

In the food industry, it is not only the end product that is judged in terms of quality, but every single critical point in the process is monitored to attain the required consumer quality of the product. When a measurement exceeds a critical limit at a certain location, an intervention is carried out at that point in the process: the critical point. Hazard Analysis of Critical Control Points' (HACCP) final aim is to check the end quality in order to guarantee its safety for consumption. The air supplied by HVAC systems is also a consumption product that can affect health and should undergo at least one quality check before consumption but it would be better to identify at which point in the process the air quality is diminished.

In addition to the well-known biological and chemical hazards, a new type of threat has arisen. Bioterrorism with anthrax spores or other biological agents can affect the lives of thousands. In 2001, this was aptly demonstrated with the spread of Anthrax spores through the US postal system. Letters contained trillions of organisms, enough to kill more than 500,000 individuals, although only 5 people died in these incidents (Shannon 2004).

This paper aims to study the usefulness of HACCP in order to identify health risks caused by bioterrorism theoretically. A bioterrorist attack with Anthrax spores has been used to demonstrate otherwise overlooked critical points in the HVAC system.

2.4.2 Methodology

The HACCP method was developed forty years ago by NASA in order to protect astronauts against food poisoning (Mortimore & Wallace 1995). Raw materials are processed in various stages. The monitoring of potential hazards takes place at different stages in the process to ensure product quality. Even product packaging is taken into account. Analogously, ventilation systems can be divided into components and treatments.

Hazard Analysis of Critical Control Points consists of 7 principles or steps: (i) conducting a complete hazard analyses at regular intervals; (ii) determining the critical control points (CCPs); (iii) establishing critical limits for measurable variables at the CCPs; (iv) establishing monitoring procedures at the CCPs; (v) establishing events when the critical limits are surpassed; (vi) establishing verification procedures for the whole HACCP process and (vii) establishing record-keeping and documentation procedures.

To validate the usability of the HACCP, eight bachelor students of the students of the building services program conducted a HACCP of a university building, Vertigo, at the campus of Eindhoven University of Technology. This building is equipped with a mechanical ventilation system including heat recovery. The CCPs were identified from observations and studying technical drawings of the building. To work out all the seven principles of the HACCP scientific literature was surveyed.

Theoretically determined CCPs were validated by a field experiment to check correctness and completeness of the CCPs. The field experiment was executed in February 2005 by the same students, two students acted as fake terrorists and six as fake building security officers. None of the fake security officers were informed who the fake terrorists were. Instead of Anthrax spores, fluorescein was used by the fake terrorists. Both the fake terrorists and the fake building security officers received a UV lamp to detect the fluorescein powder. The experiments lasted from between 12 am and 10 pm. In this time the fake terrorists had the ability to attack the building and the fake building security officers to identify the location of attack(s) and to trap the fake terrorists.

2.4.3 Results

The HACCP approach, as applied to a building with mechanical ventilation, constitutes of different steps from outdoor air to air inhaled indoors *(*Figure 2.4.1*)*. In the case of Anthrax attacks, the identification of an attack must be carried out quickly to reduce the number of casualties by preventing exposure or by providing medical treatment. In the case of more normal bio agents such as the allergenic mites and fungi which pollute HVAC systems, more time is available.

The HACCP method provides indications for reducing health risks and we propose to implement it as follows:

Step 1

Based on the observations and studying technical drawings of the building, an inventory is made of the air routing from the outside atmosphere up to the point of human inhalation. This includes the air handling unit inlet, passing filter(s), fan, recovery unit, (de)humidifier, heater and cooler, silencer, distribution system and the indoor space before the air is inhaled. The risks related to an Anthrax attack depend on the accessibility of the system's inlet and other HVAC parts. These potential hazards depend on the building layout as well as the HVAC layout. Public and non- public indoor spaces may present an Anthrax hazard as shown in 2001 by the Anthrax letters posted in the USA. Buildings containing rooms for the reception of post face this additional hazard.

Step 2

The CCPs of a HVAC system include (i) the inlet of the air handling unit, (ii) the outlet of the air handling unit, (iii) the end of the main duct, (iv) the inlet to a room and (v) indoor spaces (outlet). The variability of accessible parts will complicate this step.

Step 3

The number of Anthrax spores needed to kill human beings by inhalation ranges from 2,500 to 55,000 (Ho & Duncan 2005; Hilleman 2002). A safe limit is 250 Anthrax spores within a sample time of half an hour. The preferred sample time for the lethal threats is a matter of seconds. The air velocity in air ducts is about 4 m/s which means that after one minute the Anthrax has travelled 240 meter in the duct or is already released in the building.

Step 4

Anthrax hazards should be measured by biosensors. Since the Anthrax attack in the US many studies are directed to biosensors (Higgens et al. 2003; Hindson et al. 2005; Kuske et al. 2005; Makino & Cheun 2003; Riley et al. 2004; White et al. 2002).

Step 5

Within the building management system, all data collected at the CCPs is handled by an agent that is able to (i) take control of the HVAC (closing outside louvers, shutting down the fan, closing all fire dampers, closing all control dampers); (ii) provide information to end-users (close windows and stay inside); (iii) provide information to the departments involved (maintenance department) and (iv) provide information to emergency services (ambulance, fire and police department).

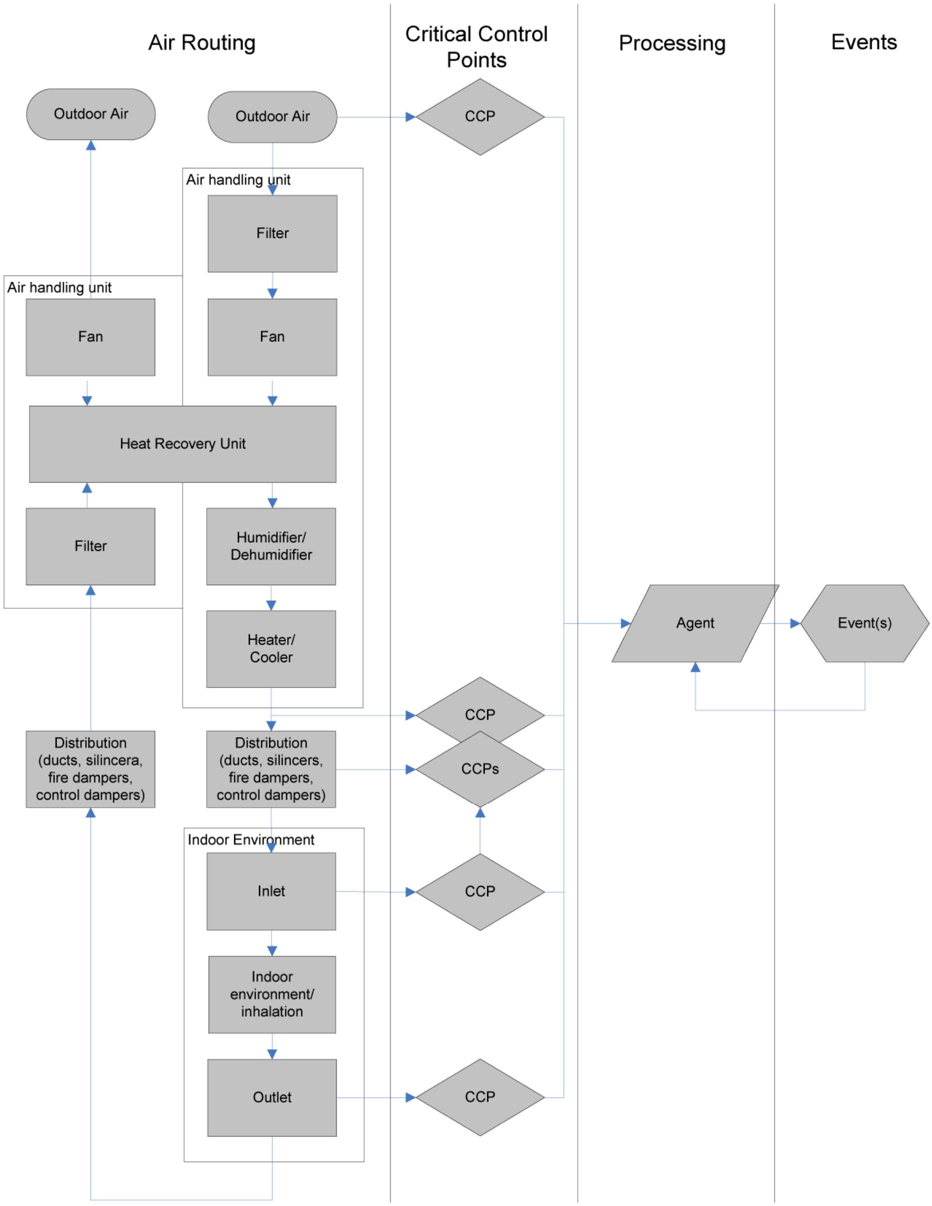

Figure 2.4.1: Schematic presentation of the HACCP process for a HVAC system; The left-hand side visualises the air routing and the related Critical Control Points (CCPs) at specific locations. Signal output is directed to an intelligent agent of the Building Management System that responds with one or more events if and when one of the CCPs exceeds its limit

Step 6
The Building Management System's intelligent software agent collects data from the CCPs that are real time monitored and performs routine analysis. Authorised professionals can watch both, trends and historical data at any point in time. Overviews are sent to these professionals automatically.
Step 7
The whole monitoring process and its results are stored by the building management system as are the interventions (events) performed. Only the maintenance engineer should have a code to restore the intelligent agent to prevent unauthorized control or events, to prevent a terrorist from disconnecting a sensor before releasing Anthrax spores.

The field study performed with fake spores revealed the following prime CCPs: open air inlets located at ground level, moving lifts, mobility of persons and especially the lack of adherence to safety procedures due to a limited number of conventional keys to lock technical rooms and the absence of a detection system for unauthorized entrance to these rooms.

In addition both the defenders and the fake terrorists pointed out most of the critical points perceived in the theoretical approach of the subject. The pumping of fake Anthrax in the building through the elevators, however, was not foreseen in the theoretical assessment. Furthermore, the building management system of the investigated building was not prepared for such an attack.

2.4.4 Discussion

After the introduction of *Bacillus anthraces* spores into the mail that subsequently infected buildings, the weak points of 59 buildings were investigated by engineers and scientists (Anon 2002). The resulting recommendations on how to design HVAC systems in order to prevent the spread of Anthrax spores were published in guidelines by the National Institute for Occupational Safety and Health of the USA (NIOSH 2002; NIOSH 2003). A few recommendations include (i) linked alarm systems and HVAC control strategy, (ii) stipulations with regard to the location of inlets and (iii) locks on the doors of machine rooms.

In our validation, the air inlet at ground level was confirmed to be a critical point for an attack. This was determined in the theoretical assessment as well as the field study. The lift, however, proved to be another critical point. This critical point was missed in the HACCP analysis but identified in the field study. As far as security was concerned, the door to the machine room was not locked during our experiment. This is noteworthy because the security department had been informed about the fake attack. We therefore propose that the doors be fitted with electronic locks. How the alarm system and the HVAC control performed, was not included in this study and could not therefore be validated. We agreed with the NIOSH report that control actions after the detection of an attack should depend on the place of attack. Outdoor attacks should lead to the immediate shutdown of the HVAC. In the event of indoor attacks, only the air supply fan should be shut down to prevent mixed air and pressurisation of stairways as laid down in the protocol for fires (Kandola 1986).

Anthrax spores are not the only harmful contaminant that might be present in buildings. Many of biological and chemical contaminants are present in buildings. To prevent unforeseen biological and chemical risks in buildings, we propose to treat air in a way similar to food or even more strictly, since human beings cannot survive as long without air as they can without food. While ventilation is increasingly brought to the user through mechanical and technological intervention, its similarity in terms of risk to the preparation of food is increasing. In both cases health and safety is at risk if the 'nutrients' are not handled properly.

The main added values of the HACCP approach to an HVAC system is (i) a hazard is detected at the earliest stage in the process, (ii) adequate handling after a limited set at a specific CCP, (iii) different events are programmed: technological intervention events, user warnings, signalling to the relevant departments and the emergency services. This will reduce the time needed to diagnose the infection and the time it takes before those affected receive medical treatment.
A dedicated intelligent agent incorporated into the Building Management System should be central to control the air handling process and should take care of monitoring, interventions required, verification and record keeping and documentation procedures. To respond to terrorist attacks with Chemical, Biological or Radiological (CBR) agents, HVAC and fire safety systems capable of alerting hospitals and police should be installed in order to prevent deaths. Intelligent software agents should be developed to perform the different steps of the HACCP method in order to minimise the number of victims. Although agent technology is well known in Building Management Systems (Clark & Mehta 1997), it has not yet been used in an HACCP manner to protect indoor air quality, even under the extreme conditions of a bioterrorist attack. This constitutes an important challenge for building services and software engineers. In addition, such a system could also be used to control more common biotic risks in HVAC systems.

The main, current technological barriers are sensors that are able to detect hazards in a short enough time. Furthermore, the number of false alarms (false positives) must be reduced to an absolute minimum in order to create trust and prevent inactivity of the staff involved (facility maintenance and emergency services).

In this way a HACCP-based safety system might also reduce SBS symptoms due to biological and chemical contaminations. For this purpose, the intelligent agent should be supplied with additional events and different sensors that detect other biological and chemical pollutants.

This study is a typical case study, limited to a single building. The HACCP approach has been compared to the NIOSH reports and the field study has validated this approach. Further research is needed to check both the completeness and validity for more buildings in order to obtain a better list of Critical Control Points. To determine the usability for other harmful pollutants such as Volatile Organic Compounds (VOC), fungi and other pathogenic bacteria, additional studies are required. By linking results from intelligent agents incorporated into Building Management Systems there is an opportunity to reduce health risks in an addition to controlling thermal comfort and energy use.

2.4.5 Conclusion

The acceptance of air as an essential 'nutrient' for human life, calls for a system of air-quality monitoring. Monitoring should be as dependable as the HACCP system is for liquid and solid food and this is especially true when possible bioterrorist attacks are taken into account. Designing and maintaining HVAC systems according to the HACCP methodology will constitute a real challenge to the Building Service engineers in the first half of the 21st century and this challenge will include providing occupants with the proper information.

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CHAPTER 3: PREVENTING CHRONIC CONDITIONS

This chapter shows the potential of modern building services to actually prevent chronic diseases. Through a uniform assessment of health, the economic consequences are provided to determine the socially acceptance of technical interventions.

We studied two examples in the combined domains of preventing chronic conditions and building services: the possible efficacy of the technology used (protection against outdoor particulate matter), and the economic feasibility of modern technology (preventing chronic lung disease).

Outdoor particulate matter that penetrates buildings is a phenomenon not fully understood. Decreasing the level of this combustion-related pollution indoors might, however, potentially decrease lung cancer and coronary heart disease. Indoors the HVAC system offers only limited protection. Innovation in both construction and building services is needed (Section 3.1)

In Section 3.2, we simulated the healthy years gained through increased ventilation and their economic implications for asthma, COPD and lung cancer.

Section 3.1[1]
Fine particulate matter and the HVAC system

A case study

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ABSTRACT. Vehicular traffic is considered the main producer of fine particulate matter, contributing to morbidity and mortality from lung cancer, coronary heart disease and asthma. HVAC systems should protect building occupants, but in practice they filter out less than half of these particulates. We studied the effect of additional HVAC maintenance on indoor air quality. To this end, particulate matter was assessed at workstations in a mechanically ventilated Dutch office building and in its environment. No humidification of indoor air took place. Indoor small particle number concentrations are strongly correlated with outdoor measurements (rho=0.93, $p<0.001$). The effects of running the HVAC system, replacing the filter and even the presence of people in the workplace are minimal in comparison to the effect of outdoor pollution. The air-tightness of building envelopes appears to be the dominant factor compared to the influence of the HVAC system.

Keywords: airborne particle penetration, indoor/outdoor ratio, exposure, particulate matter, airborne dust

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1 An earlier version of this section has been published in The Proceedings of the 11th International Conference on Indoor Air Quality and Climate, August 2008, Copenhagen, Denmark. Authors have been invited to publish the manuscript in Building Simulation and are prepared to do so.

3.1.1 Introduction

In Europe, vehicular traffic is considered one of the main producers of airborne Particulate Matter (PM) and legislation is underway to minimise its production (Cramer 2007). Traffic related PM_{10} causes 25,000 new cases of chronic bronchitis (adults), 290,000 episodes of bronchitis (children), 0.5 million asthma attacks and 16 million person-day restrictions each year in Austria, France and Switzerland (Kunzli et al, 2000). With regard to cancer, Abou Chakra et al. (2007) revealed that the genotoxicity effect was stronger for $PM_{2.5}$ than PM_{10}. Chen et al. (2005) performed an epidemiological study to establish the relative risk for $PM_{10}/PM_{2.5}$ on coronary heart disease. They found higher association for $PM_{2.5}$ for cases involving females. In the Netherlands alone, a reduction in healthy life years of 180,000 has been established (Singels et al. 2005). This is based on premature death. The ultrafine particulate matter reaches lungs, vascular system, and heart and induces inflammation and oxidative stress (Delfino et al. 2005). This implies that both coarse particulate matter and ultrafine particulate matter should be incorporated in PM studies. Although most epidemiological studies are directed to the coarse particles (<2.5 μm), the ultra fine particles (<100 nm) have a higher probability to deposit in lungs (Maynard & Kuempel 2005).

Outdoor air near traffic hotspots contains high concentrations of traffic-related particulate matter in the 0.3 to 5μm diameter range (Lonati & Giugliano 2006). In Amsterdam 30% of the $PM_{2.5}$ concentration was caused by traffic-related particles (Vallius et al. 2005). Morawska et al. (1998) showed also high concentrations for the particles with a diameter below 0.1 μm.
In general, particulate matter can enter indoor spaces of air-conditioned buildings through doors, windows and the HVAC system (Hänninen et al. 2005).
For indoor spaces, the HVAC system is a candidate for reducing exposure to small dust particles arising from traffic (Buchanan & Apte 2006; Sippola & Nazaroff 2003). The penetration of particulate matter depends on the quality of both building envelope (infiltration) and ventilation system. For the coarse particles (> 1 μm) the filters commonly used in HVAC systems have high efficiency levels. However, the efficiency of those filters is much lower, in the range of 0.1 to 0.4μm (Fisk et al. 2002). Noteworthy, the capture rate of filters increases over time: older, soiled HVAC filters retain more particles than new filters (Weschler 2003). The spheric captured pollution increases the total surface of the filter.

The question we explored is whether additional maintenance, such as the cleaning of the Air Handling Unit (AHU), the replacing of filters, and preventing air leakage around the filters, leads to better protection against outdoor sources of fine particulate matter.

3.1.2 Methodology

Study object

The office building studied has been in use since 1989 and is located in the western part of the Netherlands, 200 metres north-west of an intersection of two motorways (A4 and A13) with an average traffic load of about 180,000 vehicles per day on weekdays (VWS 2008). The building has four floors of offices (including the ground floor) with a floor that houses a conference room and a room for the central HVAC system on top of it. The HVAC system is equipped with rotational heat recovery, F7 bag filters and has both heating and cooling coils. The humidification system was turned off during the measurement period. The central HVAC system was run at the weekends according to the same schedule as during normal office days (06:00 – 19:00) in order to assess the influence of human activity (shedding skin flakes and resuspension) on particle concentration. It should be noted that on Mondays the system started one hour earlier.

Measurements

The concentration of PM (number and mass) inside and near the office building was measured before and after maintenance at three different workstations. Since most standards and legislation are based on mass measurements, PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ were assessed using an optical particle counter (Turnkey Instruments, type OSIRIS) equipped with a standard issue heated inlet. To measure particles in the lower size distribution a second optical particle counter (Lighthouse Remote 2014) was used. It was insulated and equipped with a heated inlet. It measured PM concentrations in four custom size bins: >0.2µm, >0.3µm, >0.5µm, >0.7µm. These bins allowed us to determine particle number concentrations in the ranges of 0.2 - 0.3, 0.3 – 0.5 and 0.5 -0.7µm. The sample time was set to 5 minutes.

Data on several environmental parameters (wind speed, wind direction and precipitation) was collected from the two measuring stations (The Hague and Rotterdam) closest to our office building. The stations were run by the Royal Dutch Meteorological Centre (KNMI 2007). Measurements were taken on the office building's roof, approx. 2.5m from the central air intake. We assumed the rooftop concentration to be equal to the concentration that is taken in by the HVAC system's inlet.

At the same time as the outdoor measurements, three different workstations were assessed: (A) top floor near central HVAC, (B) top floor far end of open plan office and (C) ground floor far end. The total length of air ducts from the central AHU to the workstations was 9, 47 and 58 metres respectively. The equipment was placed next to the desk at about 3 metres from the exterior structure and 1m from the air outlets at a height of about 110 centimetres. The workplace concentration represented the entire office space since we assumed a fully mixed environment.

Measurements were taken in the weeks before and after annual maintenance in the period between December 2007 and February 2008. Maintenance activities included filter replacement with additional strips to reduce air leakage around the filter and the dry and wet cleaning of the central AHU and its fans. In addition the v-belts of the fans were replaced and lubricated. The heating and cooling sections were not cleaned, since they could not be reached.

Statistical analysis

MATLAB (version 2007b) was used to prepare and sort data. Descriptive statistics, correlation coefficients (Spearman's rho) and the Mann-Whitney U Rank-Sum Test were obtained using SPSS (version 15.0) from the 5-minute interval data. The data was classified in three groups: (i) HVAC system off and no indoor activity (during nights), (ii) HVAC system turned on and indoor activity (weekdays) and (iii) HVAC system on, but no indoor activity (during the day in weekends and holidays).

3.1.3 Results

Outdoor conditions

During the measurement, the average daytime temperature was 13 ± 1^{o}C, humidity was 78 ± 3%. The wind direction was predominantly S-SW, with an average speed of 3 m/s. Maximum precipitation was 6.5 mm per hour, with a total of 95 mm over the entire measurement period (from December 14 2007 until February 8 2008) and 19% of all measured hours included some rainfall.

The outdoor particle mass concentration of PM_{10} and $PM_{2.5}$ was lower than the European threshold limits of 50µ/m^3 for 94% of the time and lower than 25µ/m^3 for 84% of the measurement period respectively (established through EU Air Quality Directive and mandatory in 2015). No threshold for $PM_{1.0}$ is available in the EU Air Quality Directive.

Particulate matter number concentration in the range of 0.2 to 0.3µm was approximately 22% higher during the week than at weekends. During weekdays, average 24h mass concentration was 23 µg/m^3 and 18 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively. At the weekends no difference was measured for PM_{10} and $PM_{2.5}$, 24 and 17 µg/m^3 respectively.

During weekdays, concentrations of the smallest PM (0.2-0.3µm in diameter) showed peaks that coincided with the peaks in traffic to and from work, and may be regarded as traffic-related dust (Figure 3.1.1).

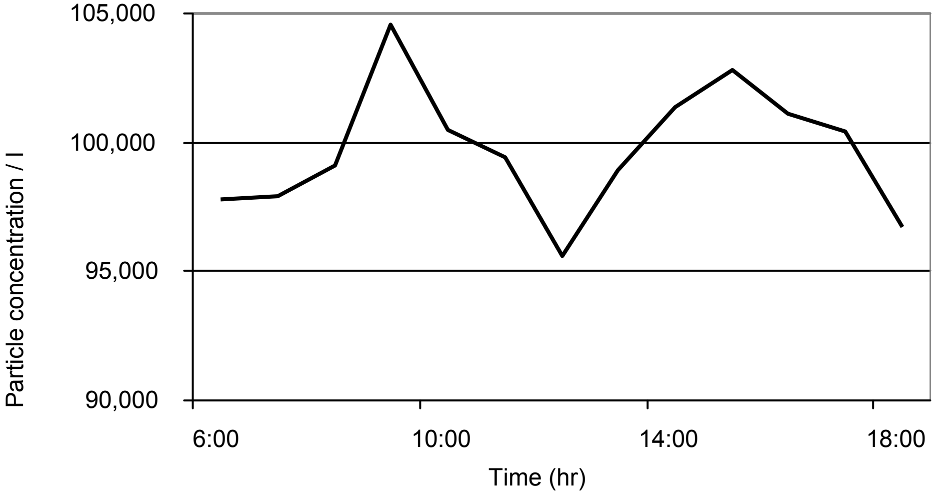

Figure 3.1.1: Average hourly concentration on workdays of airborne particles of 0.2-0.3µm in diameter on the rooftop of the office building; Note traffic peaks in morning and afternoon

The concentration of particles in the size range 0.2-0.7 µm but also $PM_{1.0}$ were significantly different in case the wind came from the south east (Mann Whitney U Rank-Sum Test). This was also revealed by the average outdoor concentration of PM sizes between 0.2-0.7µm which were approximately 40% higher if wind blew from the direction of the motorway. Other particle sizes were less strongly affected (+10%).

Indoor conditions

When the HVAC system was in operation and no indoor human activity took place (at weekends and on holidays), the median PM (for PM_{10}) was 0.1 µg/m^3. The PM_{10} concentration during the daytime on weekdays was much higher at 4.0 µg/m^3. Human activity results in higher PM concentrations. At night, the median concentration was 0.9 µg/m^3. This effect was only noticed for PM_{10} and not for $PM_{2.5}$ and $PM_{1.0}$. The threshold limits for PM_{10} and $PM_{2.5}$ have been established for outdoor concentrations. However, the indoor concentrations of PM_{10} and $PM_{2.5}$ were lower than the EU Air Quality Directive 99.9% of the time.

The median indoor particle concentration of PM in the 0.2-0.3µm range was approximately 28,000 particles/l at weekends and 37,000 particles/l on weekdays. During the night the median was 35,000 particles/l.
Apparently, a sizable proportion of outdoor PM penetrates the office building (Table 3.1.1). Correlations between indoor and outdoor particle number concentrations are highest in the 0.3-0.5 µm (r_s=0.97) diameter range, followed by the 0.5-0.7 µm (r_s=0.93) and 0.2-0.3 µm (r_s=0.88) diameter

ranges. When mass measurements are used, the relation indoor-outdoor is less strong, except for the smallest fraction ($PM_{1.0}$) with a r_s of 0.67.

Table 3.1.1: Spearman correlation of indoor and outdoor airborne particles of the same size in and around an office building in the Netherlands; for all correlations p< 0.01

Statistics	Fraction					
	PM_{10}	$PM_{2.5}$	$PM_{1.0}$	0.5-0.7 µm	0.3-0.5 µm	0.2-0.3 µm
r_s	0.22	0.43	0.67	0.93	0.97	0.88
n	14,860	14,860	14,860	16,119	16,119	16,119

Subdividing the data into (i) HVAC system off and no indoor activity (during nights), (ii) HVAC system turned on and indoor activity (weekdays) and (iii) HVAC system on but no indoor activity (during day in weekends and holidays) shows another view on the correlations (Table 3.1.2).

Table 3.1.2: Spearman correlation of indoor and outdoor airborne particles of the same size in and around an office building in the Netherlands, subdivided into groups, for all correlations p< 0.01

Situation	Fraction					
	PM_{10}	$PM_{2.5}$	$PM_{1.0}$	0.5-0.7 µm	0.3-0.5 µm	0.2-0.3 µm
	HVAC off, no indoor activity					
r_s	0.23	0.35	0.41	0.62	0.88	0.78
N	3,170	3,170	3,170	2,370	2,370	2,370
	HVAC on, indoor activity					
r_s	-0.13	0.01	0.49	0.88	0.97	0.89
N	2,869	2,869	2,869	2,125	2,125	2,125
	HVAC on, no indoor activity					
r_s	0.49	0.59	0.62	0.78	0.88	0.88
N	1,077	1,077	1,077	845	845	845

The weak, negative correlation of PM_{10} during weekdays corresponds with the PM_{10} concentration (median 4.0 µg/m^3) measured indoors. The correlation for $PM_{2.5}$ also shows the weakest correlation when the HVAC system is running and the office is occupied (indoor activity). We suggest that this is caused by the same reason as for PM_{10}. In contrast, the correlations for 0.3-0.5 µm and 0.5-0.7 µm show the strongest correlation in this group. Moreover, for 0.2-0.3 µm the strongest correlation was computed when the HVAC system was running. Remarkable is the fact that during the night (HVAC system turned off) the outdoor concentrations were not lower than during the day. For example, during the night the median for PM_{10} was 20.7 µg/m^3 compared to the median computed for the day of 18.4 and 26.4 µg/m^3 for weekdays and weekends respectively. At the other end of the spectrum, the median concentration of 0.2-0.3 µm particles during the night was 105,000 particles/l and for the day 107,000 and 74,000 particles/l for weekdays and weekends respectively.

Indoor-outdoor ratios

Since the strongest correlations were found for the smallest particle sizes, we only applied descriptive statistics to the ranges 0.5-0.7, 0.3-0.5 and 0.2-0.3 µm. This was performed before and after maintenance (Table 3.1.3).

Table 3.1.3: Spearman correlation of indoor and outdoor airborne particles of the same size in and around an office building in the Netherlands; for all correlations p< 0.01

Situation	Median ratios per particle range					
	0.5-0.7 µm		0.3-0.5 µm		0.2-0.3 µm	
	before	after	before	after	before	after
HVAC off, no indoor activity	0.18	0.22	0.32	0.31	0.60	0.38
HVAC on, indoor activity	0.21	0.22	0.37	0.31	0.55	0.39
HVAC on, no indoor activity	0.23	0.18	0.41	0.33	0.54	0.37

More particles in the 0.2-0.3 µm range penetrate the building compared to the 0.3-0.5 and 0.5-0.7 µm ranges. Surprisingly, the median in the 0.2-0.3 µm range is higher when the HVAC system is switched off than when the system is running. The correlation between indoor and outdoor concentrations is, however, weaker when the HVAC system is off. After maintenance, the ratios dropped in the 0.2-0.3 µm range and to a lesser extent also in the 0.3-0.5 µm particle range. This cannot be explained by the maintenance because the drop was measured for all groups. This means that the drop was also measured when the HVAC system was turned off.
However, the Mann Whitney test revealed that the distribution was significantly different before and after maintenance (p<0.001), except the difference for the range 0.5-0.7 µm when the HVAC system was running and there was indoor activity.

Furthermore, maintenance was negatively correlated (not tabulated) with the ratio for 0.2-0.3 µm (p<0.001), but appears approximately equal for all groups (ranging from r_s -0.47 to -0.51). Similar results were found for the ratio of 0.3-0.5 and 0.5-0.7 µm except when the HVAC system was running and the office was occupied (indoor activity). Here the correlation (r_s) was weaker -0.39 and -0.31.

3.1.4 Discussion

Decreasing the exposure to particulate matter is an important aim in public health engineering. In fact, national thresholds for PM_{10} and $PM_{2.5}$ were mostly met in this study. But no threshold limits have been formulated for the smaller PMs e.g. 0.2-0.3µm in diameter. Because the ratio is about 40% of outdoor concentrations and the correlation between indoor and outdoor is 0.78 or higher, we suggest that outdoor particles penetrate the indoor environment. Previous studies have also shown that ultrafine particles penetrate buildings (Jamriska et al. 1999; Zhu et al. 2005; Hussein et al. 2004).

During weekdays, particles from different indoor and outdoor sources are inhaled by the occupants of offices, affecting their health. The indoor/outdoor rates during weekends reveal the percentage of particulates that originate from outdoor sources. Braniš et al. (2005) conducted a study in a natural ventilated school. They reported a higher drop of the mass concentration indoors at night for PM_{10} and a lower drop for $PM_{2.5}$ and $PM_{1.0}$. This indicates that indoor activity has an important effect on the indoor/outdoor ratio for PM_{10}. Our results were similar. During the day the mass concentration of PM10 was higher compared to the smaller fractions.

The percentage of number concentration of particles (0.2-0.7µm) that end up indoors is approximately 20-30%. The correlations between the mass concentrations (PM_{10}, $PM_{2.5}$ and $PM_{1.0}$) were much weaker. Therefore, outdoor particle mass concentrations (PM_{10}, $PM_{2.5}$) are weak predictors for indoor exposure to concentrations of fine particles. These results suggest that measuring particles in sub-micrometer sizes (200-700 nm) is a better predictor for indoor exposure to fine particulates than coarse particles (1-10 µm).

The finer fraction of PM (0.2-0.3µm) outdoors correlated well with peaks in traffic on the busy motorways 200 m away. In addition the concentration was 40% higher when the wind blew from the direction of the motorway. Voigtländer et al. (2006) found a higher correlation at the lee side of the building than on the luff side for particles that ranged from 10 to 100 nm. The study was performed in a busy street with multi-storey buildings on both sides. In our investigated office building the air intake was at the other side of the building than the highway was and the side facing the highway was more in an open field. Our situation is more comparable with the study of Morawska et al. (1999) who identified no significant differences in number concentrations (16-626 nm) for horizontal (up to 200 m) and vertical (up to 15 m) distance. Furthermore, Hitchins et al. (2002) studied the best orientation for the air inlet. For the ultrafine particles (15-697 nm) no significant difference for the different sides of the building was measured in low-rise buildings.

This implies that traffic is a major contributor to this dust fraction. Traffic-related dust, including ultra fine PM down to 0.6µm, is known to travel without concentration loss over a distance of up to 200 m (Morawska et al. 1999).
The high ratios in the range of 0.2-0.3µm were expected since the efficiency of F7 filters is low for this range (Fisk et al. 2002). This is also in line with Sippola and Nazaroff (2003), who modelled the deposition of particles in air ducts and found that particles <1µm hardly deposit.

The impact of indoor activity was found for $PM_{2.5}$ and PM_{10}. This is consistent with the findings of Morawska et al. (2003). They studied 15 homes in Brisbane Australia near a major traffic road to measure the effect of indoor activity on the indoor/outdoor ratio. Not only for the larger particles ($PM_{2.5}$) this effect was found but also for the smaller particles (70-808 nm). Since this concerned all homes, at night, the windows were closed. The indoor activity took place during the evening while the indoor/outdoor ratio during the day was mainly influenced by the outdoor concentration due to the open windows. Furthermore, He et al (2004) studied the same homes to identify indoor sources. That study reported indoor sources such as frying, stove use, toasting, cooking, etc. that increase the small particle number concentration about 5 times.

In our study we measured indoor-outdoor ratios of 23% for particles with a diameter of 500-700 nm and 54% for 200-300 nm particles. Jamriska et al. (2000) showed a ratio of 17%. However, the recirculation rate was 90%. In our HVAC system no recirculation was present, only rotational heat recovery.

After maintenance, the level of resistance of the newly installed F7 filters was higher than that of a polluted filter because the new air filters were fitted with foam-tape strips in order to reduce air leakage around the filters. This may have contributed to the higher particle filtration rate after maintenance. But this higher capture rate of the HVAC system in the lower ranges, had little influence on indoor air for the reasons mentioned above.

The domination of the particle number concentration of PM 0.2-0.7µm by outdoor concentrations before and after maintenance not only occurred during weekdays and at weekends, but also during the nights when the HVAC system was turned off. This finding suggests that other transmission modes such as infiltration through the building's envelope by outdoor particulate matter are important.
This case study was restricted to a single office building (built in 1989) and a single type of HVAC system sampled in winter and will have to be repeated during other seasons, for other buildings and for different HVAC systems, including those that use humidification that could trap ultra-fine dust. In the study of Hänninen et al. (2005) the penetration rate of PM2.5 in offices built before 1990 was lower (0.48±.25, n=85) than for offices built between 1990 and 1997 (0.35±.0.21, n=9). In the sample of the older buildings 78% contained filters, while newer buildings were all equipped with filters. In this study data for all seasons were collected. For office buildings a minor effect could be observed. In case of residential buildings, the indoor/outdoor ratio is higher during summer months, suggesting occupants are having their windows open more frequently. In our study the windows could not be opened.

3.1.5 Conclusion

Common mass measurements of PM pollution ($PM_{2.5}$, PM_{10}) appeared less suitable for studying traffic related PM phenomena than particle number concentrations.

Indoor air pollution with traffic-related dust in the 0.2-0.7µm diameter range was correlated with outdoor pollution in a mechanically ventilated office building in the Netherlands that was sampled during winter. Installing better fitting filters and cleaning the AHU did not improve indoor conditions, although the capture rate increased. The HVAC is an important transmission mode, but in this study the infiltration through the building envelop appeared more dominant. Attention should be paid towards the quality of envelopes of older buildings before interventions of advanced filters in air handling units are proposed.

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Section 3.2[1]

Preventing chronic lung disease in an ageing society through improved building ventilation: a financial assessment

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ABSTRACT. Leading edge ventilation systems in buildings might slow down the degradation of quality of life due to COPD (Chronic Obstructive Lung Disease), lung cancer and asthma. We performed an economic assessment to determine the Incremental Cost-Effectiveness Ratio (the amount of money needed to produce one healthy life year) for a full-scale ventilation upgrade of the building stock in the Netherlands. The upgrade includes the capacity increase of ventilation systems in dwellings and schools, as well as demand-driven ventilation control. Ventilation systems are compared by (i) operating costs, (ii) health care costs, and (iii) changes in DALYs (Disability Adjusted Life Years). This resulted in a yearly additional technical operating cost of the upgrade of €113 × 10^6 per million inhabitants of the Netherlands. Yearly health benefits per million inhabitants consist of 5,000 DALYs and €23.9 x10^6 of health care expenditure. This leads to an Incremental Cost-Effectiveness Ratio (ICER) for one extra healthy year (DALY) of € 18 × 10^3, which is an acceptable amount for a healthy life year in the Netherlands. Future simulation studies will be required to increase the accuracy of this assessment.

Key words: building ventilation, demand-driven control, economic assessment, lung disease

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[1] Published in *Gerontechnology* 7(4): 374-387.

3.2.1 Introduction

In general, the prevalence of chronic disease is highest at higher ages resulting in increasing health care expenditures (Boyd 2006). However, for asthma, the prevalence appears to be highest in children of 0-14 years old (26%) compared to adults of 60 years or older (15%) (Smit et al. 2007). Discounting for multiple diseases, 700,000 of the 16 million Dutch inhabitants in 2003 had asthma, COPD or lung cancer. About 210,000 of these persons were in the 65-years and older age category (Hoeymans et al. 2006). Asthma, as well as COPD and lung cancer, is expected to increase by 26-47% (Hoogendoorn et al. 2004; Baan et al. 2007) in 2025, mainly due to ageing.

One of the characteristics of chronic lung disease is its relationship to the lifelong sum of exposures to allergens and ETS (Environmental Tobacco Smoke) (Annesi-Maesano & Dab 2006). This means that all types of indoor spaces that people visit during their lifetime, need to be taken into account. A recent Silver Paper (Cruz-Jentoft et al. 2008) asks for such a life course approach to health promotion and preventive action. To be effective these actions should be both technically and economically feasible and start with providing children with a ‘clean’ environment.

Dedicated ventilation systems may slow down the development of disease and preserve the independence of those affected (Snijders et al. 2001). For ETS, the efficiency of ventilation plays an essential part in removing tobacco smoke from indoor spaces (Ning et al. 2006). The number of allergen producing mites and fungi in buildings is reduced by low indoor relative humidity affected by a suitable ventilation system (Harving et al. 1994).

In this article we will assess an upgraded ventilation design for buildings from a macro-economic viewpoint. To evaluate the financial feasibility of this intervention, we include the costs of preventing chronic lung conditions, the reductions in health care expenditure, and the resulting decrease in the individual disease burden. We calculated the Incremental Cost-Effectiveness Ratio (ICER), i.e. the amount of money needed to produce one extra healthy life-year, of an upgraded ventilation design for the Dutch building stock.

3.2.2 Methodology

Since climatic conditions (e.g. seasonal temperature and humidity), local building standards (e.g. prescribed minimal ventilation rate) and the quality of the building stock (e.g. insulation, airtightness of building envelopes and ventilation systems) are all parameters that vary among regions, we chose to confine this first assessment to a single country: the Netherlands. To determine the Incremental Cost Effectiviness Ratio (ICER), the extra operating costs of the intervention, the reduced health care expenditures and the gained DALYs (Disability Adjusted Life Years) are required. Therefore, the reduced exposure to disease-related pollutants (Reduction Factor) as a result of the intervention, and the health effect of lower exposures to these pollutants (Attributable Factor) were established. Both the Attributable Factor (AF) and the Reduction Factor (RF) are needed to compute the gained DALYs (benefits) as well as the extra operating costs of the intervention and reduced health care expenditure (costs). This study is limited to asthma, COPD and lung cancer, which are all indoor air associated diseases. The disease-related pollutants are limited to house dust mite allergens (asthma) and ETS (COPD and lung cancer). The calculation model used in this study is presented in Figure 3.2.1.

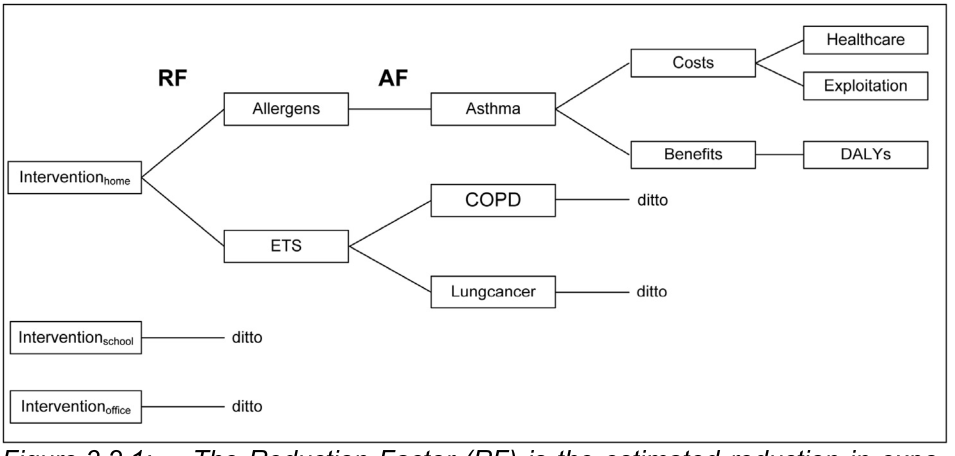

Figure 3.2.1: The Reduction Factor (RF) is the estimated reduction in exposure as a result of the upgraded ventilation systems; The Attributable Factor (AF) is the estimated health effect attributable to exposure; The costs and benefits for COPD and lung cancer are identical to those for asthma, in the diagram indicated by ditto; The intervention for schools and offices is identical to the intervention for homes

Current building ventilation

The 2003 Dutch building stock contained approximately 7 million dwellings (CBS Statline 2007a), eight thousand schools (CBS Statline 2007c) and 42 x 10^6 square meters of offices (Zuidema 2007). Dutch homes have natural ventilation (35%), mechanical exhaust ventilation (55%) or ventilation with heat recovery (10%) (Gids & Op 't Veld 2004). There is no such data available of schools and offices. On the basis of our own observations, we assumed that 10% of the schools are equipped with natural ventilation and 90% with mechanical exhaust ventilation. For offices, we assumed that 10% are equipped with mechanical exhaust ventilation and 90% with heat recovery in the ventilation system.

The efficiency of current systems in removing pollutants (including moisture) appears to be limited as evidenced by the high prevalence of chronic lung diseases mentioned above. Studies showed an average of 0.59 ACH (Air Changes per Hour) in mechanical ventilated homes (n=22) and 0.27 in homes with mechanical exhaust ventilation (n=29) and 1.7 ACH for schools (Emenius et al. 1998; Smedje et al. 1997). For offices ventilation rates are reported mostly above the codes (7.0 l/s per person), only natural ventilation performed below the ventilation requirement (Bluyssen et al. 1996). The low ventilation rate in homes in Sweden is comparable to mechanically ventilated Dutch homes. The capacity in 84% of the homes was below 21 l/s (only sufficient when occupied by three persons or less) (Dongen & Vos 2007).

Required ventilation rate

Increased ventilation rates are required to remove more indoor pollutants. Therefore, a required ACH has to be set.

Regarding mite allergens, ventilation does not only remove allergenic particles, but also keeps the indoor air humidity at lower levels in order to prevent mite growth (<45%) (Emenius et al. 2004). Low relative humidity (RH) levels can only be achieved in the heating season (winter) when indoor air is heated by a heating system. A case-control study performed in Denmark showed an ACH value of 1.5 reduced mite concentrations in mattresses (Harving et al. 1994). The relationship between dampness and growth of house dust mites showed that within 15 months, an increase of the ventilation from 1 to 1.5 ACH resulted in 80% less medication use. The mite concentration in house dust decreased from 210 mites/g to 30–55 mites/g, well below the hygienic limit of 100 mites/g. This would mean that this intervention is 100% effective for mite concentrations. Fisk (2000) reviewed six papers for the association of domestic mechanical ventilation systems with indoor air humidity, dust mite levels and allergy symptoms. Five of the six reviewed papers did indeed show a significant correlation between increased ventilation and/or lower humidity levels and mite concentrations

and/or reduced asthmatic symptoms. The one study that did not show significant results was conducted in a mild and humid climate. Also Peat et al. (1998) reviewed 20 papers for housing characteristics and house dust mite levels in homes. Eleven papers stated that indoor humidity as a housing characteristic is associated with house dust mite levels.
In the Netherlands, mattresses are one of the major niches for house dust mites (Snijders 2001). Another major niche is upholstered furniture. Our study is limited to mattresses since no case-control studies on upholstered furniture and increased ACHs is available. A Swedish study by Munir et al. (1995) found, however, a correlation between relative humidity and mite counts in soft furniture. As the heating season in the Netherlands is shorter than that in Denmark, a higher ACH value is needed to exterminate mites. In the Netherlands there is a 20% higher risk of noxious mite allergen levels compared to Denmark (Lynden-van Nes et al. 1996). In order to apply the data from the Danish case-control study to the Dutch climate, an adjustment needs to be made. With a threshold limit of 45 % relative humidity during winter, a value of 2 ACH is required (Luxemburg et al. 1997). Although the studies of Harving et al. (1993; 1994) showed mite counts below hygienic level in 100% of cases after intervention, we set the reduction at 75%.

To establish the required ACH to reduce ETS, a distinction should be made between cigarette constituents in the vapour phase and those in the Respirable Suspended Particles (RSP) phase. Concerning RSP, Ning et al. (2006) showed a decrease in particle concentrations at three different ventilation rates (3.6 ACH, 55 ACH and 79 ACH). The background level of RSPs was reached after 30 min at the highest rate and after 90 min at the lowest one. However, high ventilation rates cause more absorption of vapour constituents (such as nicotine) by furnishings and finishing material in indoor spaces, resulting in increased concentrations after desorption. Singer et al. (2002) and Nelson et al. (1992) showed a rise in nicotine concentrations over time. However, in these experiments, additional fans were present to provide better air circulation, causing more absorption and later desorption of vaporised constituents of ETS on wall surfaces. In real indoor settings, however, there is no perfectly mixed air. Singer et al. (2002) also reported on the impact of different ACH values (0.3, 0.6 and 2 ACH) and the presence of finishing material and furniture in a test chamber on the exposure-relevant emission factor of nicotine. They reported a threefold lower exposure-relevant emission factor (effect of absorption and re-emission over 24 hours) for nicotine in a fully furnished room compared to a wall board covered room (without furniture).

Sistad & Bronsema (2002) developed steady-state models to calculate the air supply rates required to remove nicotine and RSP to an acceptable level (0.5 μg/m3 and 50 μg/m3 respectively). Since the model for nicotine ignored the absorption effects of finishing materials and furniture, and several studies described the adverse effect of higher ventilation rates, we did not apply

Sistad and Bronsema's nicotine model, but only the model for computing the required ventilation rate for removing RSPs.

$$q_v = \frac{p \cdot n \cdot g_{pm} \cdot 10^3}{A \cdot c_{pm} \cdot 3{,}6} \qquad (1)$$

p	percentage of smokers	30% (CBS Statline 2007b)
n	number of cigarettes smoked per hour	2 cigarettes per hour
g_{pm}	average particle emission in mg/cigarette	25 mg/cigarette (Martin et al. 1997)
A	floor area per person in living room in m^2	25 m^2
c_{pm}	particulate concentration in µg/m3	50 µg/m^3

These input parameters lead to an Air Exchange Rate (ACH) of 5 to lower the RSPs to 50 µ/m3 (height of living room: 2.5 m). The model is based on continuous smoking, but the hours spent in the home environment do of course also include sleeping and other non-smoking activities. This means that production of ETS in the home environment only occurs during the hours of smoking. According to Singer et al. (2002), the ACH should be set lower after smoking in order to minimise the absorption and desorption of the vaporised constituents. The concentration of vapour constituents take many days to drop to background level. Assuming occupants smoke cigarettes on a daily basis, there is no reduction to acceptable levels achievable. Since we are only able to lower the particle constituents and not the vapour constituents, we established a reduction in noxious exposure of 50%.

Assuming that ETS exposure only takes place in living rooms, the maximum ACH value is based on 5 ACH in a living room (during smoking) and on 2 ACH in other rooms to decrease mite growth only (e.g. the bedroom). It is assumed that occupants only smoke 3 hours a day, resulting in 5 ACH in the living room during 3 hours needed to remove RSP. For the other 21 hours, the ACH value can be set at 2 ACH to exterminate mites in furniture. The average ACH in living rooms in smoking households should be therefore 2.4. When the ACH in other spaces is 2, the average ACH in homes occupied by smokers is 2.2. For non-smoking households, the ACH in living rooms is 2 and in others spaces 2, resulting in an average ACH of 2 in homes without smokers. Since our assessment is applied to the Dutch housing stock, the weighted average ACH in Dutch dwellings is 2.1 (30% smoking- and 70% non-smoking households).

In schools, the increased ventilation rate is based on scaling up to the national standard of 1.7 ACH or 7.0 /person (Gezondheidsraad 1984). In this study, we do not recommend an additional increase of ventilation rate beyond the standard level, as the amount of house dust mite allergens in

schools is below the hygienic level (Van Dijken et al. 2006) and ETS is not present in schools (Staatsblad 2002). Therefore, these exposures are not associated with the development of asthma, COPD or lung cancer.
Offices do not require an increase in ventilation rate as the ventilation rate in offices usually meets the hygienic limits (Bluyssen et al. 1996). Since this study is limited to house dust mite allergens and ETS, no adverse related health effects of the current systems are expected.

Intervention

To increase ventilation efficiency in buildings, we suggest upgrading the existing ventilation systems. For this purpose, most of the existing systems can be left intact, including the ventilation principle (natural or mechanical air supply), but the control mechanisms and actuators need to be replaced in order to obtain demand-driven control. In case no ventilation system is present (fully natural ventilation), a new demand-driven ventilation system with natural supply (controlled grills) and mechanical exhaust (supply driven) should be installed.
To realize demand-driven control, tobacco smoke detectors are to be installed in living rooms of dwellings and presence or humidity detectors in all rooms to control mites. In schools and offices demand-driven control can be based on presence detection.

In addition, ventilation fans will have to be replaced to supply and/or exhaust more air. Particular attention should therefore be paid to the noise generation of the ventilation upgrade. Currently up to 20% of the occupants of dwellings complain about noise discomfort caused by ventilation systems (Dongen & Vos 2007). Unacceptable noise levels (above 35 dB(A)) may be prevented by fans maintaining air velocities below 4 m/s in ducts, and by placing proper silencers (Gids & Op 't Veld, 2004).

Attributable Factor

The most important indoor pollutants are ETS, nitrogen dioxide (NO_2), Carbon Monoxide (CO), total Volatile Organic Compounds (VOCs), particulate matter (PM), and biological allergens. ETS is a significant contributor to NO_2, CO, TVOCs and PM in the indoor environment (Viegi et al. 2004). All these effects are incorporated into the AF for ETS. Aside from ETS, the combustion pollutants (CO, NO_2, and TVOCs) stem chiefly from malfunctioning, or inappropriate, inefficient use of heating devices. TVOCs are also emitted by common household products (US-EPA, 1994). In Europe, the CO and NO levels are below the WHO threshold for long-term exposure, and noxious effects of TVOCs seem to be less relevant than those of other typical indoor pollutants (Viegi et al. 2004.). Towards Asthma, only ETS and House Dust Mites showed sufficient evidence for the exacerbation of asthma in sensitive individuals as well as an association for the development of asthma (Institute of Medicine 2000).

Since the relevant exposures to pollutants may start early in life, the entire lifespan of the Dutch population in 2003 was taken into consideration. Dutch inhabitants spend 83% of their indoor life at home, 3% at school, and 11% in offices. This is based on a population-weighted calculation using data on the living, working and school situations for people over the age of twelve (CBS Statline 2006; CBS Statline 2005a) as well as on an estimate based on additional data for children under twelve (CBS 2003; Bostelen et al. 2007). Seen from the perspective of duration of exposure, dwellings are the most crucial locations. Exposure time and intensity both affect human health. It is therefore not only on the basis of exposure time that homes are crucial, but also because the intensity of allergens and ETS is highest in homes. Mite allergens in schools and offices are in general below the threshold level for allergic disease development of 100 mites per gram (Dijken et al. 2006; Macher et al. 2005).

The AF for asthma as a result of house dust mite allergens was set at 80%. This is mainly based on the medium-term association of asthma and house dust mites found in a 12-month retrospective study by Miraglia del Giudice et al. (2002) for 7-12 year old children (Odds Ratio 4.84, 95% CI = 2.42-9.60). The associations for 0-3-year old children and 4-6-year old children were lower, suggesting that the exposure time appears relevant. However, the AF is also based on the significant short-term effects that indicate that immediate hypersensitivity can lead to asthma (Lanphear et al. 2001) and sensitised children have more daytime asthma attacks (Nitschke et al. 2006). According to a review by Richardson et al. (2005), there is sufficient evidence for a causal relationship between house dust mite allergens and the development of asthma, allergen exposure and exacerbations of asthma in individuals already sensitised.

The AF for COPD as a result of ETS was set at 60%. This percentage is a conservative estimate based on a study by Robbins et al. (1993), who computerized an algorithm through analysing questionnaires of subjects obtained between 1977-1987 (n=3918) in order to identify new cases of airway obstructive disease due to passive smoking in both childhood and adulthood (relative risk: 1.72 (95% CI = 1.31-2.23). Although a meta-analysis by Law and Hackshaw (1996) mentions a lower risk of ETS for adults with chronic respiratory disease, the estimate for both children and adults appears plausible as Leuenberg et al. (1994) found a similar high elevated risk of symptoms of chronic bronchitis for adults exposed to passive smoking.

The AF for lung cancer as a result of ETS was set at 25%.This is based on three meta-review studies that pooled the effects of increased risk of lung cancer from second-hand smoking. Although the Dutch Health Council suggests a value of 20% (Gezondheidsraad 2003), the chosen value of 25% is within the range of the 20 to 30 percent suggested by the US Surgeon

General (US-DHHS 2006) for the increased risk of lung cancer from second-hand smoke exposure associated with living with a smoker. Furthermore, this result fits the 26% (95 % CI = 7%-47%) excess risk stated by Hackshaw et al. (1997). Next to smoking, a major risk factor for lung cancer is radon (US-EPA 1994). In the Netherlands, the average concentration is 28 Bq/m3 which is mainly due to emission from building materials (Janssen 2003). As the risk of lung cancer linearly increases by 16% per 100 Bq/m^3 (WHO 2005), the AF for radon would be 4,5%, which is clearly less than the 60% for ETS and therefore excluded in our study.
The AF for ETS in relation to asthma was not taken into account. Although it must be said that the Dutch Health Council concluded that passive smoking can lead to an increased risk of asthma of 20 to 50 percent (Gezondheidsraad 2003) for children. Averaging the risk stated by the Dutch Health Council, led to an AF for asthma of 35%. However, the estimated AF for mite allergens in relation to asthma is currently higher than that for ETS.

Operational costs

The investment needed to upgrade existing ventilation systems was estimated at 2 times the cost of current ventilation systems with heat recovery (balanced ventilation systems) for dwellings, 2 times the cost for schools and 1.2 times the cost for offices.

The higher cost for dwellings is based on both increased ventilation rate (bigger fan(s), extra ductwork and noise silencers) and the equipment required for demand control (humidity, presence and ETS detection). A new demand controlled ventilation system was accounted to twice the cost for a mechanical ventilation system with heat recovery, approximately €20 per m^2 (Klein Gunnewiek 2005). Since the ventilation system is only an upgrade, the investment for the existing ventilation system is subtracted.

An increase in capacity requires more powerful fans and bigger distribution systems (e.g. ducts). In schools, only the upgrade to the ACH according to national standards and the equipment for demand control (presence detection) need to be installed. In offices, only additional equipment needs be integrated into the existing control system.

The depreciation costs ($C_{depreciation}$) were simply calculated by dividing the investment ($C_{investment}$) by the depreciation period. In this calculation, the depreciation period was 15 years. Besides depreciation costs, there will also be the costs of interest rate (I). These costs can be calculated on the basis of the average investment (50% of the total investment during this period) and the interest rate. As to the interest rate (I), we used the recent average interest on loans in the Netherlands of 5% per year. The interest costs ($C_{interest}$) were calculated as follows:

$$C_{interest} = \frac{C_{investment}}{2} \cdot I \qquad (2)$$

Maintenance costs ($C_{maintenance}$) indicators for HVAC systems in the Netherlands were also used (Klein Gunnewiek 2005). We assumed that the maintenance costs for the upgraded ventilation systems equal the maintenance costs for balanced ventilation systems. No additional costs were calculated for the ACH upgrade itself.

The Dutch standards for energy performance (NEN 2004a; NEN 2004b) constituted the basis for calculating the additional energy costs (C_{energy}). Upgrading ventilation in dwellings was scaled up to temporary 5 ACH (living rooms) or 2 ACH (other spaces).

For schools, the energy costs were based on 1.7 ACH. The energy costs of offices were based on similar ACH values compared to the current office stock. Since all the ventilation systems are demand driven, an energy reduction in homes, schools and offices of 50% (Pavlovas 2004), 40% (Fisk & De Almeida 1998) and 22% (Fisk & De Almeida, 1998) respectively is expected.

The operating costs were calculated as follows:

$$\Delta C_{exploitation} = \Delta C_{depreciation} + \Delta C_{interest} + \Delta C_{mainainance} + \Delta C_{energy} \qquad (3)$$

Health care expenditure

In 2003, health care expenditures of asthma and COPD in the Netherlands amounted to € 739 x10^6 (Slobbe et al. 2006). Unfortunately, the costs of asthma and COPD care in the Netherlands are grouped under one header. We therefore used the ratio of costs that Hoogendoorn et al. (2006) found for asthma and COPD in order to separate the costs of asthma and COPD.

The Attributable (*AF*) and RFs (*RF*) (see above) were applied to the total costs of the chronic diseases to calculate the reduction in health care expenditure per disease (*d*):

$$\Delta C_{healthcare} = \sum_{d=1}^{n} AF_d * RF_d * C_{d,healthcare} \qquad (4)$$

Calculation of DALYs

Health gains were measured in *DALYs*, a health gap measurement for the impact of a specific disease on the quality of life by calculating the years of life lost due to a disease using mortality and weighted morbidity data (Lopez et al. 2006)

$$DALY = YLL + YLD \tag{5}$$

Where:
YLL: Years of Life Lost,
YLD: Years Lost to Disability

The Years of Life Lost correspond with premature death and the Years Lost to Disability. Years Lost to Disability is the multiplication of the prevalence of the disease and a weighting factor. This weighing factor was established for all diseases by the National Institute of Health and Environment (Hoeymans & Poos 2006) and depends on the physical or mental limitations caused by a disease (WHO 2006).

Incremental Cost Effectiveness Ratio

The annual extra costs (ΔC_{net}) for the intervention were calculated by first determining the extra annual operating costs ($\Delta C_{operating\ costs}$) and subtracting reduced health care ($\Delta C_{healthcare}$):

$$\Delta C_{net} = \Delta C_{\exp loitation} - \Delta C_{healthcare} \tag{6}$$

The costs of an extra healthy year (*DALY*) come from a macro-economic calculation based on figures normalised for the year 2003. The costs per 1 DALY follows from the *ICER*. If the total annual extra costs (ΔC_{net}) of the intervention and the number of gained DALYs ($\Delta DALYs$) are known, the extra costs for 1 *DALY* gained can be easily calculated as follows:

$$ICER = \frac{\Delta C_{net}}{\Delta N_{DALYs}} \tag{7}$$

The *ICER* is the amount of money needed to produce 1 *DALY*, in our study, the extra operating costs of upgraded ventilation systems invested for improving building ventilation. Such a result can easily be compared to the *ICERs* of other socially investments.

3.2.3 Results

Improved human health

Buildings contributed significantly to the disease burden, with AFs of 80% for asthma, 60% for COPD and 25% for lung cancer. The AF and the established RF per exposure together constitute the reduced ratio for chronic disease burden related to the upgrade of the ventilation systems. It ranges from 13% for lung cancer to 60% for asthma (Figure 3.3.2).

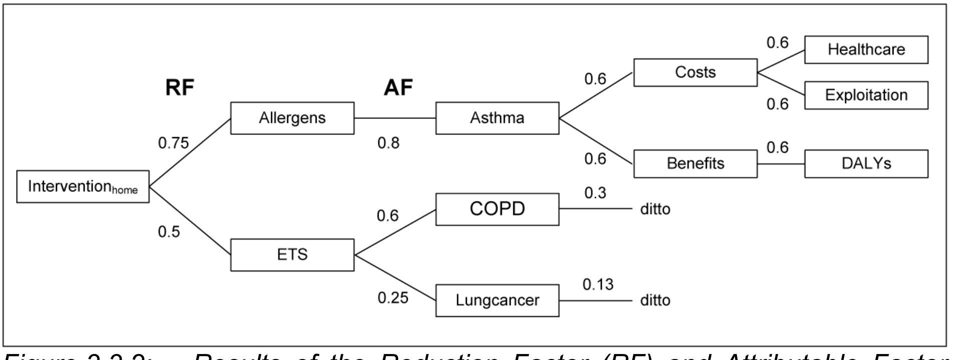

Figure 3.3.2: Results of the Reduction Factor (RF) and Attributable Factor (AF) per exposure and disease in the Calculation Model for Homes

Costs

Total investment costs are huge, amounting to €1.4 x10^9 of which dwellings alone take up 100% of the reduction in health care expenditures and DALY gains, since only house dust mite allergens and ETS are considered. Besides investment costs, the additional operating costs of the upgrading such as (i) the depreciation of investment, (ii) interest, (iii) maintenance, and (iv) energy costs of the dwellings are also dominant factors. The total additional operating costs are €1.8 x 10^9 a year (Table 3.2.1). Calculated per million inhabitants, this would amount to €113 x 10^6 a year.

Table 3.2.1: Yearly additional operating costs after full penetration of the ventilation upgrade in different types of buildings (Index year 2003, investment €22.1 x 10^9, €47 x 10^6 and €1.2 x 10^9, for dwellings, schools and offices respectively)

Cost origin	Changes in operating costs in € x 10^6			
	Dwellings	Schools	Offices	Total
Depreciation	1,400	3.0	80	1,500
Interest	500	1.0	30	500
Maintenance	300	0.2	13	300
Energy	-400	-21.0	-65	-500
Total	1,800	-16.8	57	1,800

Benefits

On the benefit side we see a yearly gain of 81 x 10^3 DALYs and €383 x 10^6 for health care expenditure (Table 3.2.2). This equals approximately five thousand healthy years (DALYs) and €24 x106 per million inhabitants.

Table 3.2.2: Benefits for Health Care Expenditure (in €), and healthy years (DALYs) gained for different diseases (index year: 2003)

Cost origin	Expected Disease Reduction Rate in %	Health Care Expenditure		DALYs	
		Total 2003 x 10^6	Expected gains x 10^6	Total 2003 x 10^3	Expected gains x 10^3
Asthma	60	496	297	34	20
COPD	30	212	64	146	44
Lung cancer	13	173	22	135	17
Total		881	383	315	81

Since the AFs are fully based on allergens and ETS, the benefits are gained through the intervention in dwellings only.

Incremental Cost-Effectiveness Ratio

ICER (cost of one extra healthy year) at full penetration of the ventilation upgrade is €18,000.

The *ICER* determines, after subtracting the benefits gained by a reduction of health care expenditure, what society has to pay for one additional healthy life-year. Whereas health care expenditure is of direct value to society, *DALY* gains contribute to better socially quality of life.

Sensitivity of analysis

Varying the disease-specific RF and AF, gives an indication of the sensitivity of the calculations. When the multiplication of Reduction and AFs are lowered to two-thirds, from 60, 30 and 12.5% to 40, 20 and 8% for asthma, COPD, and lung cancer respectively, the *ICER* for the ventilation upgrade increases to €29,000.

Since the investment determines the depreciation and interest costs, and both of these account for almost 70% of the total exploitation costs, the variance of the investment is a nearly linear function. If the investment to achieve full penetration of the upgrade in dwellings is not 2 times, but 3 times the cost of a standard balanced mechanical system, the *ICER* is €26,000.

When the penetration of the upgraded ventilation design only takes place in dwellings and not in schools and offices, the *ICER* remains €18,000.

The energy cost reduction in schools and offices through demand control is more or less equal to the financial operating costs and additional maintenance costs. The reduced energy consumption in dwellings has been established at 50%. When the energy reduction through demand control in dwellings is reduced from 50% to 25%, the *ICER* is €23,000.

This sensitivity analysis shows the importance of the accuracy of (i) the AF and RFs, (ii) the investment of the upgraded design in dwellings and (iii) the energy reduction by demand-controlled ventilation systems. This analysis also shows the dominance of the full penetration of the intervention in dwellings.

3.2.4 Discussion

This contribution of this study bridges a gap between the building and health domains as it considers both health benefits and ventilation operating costs (including energy costs) in its assessments. Its feasibility depends on the amount of money society is willing to spend on one extra healthy year in a lifespan (Brown et al. 2003; Coast 2004). The WHO suggested a value of one to three times the GNP (Gross National Product) per capita; within this range, an intervention is deemed to be cost-effective (Sachs 2001). For the Netherlands in 2003, this would amount to €29,000 to €87,000 for 1 DALY (CBS Statline 2005b). It is interesting in this respect that the *ICER* of one healthy year of €18,000 is well within the acceptable Dutch range, even when the higher value of the sensitivity analysis of €29,000 is taken into account. Macro-economically speaking, the ventilation upgrade we suggest is financially feasible. Technically speaking, feasibility is also high since only known technologies are included in the upgrade.

The fact that the *ICER* (cost of one healthy year) appears to be most sensitive to a proportional change in the reduction rate of COPD, can be explained by the high DALY attributed to COPD, nearly all derived from disease year equivalents in the older age categories, and not from premature deaths (Hoeymans et al. 2006).

Current Dutch building code requirements for ventilation systems are primarily geared to the reduction of energy consumption (Staatscourant 1995), and not to the prevention of chronic disease (Gezondheidsraad, 1984). However, Fisk & De Almeida (1998) showed that improving indoor air quality does not have to lead to higher energy consumption. They concluded that demand-controlled ventilation is an increasingly attractive technology for controlling both indoor air quality and the ventilation system's energy consumption. This study confirms the ability of upgraded ventilation systems to improve health without an increment of energy consumption.

The AF for COPD and lung cancer was established on the basis of population studies in which no distinction was made between the vaporised and particle constituents of ETS. In our intervention, the upgraded ventilation systems, only the particles constituents can be controlled, not the vaporised constituents. ETS contains thousands of gases. This makes it rather complicated to establish the effect of every single component on COPD and lung cancer. This implies a major uncertainty in our assessment. The AF for asthma on the other hand in our study was only determined by house dust mite allergens. A house dust mite is a single organism and therefore it is less complicated to establish its effect on asthma.

Our macro-economic assessment did not incorporate productivity gains and diminished sick leave (Wargocki et al. 2002), nor the effects of improved school performance (Shaughnessy et al. 2006) on the benefit side, and, on the cost side, the extra health care costs related to the increased number of surviving older adults since indoor conditions have improved (UN 2006). We assume the two amounts are about equal, since Fisk & Rosenfeld (1997) found additional productivity gains within the range of \$14 to 32.5 $x10^9$ (indexed for 1993, currently equal to €10 to 24 $x10^9$). This equals €33 to 80 $x10^6$ per million inhabitants. Translated to the Dutch population, approximately €0.5 to 1.3 $x10^9$ can be gained by increased productivity. In the same study the reduction in medical costs were calculated to be \$3.7 to 10.7 $x10^9$, corresponding (currently) to €2.7 to 7.8 x109. Adapted for the Netherlands, the medical costs would be €144 to 416 $x10^9$ (€9 to 16 $x10^6$ per million inhabitants). In our assessment, the reduction in health care expenditure amounted to €383 $x10^6$; which is of the same order of magnitude. Whereas Fisk and Rosenfeld included allergy, asthma and respiratory diseases for health care expenditure, we included asthma, COPD and lung cancer. Future research involving long-term simulations may improve the accuracy of our calculations.

Since Dutch citizens spend over 70% of their lifetime in dwellings (CBS Statline 2005a) and as these buildings are more polluted than schools or offices, it appears that upgrading ventilation systems should focus on existing dwellings, in spite of the high operating costs for these buildings. It could be argued that we calculated costs and benefits for the whole population, although diminishing pollutants only benefits persons developing asthma, COPD or lung cancer. However, homes are built for at least 50 years and will have different owners, tenants and visitors during their lifespan. Chances are that at least part of the time an occupant will be part of the risk group. Although people spend less than 3% of their lifespan in schools (CBS 2003), it is mainly in the sensitive early years that allergies develop. So, upgrading ventilation systems in this domain remains crucial. The ventilation rates in offices already meet the hygienic requirements in the Netherlands (Bluyssen et al. 1996). Our upgrade will be especially important for a reduction in energy use in offices.

Given the building-related exposure levels of house-dust mites and ETS, exposure at home remains a major health risk. To improve the overall health of the population, it may be wise to start the ventilation upgrade in dwellings.

Outside the Netherlands, the financial and technical feasibility of the new ventilation design may vary since the socially acceptable value of one DALY depends on economics and local standards. Furthermore, disease prevalence, exposure levels, health care expenditures, the state of the current ventilation systems in relation to outdoor climate, energy costs, etc. are all parameters that may vary from region to region. We recommend that our colleagues in other countries also apply a macro-economic assessment of the interdisciplinary domain of indoor air science and health to their regions as a first step towards improving public health.

3.2.5 Conclusion

The suggested ventilation upgrade will prevent and diminish chronic lung diseases such as COPD, lung cancer and asthma at a monetary cost for an additional healthy year of €18,000. This will especially benefit the older age categories in the population (where COPD and lung cancer is most prevalent), and is socially acceptable and technological feasible in the Netherlands. For other regions, new calculations with local values of the parameters will be required.

3.2.6 References

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CHAPTER 4: SUPPORT OF WELL-BEING

In our ageing society, not only physical ailments stress the health care system and increase expenditures, but also reduced well-being. Home automation was chosen to determine the effect on well-being, the third branch in this dissertation.

We studied the following home automation appliances that are related to well-being: community alarms, burglar alarms and video-entry phones (Section 4.1). Senior citizens have a different perception of home appliances as compared to the one that their designers or engineers expected them to have.

This chapter shows the need for building services to collaborate with professionals of the gerontological domains.

Section 4.1[1]

The effectiveness of supply-driven home automation appliances among different household structures

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ABSTRACT. Home automation appliances such as burglar alarms, personal alarms and video-entry phones are installed in the homes of older persons to prolong their autonomy. These technologies should support their needs at the level of safety and social activities as defined by Maslow's needs hierarchy. We studied the actual needs for the supplied burglar alarms, community alarms and video-entry phones. Five homes at 15 publicly funded housing projects were studied to determine (i) which technologies were installed, (ii) what the user experiences were like, (iii) what the individual characteristics of household members were (average age 78), and (iv) what the possible effects on perceived safety were and how their daily life changed as a result. Bivariate analyses revealed no correlations between the installed home automation appliances and perceived safety or daily life parameters. Our results showed that only for single women a slight increase in social interaction could be noted. Single women also reported more often that they made use of the installed home automation appliances. We propose a more demand-driven approach to better meet the actual needs of individuals.

Keywords: change in daily life activities, security, home automation appliances

[1] Submitted to *Gerontechnology*

4.1.1 Introduction

The WHO adopted the term ‘active aging’ meaning that people are realizing their potential for physical, social, and mental well-being throughout the life course and participating in society according to their needs, desires and capacities. Providing adequate protection, security and care is also part of this concept (WHO 2002).
Considering ‘active ageing’, technology may have a positive effect on enhancement, prevention, compensation, and care support for older people (Bronswijk et al. 2002).

In a case-control study with frail elderly, Mann et al. (1999) showed the effectiveness of assistive technology and environmental interventions. In their study, assistive technology was meant to assist people with motor, hearing or vision impairments. The environmental interventions contained bathroom modifications, intercoms, lighting installations, etc. The investigators showed that the rate of decline of the Functional Independence Measure (FIM) is slowed down by assistive technology and environmental interventions. Furthermore, the control group required significantly more nurse visits compared to the group who received assistive technologies and environmental interventions. To decide which assistive technologies and environmental interventions were needed, an occupational therapist assessed the FIM using a demand-driven approach.

In 2000, the Dutch government launched a 4-year, 47.5 million Euro programme for innovative living and healthcare services for Dutch citizens who need health care or health support (Staatscourant 2000). In total, 637 housing and care infrastructure projects were funded; 241 projects received funding to perform a feasibility study (average costs 16 thousand Euro per project), 101 projects for communication about lessons learnt (average costs 58 thousand Euro per project), and 295 projects for care facilities (average costs 129 thousand Euro per project) (Schippers 2004). The application form to obtain the grant, included items to ensure full penetration of technology for care facilities in homes such as personal alarms, and care infrastructure in residential districts such as local care centres. Needs of individual house occupants were not included. This was in fact, a supply-driven approach.

The installed home automation appliances included burglar alarms, personal alarms and video-entry phones. Personal alarm consisted of an apparatus with a large red button and a pendant or chain The bearer calls for help by pushing the red button (Berlo 1998).
An attempt was made to attain full penetration of home automation appliances while ignoring the variety of individual needs. The motivation theory of Maslow shows this variety in ranked layers of individual deficit needs (Maslow 1946). The question is whether full penetration of the

relevant technologies is feasible when individual ranks of needs are not taken into account.

Another factor that was ignored in the Dutch program is the marital status. A European study on ageing and the vulnerability of older persons, revealed that marital status is closely associated with psychological well-being and the receipt of care (Waite 1995). Perceived safety by people who live with a partner is higher than that of singles (Ross & Mirowsky 2002). This feeling of safety belongs to the second layer of needs of Maslow's theory. Most home automation appliances incorporated in the Dutch funding program aim to enhance perceived safety.

The marital status of older adults also showed differences in social relationships (Arber 2004). There were no differences between men and women as such, but the ones of couples do differ. Divorced men and never-married men have fewer memberships of social organisations such as sport and hobbies clubs than married men. In contrast, never-married women have more memberships of social organisations compared to married women, but divorced women, however, have fewer memberships. Using a supply driven approach these differences are not addressed. Therefore, we studied the effectiveness of home automation appliances in relation to the safety perception on safety and changes in daily life among single men, single women and couples.

4.1.2 Methodology

To identify the impact of home automation appliances for different household structures on the perceived safety as well as the changes in daily life, data were collected by a structured interview based on a questionnaire. We took a sample from the projects that received grants from the Dutch programme for innovative living and healthcare services. The projects published in the database on the website that were part of the program (www.iwz.nl) were included in the survey.

Survey

To assess the perceived safety as a result of the installed security technology as well as the changes in daily life, 489 projects in the IWZ internet database (IWZ 2006) were retrieved. Unfortunately, 148 projects were not accessible in the database. This was probably due to the fact that project administration and archiving in the publicly available internet database were carried out by two different parties. Forty-one projects that were completed, were occupied for at least one year by older persons (> 50 years old), and were equipped with at least one security technology (burglar alarm, personal alarm and/or video-entry phone). Videophone was included as technology to enhance social cohesion. The period of one year after building completion was chosen to rule out the effects moving stress and disturbances caused by building faults such home appliances that are not connected.

A random sample of 15 projects was drawn from the total of 41 projects. For two of these 15 projects, the mental abilities of the subjects did not permit reliable interviewing. At another project the management refused collaboration. Five households were visited at each of the remaining 12 projects (n=60).
The structured interviews were carried out by 15 master's level students of the course Home Automation and Robotics in 2006. The students received a short introduction to the aim of the structured interview. They were told that the structured interviews were meant to assess the added value of the installed appliances. They were asked to communicate this purpose to the subjects. The residents were interviewed and the presence of home automation appliances was checked.
All 60 subjects completed the survey. Neither the master students nor the subjects were paid in this study. The students produced an essay including the results of the survey to earn their credits in order to pass the course successfully.

Questionnaire and data analysis

The questionnaire contained 39 items (Table 4.1.1; Appendix A).

Table 4.1.1: the 39-items specified to type of characterization

No items	Category
13	Subjects
7	Home
9	Home automation appliances
1	Perceived safety
9	Changes in daily life

For the data analysis SPSS release 16.01 and Vassarstats (Vassar 2009) were used. SPSS was used to structure the data and to construct new variables. Vassarstats was used for the statistical analysis. The statistical differences between single men, single women and couples were determined using the Fisher Exact Probability Test (2x3 matrix) for nominal variables and the Kruskal Wallis Test (k=3) for ordinal variables. The correlations were computed with the Spearman rank-order correlation coefficient (r_s), two tailed. The Cramer's V was taken to check whether two variables were independent from each other.

Characteristics of subjects

The median age of the interviewed subjects (28 men and 32 women) was 79 (range: 56-95 years). 5 subjects were in the 55-64 age group, 12 in the 65-74 age group and 43 in 75 and older age group.

Households consisted of couples (20 cases) or singles (40 cases; 12 men and 28 women). Only one adult of every couple was interviewed. The interviewer determined who of the household members needed the technology the most. The interviewers decided that in 16 cases, the men would benefit most of the appliances, whereas the women did in four cases. Since a group of four was considered as statistically problematic, this group was excluded from this study. The median age of single men (n=12), single women (n=28) and couples (N=16) was 78.5, 78.5 and 83 respectively.

Health was measured as self-reported health (4 points scale: 1=poor, 2=moderate, 3=reasonable and 4=good). The median self reported health was 3.5, 3.0 and 3.0 for single men, single women, and couples respectively.

Mobility was measured as a self-reported physical ability (5 points scale: 1=wheelchair, 2=wheelchair and walker, 3=using walker, 4=mobility has worsened last years, and 5=fully mobile). The median self-reported mobility was 4, 4 and 5 for single men, single women, and couples respectively.

We considered received support to be an indicator for dependence. All subjects received some form of support: housekeeping (48 cases, 80%), assistance in personal care (60 cases, 100%) or other support (57 cases, 95%). Other types of support included support in personal transport (4), support in shopping (5), and support in social cohesion (1).
The support received was provided by non-professionals (20 cases) and/or by professionals (52 cases). As to housekeeping, all men received support in housekeeping compared to 64% of the single women and 90% of the couples. Single men, single women and couples all received support for daily tasks by non-professionals or professionals.
A measure of dependence was constructed from three categories of support: (i) housekeeping, (ii) daily care and (iii) other support and two types of providers; professionals and/or non-professionals. We did not make the distinction whether the support that was provided by professionals or non-professionals.
The maximum amount of types of support is therefore three which means there are a total of four categories (0= no support and three types of support). Support for housekeeping, support for daily care, and other support were independent of each other (all Cramer's V's < 0.29).

The capability for technology usage was assessed with the self-reported ICT skills (4 point scale: 1=poor, 2= moderate, 3= reasonable, and 4=good). Self-reported ICT skills were computed as the sum of self-reported ICT skills for PC use and mobile phone use. The number of times that 'reasonable/good' was reported, was equal for both PC and mobile phone capabilities (17 times). Therefore, the average of both was taken as measure for ICT skills.

For all variables regarding subject characteristics no significant differences ($p<0.05$) were found. Only the housekeeping support provided by non-professionals showed a statistical difference ($p= 0.0085$).

Home characteristics

For all home characteristics only the floor space of the residence was significantly different ($p=0.022$). The floor space of households occupied by couples was larger. Furthermore, only four homes were owned by the household members. None of the homes had a staircase. Seven households were already living in the home were the technology was installed. They did not temporarily move to another location. Since only the floor space was a significant difference, the items of home characteristics were disregarded in the analysis.

Home automation appliances

The usefulness of the installed appliances was determined by counting how many technologies were used divided by the number of technologies installed.

Technology training was based on the training quality level (1=No training, 2=Manual, 3=Demonstration, 4=Workshop, and 5=Course). We assumed these categories have a logical order. When more types of trainings were reported, we took the highest quality level reported type of training. The constructed variable showed no significant differences among the groups.

Perceived safety and changes in daily life activities

The effect of increased safety of the installed home automation appliances was measured by an item on the impression of safety (0=disagree, 1 agree).

The parameter changes in daily life activities resulted from the sum of positive answers to 9 questions. These items were related to the safety level (5 items) and social level (4 items) of the Maslow hierarchy needs (Table 4.1.2).

Table 4.1.2: Questions regarding change in daily living after installation of the home automation appliances categorized according Maslow's classification of human needs (Maslow 1946)

Maslow's level of needs	Question
Safety	More daytime walks More evening walks Going to bed later Improved sleep quality More visits to leisure centre
Social	More social contacts in the neighbourhood More hobbies More sports activities More shopping alone

4.1.3 Results

Characteristics of subjects

Older women received more support than younger women (r_s=0.39, p=0.04, n=28). For single men and couples no significant correlations were found between age and dependence. The descriptive statistics showed that 57.1% of the women received more than one type of support, for single men and couples, this was much lower 41.6% and 43.8% respectively. However, no significant difference was found for dependence but also not for age. Interesting is that 18.8% of the couples received no support at all. Furthermore, people in poor health received more support. Dependence was correlated with health for single women and couples (r_s=-0.51, p=0.005, n=28 and r_s=-0.58, p=0.024, n=16 respectively) but not for single men. Also mobility was correlated with dependence, for single men and single women these correlations were found (r_s=-0.72, p=0.008, n=12 and r_s=-0.51, p=0.034, n=28 respectively). When a person becomes less mobile then s/he receives more support. For couples such a correlation was not found. This might be explained by the fact that spouses can provide the needed support.

For single women there was also a correlation between health and mobility (r_s=0.44, p=0.021, n=28). This correlation corresponds to the idea that healthy people are more mobile than unhealthy ones. The descriptive statistics showed that single women needed more technical aids such as wheelchairs and walkers (40%) compared to single men (25%) and couples (19%). The self-reported health was more or less equal for all groups. Again no significant differences were found, neither for health nor mobility. From the Dutch statistics (Statline 2009) we know that women older than 65 years are using technical aids more often (19.6%) than men (13.5%). For the subgroup 55-65 years the difference (1.8 %) is lower than that of 75 years and older (5.0%). Note that the interviewed members of the couples were all men in our analysis.

Usefulness of home automation appliances

The home automation appliances encountered at the 60 residences visited were: 16 burglar alarms (4 different projects), 53 community alarms (12 projects) and video-entry phones (8 projects) (Table 4.1.3). In none of the projects the videophone was installed.

Table 4.1.3: Frequencies of installed home automation appliances per household structure (penetration ratio)

	Single men	Single women	Couples	Total
Burglar alarm	2 (16.6%)	10 (35.7%)	4 (25.0%)	16 (28.6%)
Personal alarm	11 (91.6%)	26 (92.9%)	16 (100.0%)	53 (94.6%)
Video-entry phone	6 (50.0%)	18 (64.3%)	12 (75.0%)	36 (64.3%)

A moderate degree of association was found for video-entry phones and burglar alarms (Cramer's V=0.47). The probability could not be derived because the cross table contained a cell with a frequency of zero and as a result, more than 20 percent of the cells had a frequency lower than five.

The installed home automation appliances were judged to be useful by 21.1% of the single men, 55.6% of the single women, and 31.3% of the couples.

Some subjects complained about the installed technology. The following complaints were reported: breach of privacy (1), technology installed at awkward positions (2), range of personal alarm sensor was too short (2), bad view on the display of the entrance control (4), when the telephone was used the door could not be opened (2), and no different ringtone between phone and doorbell (1).

Furthermore, seven subjects judged all installed technology to be unnecessary and two subjects said the video-entry phone was unnecessary.

For all groups no correlations were found between variables that measured whether the installed appliance was actually used and whether technology training were given. It seems that training has no effect on the perceived usefulness.

Single women who received more support (more dependent) judged their personal alarm to be useful (r_s=0.57, p=0.002, n=26).

In contrast, couples who received more support did not use their video-entry phones less (r_s=-0.80, p=0.002, n=12). Eight couples used the video-entry phone; this means 50% were actually using the phone. The other variable, dependence, showed that 56.2% received only one type of support or no support.

Perceived safety

The perceived safety provided by the installed home automation appliances was assessed by one item of the questionnaire. The impression of added safety was asked. Couples experienced the added safety through the home automation most (80.0%), followed by single women (71.4%) and single men (58.3%). However, the differences were not significant.

The older single women, the less they agreed that the home automation had an added value of their safety (r_s=-0.44, p=0.019, n=28). For couples a correlation was found between mobility and perceived safety (r_s=0.58, p=0.022, n=15). When they needed less technical aids (wheelchairs and/or walkers), then they experienced more added safety through the home automation appliances.

A higher intensity of training appeared to correlate with added value of safety by the home automation appliances. However, this correlation was only found for couples (r_s=0.62, p=0.014, n=15).

Changes in daily life activities

The questionnaire items categorised according to Maslow's motivation theory (1946), constitute the measure of beneficial Change in Daily life activities (Figure 4.1.1). Single women render more visits to leisure centres because of the installed home automation appliances as demonstrated by a significant difference between the groups under study (p=0.011). In descriptive statistics we can see that single women report ‘More visits to leisure centre’ (46.4%) compared with single men and couples (16.7% and 6.3% respectively). The low number of visits by the couples might be explained by the fact that couples are spending their time together. The other item that showed a significant difference between the groups was ‘More social contacts in the neighbourhood’ (p=0.024). Again the descriptive statistics showed more contacts for single women (51.9%) than for single men and couples (25.0% and 12.5% respectively).

The total score of all items appeared also significantly different between the groups (p=0.019). The overall score is the final measure of changes in daily life through the installed home automation appliances. This is mainly caused by the social items. The total score of the social items appeared also significantly different between the groups.

The total score of changes in daily life activities due to the installed home automation appliances for single women, is almost 2.5 times higher than for single men and couples. In particular the items ‘more visits to leisure centre’, ‘more social contacts with neighbourhood’ and ‘sports activities’ determine this difference.

There is a negligible difference between single men and couples. On Maslow's safety level, no significant differences were found between single men, single women and couples (15%, 16% and 15% respectively).

The number of installed technologies did not correlate with any measure of changes in daily life.

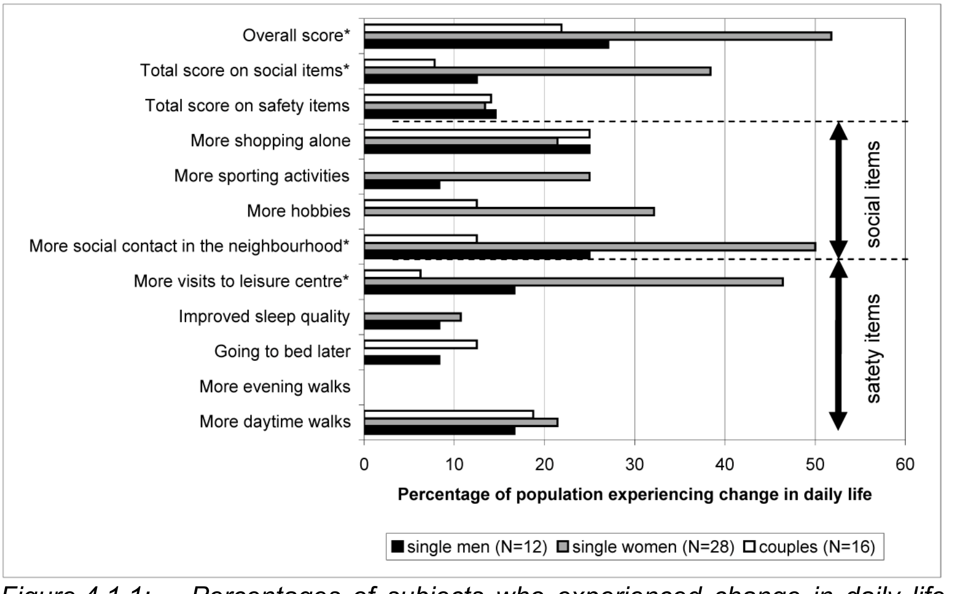

Figure 4.1.1: Percentages of subjects who experienced change in daily life due to the home automation appliances per household structure (significant differences p<0.05)*

The statistical analysis also showed that single women who perceived added value on safety, also showed more changes in daily life (r_s=0.44, p=0.02, n=27). A similar correlation was also found for changes in activities on the social level alone (r_s=0.49, p=0.004, n=28). For single men and couples no such relationships were found. For single men, we found a correlation between dependence and the safety related changes in daily life activities. More dependent single men experienced more changes in daily life with respect to safety (r_s=0.59, p=0.04, n=12).

The intensity of training among single women had a positive effect on the changes in daily life (r_s=0.43, p=0.026, n=27).

4.1.4 Discussion

There were two items on the social level which showed significant differences among the studied groups; more social contacts with the neighbourhood and more visits to the leisure centre. Single women reported the highest score on visits to leisure centre. This is partly in contrast with the findings of Arber (2004). Arber reported no differences in memberships of social organizations between men and women but only a difference between divorced/separated men, never-married men and divorced/separated women. Since we did not ask our singles whether they were widowed, divorced/separated or never married, a clear comparison could not be made. However, Arber's study showed that in general single women entertained more frequently a membership in social organizations as compared to single men.
There were no significant differences found for the safety items describing changes in daily life activities. Strain et al. (2002) did not find significant differences either between the participation in leisure activities such as watching television, walking, shopping, etc. and marital status. Also gender did not show significant differences in the participation of leisure activities.

The use of any single installed home automation appliance did not show a correlation with perceived safety and changes in daily life. However, the single women judged the home automation appliances as useful more often than single men and couples and they also experienced changes in daily life activities. Since we did not find a correlation, there is no direct evidence that the installed home automation appliances really contributed to the changes in daily life.

There were a few variables which were correlated with perceived safety. For women age appeared to affect the perceived safety and for couples this was mobility and type of training. These variables are showing their impact on perceived safety through the home automation appliances. The quality level of training appeared also important for single women in order to experience social changes in daily life activities.

All these variables should be taken into account for a demand-driven approach before future home automation appliances are installed.

The installed appliances, burglar alarm, personal alarm and video-entry phone, were meant to increase the perceived safety of the users. However, this was not experienced by the subjects. Only single men showed a relation between dependence and the safety related changes in daily life activities. The installed appliances had only a minor effect on the socially related changes in daily life activities. However, this was only found for single women.

In conclusion, no evidence has been found that the supply-driven installed home automation appliances indeed enhanced the perceived safety for all groups.

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4.1.6 Appendix A

Characteristics of subjects

1. Age ……
2. Number of Household members ……
3. Household structure
   - ☐ single man
   - ☐ single women
   - ☐ men living with wife
   - ☐ women living with husband
4. Self-reported Health
   - ☐ bad
   - ☐ moderate
   - ☐ reasonable
   - ☐ good
5. Self-reported physical ability
   - ☐ wheelchair
   - ☐ wheelchair and walker
   - ☐ walker
   - ☐ less mobile than before
   - ☐ fully mobile
6. Support in Housekeeping by volunteers
   - ☐ yes
   - ☐ no
7. Support in daily care by volunteers
   - ☐ yes
   - ☐ no
8. Other type of support by volunteers
   - ☐ yes
   - ☐ no

   What kind of support was provided

   ……………………………..
9. Support in Housekeeping by professionals
   - ☐ yes
   - ☐ no
10. Support in daily care by professionals
    - ☐ yes
    - ☐ no

11. Other type of support by professionals
    - □ yes
    - □ no

    What kind of support was provided

    ……………………………..

12. Self-reported computer skills
    - □ bad
    - □ moderate
    - □ reasonable
    - □ good

13. Self-reported cell phone skills
    - □ bad
    - □ moderate
    - □ reasonable
    - □ good

Home characteristics

14. Owner/ renter of home
    - □ owner
    - □ renter

15. Surface home

    …… m^2

16. Staircases
    - □ yes
    - □ no

17. Presence of elevator in home
    - □ yes
    - □ no

18. Appliances present before occupying residence
    - □ yes
    - □ no

19. Appliances installed while residence was occupied
    - □ yes
    - □ no

20. During installation of appliances occupants moved temporarily
    - □ yes
    - □ no

Home automation appliances

21. Presence of personal alarm
    - ☐ yes
    - ☐ no

22. Usage of personal alarm
    - ☐ yes
    - ☐ no

23. Presence of burglar alarm
    - ☐ yes
    - ☐ no

24. Usage of burglar alarm
    - ☐ yes
    - ☐ no

25. Presence of video-entry phone
    - ☐ yes
    - ☐ no

26. Usage of video-entry phone
    - ☐ yes
    - ☐ no

27. Presence of video-phone
    - ☐ yes
    - ☐ no

28. Usage of video-phone
    - ☐ yes
    - ☐ no

29. Type of training
    - ☐ manual
    - ☐ workshop
    - ☐ demonstration
    - ☐ course

Perceived safety through home automation appliances

30. Advanced safety
    - ☐ fully disagree
    - ☐ disagree
    - ☐ neutral
    - ☐ agree
    - ☐ fully agree

Changes in daily life through home automation appliances

31. More daytime walks
    - ☐ agree
    - ☐ disagree

32. More night time walks
    - ☐ agree
    - ☐ disagree

33. Going to bed later
    - ☐ agree
    - ☐ disagree

34. Improved sleep quality
    - ☐ agree
    - ☐ disagree

35. More visits to leisure centre
    - ☐ agree
    - ☐ disagree

36. More social contacts in the neighbourhood
    - ☐ agree
    - ☐ disagree

37. More hobbies
    - ☐ agree
    - ☐ disagree

38. More sports activities
    - ☐ agree
    - ☐ disagree

39. More shopping alone
    - ☐ agree
    - ☐ disagree

CHAPTER 5: GENERAL DISCUSSION

Do building services indeed have a role to play in increasing the human population's vitality in the 21st century? Yes, they do. To study this, we divided building services into three branches (i) infection control, (ii) preventing chronic disease and (iii) supporting well-being. This approach forced us to implement other domains in our research such as epidemiology, psychology and economics in order to assess the health potential of building services.

Applying epidemiology to the effect of building services resulted in the quantification of health risks. Understanding individual needs appeared important for predicting the success of home automation appliances in senior citizens' homes. Even more interesting is the economic feasibility of some upgraded building services. Applying other disciplines, leads to new challenges for the building services engineers.

5.1 The infections

Concerning the first branch, infection control, additional infection risks due to *Legionella* colonisation are caused by district heating and floor heating. Measures such as chlorination are technically and economically feasible, but without such treatments, modern heating systems cause unwanted extra risks. This reveals that designing and constructing safe heating systems and potable water systems need to be better understood.

Chlorination with monochloramines against *Legionnela* species disease is an effective measure for preventing *Legionella* colonisation in potable water. Our simulation of the effect of locally supplying monochloramines to potable water systems, resulted in a gain of 1,360 healthy years per year in the Dutch population. An investment of € 35-100 per household is macro-economically acceptable. The costs of chlorination plants are known from their application in hospitals. Taking the cost of installation in hospitals into account, it appears that chlorination with chloramines as a disinfectant in residential areas is a socially acceptable investment.

Due to environmental issues, centralised chlorination is not permitted in the Netherlands, but chlorination at district level is possible. Another argument against chlorination is the diminished taste of water. Dechlorination at the faucet in kitchens is therefore recommended. This procedure is well-known in the United States.
Another infection risk, as predicted by WHO is the new pandemic of Avian influenza. Brahmbhatt, a senior economist, together with the World Bank, expects the financial burden will amount to 800 billion dollars (The World Bank 2005).

Influenza A viruses prove to be vulnerable to higher relative humidity. Therefore, ensuring relative humidity above 50% will result in a six day delay of infection in households. Humidifying dwellings could be carried out by the ventilation system, but (more easily) occupants could evaporate 4 litres of water four times a day. This makes the intervention very cost effective.

Measures against bioterrorist attacks, another infection risk in the 21st century, are prescribed by the National Institute of Occupational Health and Safety. Pertaining to buildings, they include HVAC systems and security technology, but in our assessment we noticed an additional critical point in buildings: the lifts.

To be able to detect lethal agents in buildings, adequate bio-sensors should be installed to buy time for supplying the right medication as early as possible. This is technologically feasible, but acceptability depends on the attack risk of a building or built environment. Ten years ago, Kaufmann et al. (1997) calculated that an Anthrax attack costs $26.2 billion per 100,000 people exposed. They concluded that preparedness measures are therefore economically justified.

5.2 Chronic disease

To prevent chronic disease such as Asthma, COPD and lung cancer, the second branch studied, an upgrade of existing ventilation appliances appears feasible both technically and economically. Increasing the ventilation rate to 2.1 air changes per hour in homes in the Netherlands, would result in a reduced prevalence of asthma (60%), COPD (30%) and lung cancer (13%). Translated into healthy years, this would lead to a gain of more than 80,000 healthy years per year in the Dutch population (5,000 years/year per million citizens). As to environmental concerns, using demand- driven control for ventilation systems results in lower energy consumption despite of the increased ventilation rate at during a few hours of the day. The investment required to upgrade all domestic ventilation systems in the Netherlands appears macro-economically acceptable: € 18,000 per healthy year gained.

Our experiment in order to determine the transmission of vehicular traffic related particulate matter revealed that the penetration through the building envelope was dominant over penetration through the HVAC system. However, this experiment must be replicated in other (office) buildings and during other seasons to gain more evidence about the transmission modes of particulate matter. Improved understanding of this phenomenon is desirable.

Upgrading building services is proposed to prevent lung cancer and cardiopulmonary mortality due to fine particulate pollution (Pope et al. 2002), but the air-tightness of building envelopes should also be taken into account. The particulate matter related mortality is estimated at 10,000 – 15,000 deaths per year in the Netherlands, equivalent to the loss of 180,000 healthy years in the Netherlands alone (RIVM 2002; WHO 2005). This constitutes a financial burden of € 4.5 billion on the Dutch economy, including both the short and long- term effects of exposure (Singels 2005).

5.3 Well-being

To support well-being, the third branch of building services, the need for more technology, especially technological aids, to support our ageing society is recognised by policy makers and gerontologists (Staatscourant 2000; Cruz-Jentoft et al. 2008). As a result, government funding has been provided to stimulate this kind of technology in new or renovated dwellings. Most of the technology actually installed is aimed at supporting safety in order to safeguard people’s autonomy. This was not experienced by the subjects. Only single men showed a relation between dependence and the safety related changes in daily life activities. The combined installed appliances had a minor effect in the social related changes in daily life activities in case of single women.

No evidence has been found that the supply-driven installed home automation appliances indeed supported the perceived safety for all groups.

We showed that the composition of the household (single men, single women and couples) is a factor that should be incorporated in technology planning before installing new technologies. Since needs together with impairments change over time, technology should be installed at the precise point in time in order to fulfil a deficit need of the Maslow hierarchy. ICT architecture should therefore be capable of receiving all kinds of technologies that might be supportive. In other words, successful building services are engineered in a demand driven way. A study by Mann et al. (2006) revealed a 50% reduction in health care costs for frail older persons when assistive technologies (hearing aids, wheelchairs, etc.) and environmental interventions (modification kitchen intercom, entrance control, etc.) were provided on demand (recommended by occupational therapists). In Dutch society the benefits of extramural health care depend on the vitality of the older adults concerned. Extramural health care for older adults with only minor impairments save society almost € 16,000 while older adults with severe impairments, save almost € 6,000 (Kok et al. 2004) in both cases compared to adults receiving intramural care.

5.4 Other building services related to health

Although many building services were assessed in this dissertation (potable water systems, HVAC systems, security technologies), others were omitted from the scope of this study. These were studied in the past and included lighting, refrigeration, fire detection and protection, sewage systems, telemedicine and telecare. In fact, building services are all related to human health.

Lighting levels provided by artificial light and daylight are related to melatonin (a hormone that regulates circadian rhythms) production (Brainard et al. 1988). The lighting level also effects alertness during office work (Górnicka 2008). Aries (2005) assessed the technical feasibility of lighting systems aimed at improving non-visual aspects such as circadian rhythm.

Refrigeration of indoor environments was invented to reduce infections such as yellow fever and malaria, but in the 20^{th} century refrigeration is used for comfort cooling (Nagengast 1999).

Fire detection and protection are meant to aid the evacuation of a building's occupants in the event of fire.

Sewage systems, another building service, made a major contribution to the enhancement of public health in the 19^{th} century. More recently, Swaffield & Jack (2004) showed that dried out traps in high rise buildings still result in infection risks.

Telemedicine and telecare are also recognised as supporting health. Nakajima et al. (2007) showed that mobile videophones used to advise participants on orthopaedic issues, stress control and nutrition, decrease cholesterol levels and enhance the internal locus of control.

5.5 The need for a systematic approach

The interdisciplinary nature of building services was shown in the study of the additional *Legionella* risk due to district heating and floor heating.

Cheng et al. (2008) investigated the transmission modes of SARS using the Failure Mode Effect Analysis (FMEA). The FMEA identifies and ranks potential failures in a technical system. This systematic approach resulted in the involvement of two building services that transferred infectious particles: dried out drainage traps and the ventilation system.

In our Anthrax study, we applied the Hazard Analysis Critical Control Points (HACCP). Both tools originated from Total Quality Management (TQM); both assessments are based on the collaboration of multidisciplinary teams to identify hazards (Stamatis 1995; Mortimore & Wallace 1995). In our analysis lifts proved to be an additional vector. We applied HACCP because of the similarity of inhaled air and consumed potable water to consumed food. The FMEA approach is based on risk in general, mostly from an engineering perspective. HACCP was developed to prevent health damage caused by food products. It identifies physical, biological and chemical hazards in the food chain.

5.6 The interdisciplinary approach

In order to deliver more health at an economically acceptable level, this dissertation showed that all disciplines within building services should be used as well as disciplines outside building services. The studies on reducing infection risks (*Legionella*, avian influenza, anthrax) and preventing chronic disease (asthma, COPD, lung cancer and coronary heart disease) could only be conducted by integrating knowledge of epidemiology, biology, psychology, economics and statistics. Assessing the macro-economic acceptability of upgraded building services in order to deliver more health, was only possible while using models of health economics (DALY). Last, but not least, understanding the perception of the home automation appliances among older adults could only be done by using models borrowed from psychology (Maslow).

To fully utilise building services to deliver more health, we have to incorporate infection risks again, and shift from comfort to health parameters of performance. When the WHO definition of health is taken into account, building services are able to deliver an environment that allows for complete health.

5.7 Conclusion

The assessed building services showed a strong relation to human health. Incorporating other scientific domains in order to quantify the effects, resulted in guidelines for upgrading these services in a feasible manner to gain thousands of extra healthy years for the human population in the Netherlands alone. Abiding to these guidelines will offer the building services engineers of the first half of the 21st century an important role in keeping the ageing society healthy. This makes them worthy heirs to their colleagues of the first half of the 20th century, who almost eliminated infection mortality among infants.

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SUMMARY

Building services are rapidly evolving; in residential and non-residential buildings they were previously restricted to delivering safe potable water, ventilation, electricity and natural gas, as well as removing liquid waste. Later, complete climate control, home automation devices, telemedicine and telecare have been added to this domain. Are today's building services capable of providing increased health in the 21st century?

Trends

Building services have the potential to reduce the disease burden of society and individuals, and improve well-being. In the 19th century improved nutrition resulted in a drastic reduction in infant mortality. Nevertheless, infection control through safe potable water systems, closed sewer systems and improved ventilation of buildings were building services which had beneficial effects on health.

Although building services proved effective against yellow fever, cholera, etc., ventilation and potable water systems are currently based on comfort values instead of health values that we had in the past. This is considered to be the first trend. This was based on the ventilation requirements to prevent odours and the energy savings measures as consequence of the energy crisis in the 70s. As a result, new infectious diseases such as Legionnaires' disease, Pontiac fever, SARS, infections due to bird flu or biological warfare emerged as additional risks that needed to be addressed by building services in the late 20th and early 21st century.

Another result of this trend arose at the end of the 20th century, that is the need to save energy. This has led to more air-tight buildings together with a comfort ventilation rate causing a higher prevalence of chronic allergic disease. In the 80s, after sealing of offices, the so called Sick Building Syndrome (SBS) came up, ensuing reduced productivity of office workers. The problem was partly solved by an increase of the office ventilation rate. A building ventilation upgrade of dwellings that focuses on health while reducing energy consumption as far as possible, could contribute to a reduction of chronic disease, thus improving community health in our ageing society. The chronic conditions addressed include asthma, COPD (Chronic Obstructive Pulmonary Disease), lung cancer, and heart disease.

A third trend in the 21st century is the continued ageing of society. Conserving autonomy of older people and improving their well-being led to the introduction of home automation appliances such as community alarms and videophones. Increased well-being is the aim here, an element of the WHO definition of health.

Currently these three trends result in three distinct branches of building services: (i) reducing infection risks, (ii) preventing chronic conditions, and (iii) supporting well-being. Please note that the engineering discipline ‘building services’ is here categorized by its functions and not by the hardware used.

To evaluate the potential of building services to improve the health and vitality of end users we studied examples of all three branches in more detail.

Fighting infections

We studied infections related to both potable water and building ventilations systems. Sewage systems were not included. The target organisms were *Legionella* species, avian influenza virus and Anthrax as biological warfare agent.

Modern heating systems, such as district heating and floor heating, result in a temperature increase in the potable water system. In both cases, the temperature of cold water supply surpasses the 25°C threshold limit most of the time. Adding monochloramines to the potable water system of residential areas, is considered the best response to the *Legionella* threat. Under Dutch conditions it would result in a gain in healthy years (DALY) of 1,360 on a yearly basis. Over a depreciation period of 5 years, this concerns a maximum allowable investment of €35 - €100 per dwelling, a socially acceptable amount.

In future, during the winter months, a new pandemic (caused by avian influenza virus) comparable to the Spanish Flue of 1918-1920 is expected. This is especially the case in countries where heating is required, since the indoor air is usually dry and the virus can survive a number of days. Above 50% relative air humidity, the viability of the influenza virus decreases rapidly. In Dutch winter conditions and an air exchange rate of 0.5, the evaporation of 4 litres (during two hours) of water, 4 times a day is sufficient to keep the indoor relative humidity above 50%. This reduces the probability of infection from almost 100% to 82%, when a susceptible person is exposed for two days (the incubation period of Influenza A virus). This measure should be taken in each household. A 18% lower probability of infection through the intervention reduces demands on the healthcare system for medication and other services to the population. In short, it decreases the rate of spread of the infection in a population.

The HACCP (Hazard Analysis of Critical Control Points) analysis has been adapted from the food industry to identify critical spots in buildings that are most susceptible to bio-terror attacks. In this case it is not food that has to be protected, but the inhaled air. The position of the air inlets of buildings proved to be a point of concern, as are lifts that may pump pollutants into the building.

In summary, it is clear that these new infectious threats should lead to upgraded standards and guidelines for HVAC systems and cold potable water systems in the 21st century.

Addressing chronic disease

The prevalence and severity of chronic conditions such as (i) asthma, (ii) COPD and (iii) lung cancer may be lowered by improving indoor air quality. Allergens from house dust mites and tobacco smoke are classical pollutants of indoor air associated with these diseases. In addition, the increasing number of vehicles results in more particulate matter near busy roads. This particulate matter is associated with airway inflammation and coronary heart disease. The dust particles of 200-700nm in diameter, penetrate buildings not only through ventilation systems, but also through the building's envelope. In the Netherlands the loss in healthy life years by these chronic conditions has been estimated at 180,000 years per calendar year.

Simulations showed that an increment of 1 to 2.1 air changes/hour in dwellings, results in a 75% reduction of house dust mites and a 50% reduction of environmental tobacco smoke (ETS) particles. In the simulation, this was associated with a reduction in the prevalence of asthma (60%), COPD (30%) and lung cancer (13%). Traffic dust was not included in this simulation.

The cost of the required upgrade of ventilation systems in dwellings amounts to €18,000 for each healthy year (DALY) gained. This is far below the WHO limit of financial acceptability (1 to 3 times Gross National Product per capita), making a healthy upgrade of dwelling ventilation economically feasible.

Therefore, also new standards and guidelines are required for ventilation systems in order to prevent chronic conditions.

Support of well-being

We analysed data on perceived safety of installed home automation appliances such as community alarms, burglar alarms and video entrance phones. The home automation appliances were installed without assessing individual needs. All appliances installed appeared to be aimed at addressing safety needs. The studied subjects were grouped in single men, single women, and couples. More single women used the home appliances as compared to singe men and couples. A direct relation was found between the actual usage of the installed appliances and perceived safety for none of the groups. A more indirect effect of the installed appliances was experienced by single women; they perceived more changes in daily life while

using the home automation appliances. However, these changes were more related to the social aspects rather than the safety. The single women experienced more freedom in their social contacts. For single men and couples this relationship was not found. The results showed different perceptions for the three groups.
To truly support well-being in the future, technology should be supplied on the basis of actual individual needs. Models of the psychological domain can support these endeavors (Maslow).

Challenges for building services engineering

Research with methodologies of the food industry (HACCP), psychology (Maslow) and public health (DALY), showed the potential of innovating building services to deal with 21st century societal problems. The required investments to prevent health damage appear to be acceptable to society. With regard to the support of well-being, future research should include more demand driven home automation appliances such as videophone and newer communication tools to support telecare and telecure.

But even without this future research it is clear that new opportunities have arisen for the building services industry: building services engineering for health!

Samenvatting

Van oudsher verzorgt de installateur de toevoer van water, gas, elektriciteit en de afvoer van het rioolwater voor een gebouw. Daar zijn in de loop der tijd diverse taken bijgekomen: van ventilatie tot complete klimatisering, telefonie en internet, kabeltelevisie, beveiliging tegen brand en inbraak, domotica en tegenwoordig ook de hardware voor telegeneeskunde en telecare. Kan de innovatieve installateur en adviseur met al deze oude en nieuwe taken ook inderdaad meer 'gezondheid' leveren voor de 21ste eeuw? Dit is de vraag waar dit proefschrift zich mee bezig houdt.

Trends

Al eerder werd duidelijk dat de installaties ziekten kunnen terugdringen en het welbevinden kunnen vergroten, waardoor in de loop van de 20ste eeuw de kindersterfte drastisch verminderd is. Verbeterde voeding leidde tot gereduceerde sterfte maar ook de aanvoer van veilig drinkwater en gesloten systemen om het rioolwater af te voeren en later droegen verbeteringen in het gebouwventilatiesysteem hieraan bij.

Ondanks het feit dat gebouwinstallaties ons tegen cholera en typhus beschermen, zijn er nieuwe gevaren opgedoken in de vorm van veteranenziekte, legionellagriep, SARS, vogelgriep en de dreiging van biologische oorlogsvoering. Een trend waarbij de vraag is of de installaties hierin een beschermende rol kunnen spelen.

Een tweede trend is de drang naar een beperking van het energiegebruik. Het minimale voorgeschreven ventilatievoud van gebouwen is tegenwoordig niet meer gebaseerd op gezondheidsbehoeften maar slechts op comfortbehoeften. Samen met de reductie van de infiltratie van buitenlucht door dak en gevel, heeft dit geleid tot een vergroting van de prevalentie van allergische aandoeningen. Dit houdt ook in dat een op gezondheid gestoelde verbetering van ventilatiesystemen kan bijdragen aan het terugdringen van chronische aandoeningen als astma, chronische bronchitis en longemfyseem, longkanker en hart- en vaatziekten.

De derde trend aan het begin van de 21ste eeuw is de vergrijzing en ontgroening van onze maatschappij. Het grotere aandeel ouderen stelt andere eisen: behoud van autonomie en welbevinden. Persoonsalarmering en videotelefonie zijn aan het palet van gebouwinstallaties toegevoegd om tegemoet te komen aan de volledige definitie van 'gezondheid' conform de Wereldgezondheidsorganisatie.
Tegenwoordig hebben gezondheidsbevorderende gebouwinstallaties dan ook drie verschillende taken: (i) het verminderen van infectierisico's, (ii) het voorkómen van chronische aandoeningen en (iii) het ondersteunen van welbevinden. Hierbij zijn de activiteiten van de installatiebranche niet meer ingedeeld naar de aard van het geïnstalleerde materiaal maar naar de functie die wordt nagestreefd!

Om het gezondheidspotentieel van de gebouwinstallaties te bevorderen, zijn in dit proefschrift voorbeelden onderzocht uit alle drie de taakpakketten.

De strijd tegen infecties

In dit proefschrift komen *Legionella*, vogelgriepvirus en antrax (een 'biowar' agens) aan bod in relatie tot het ontwerp van het drinkwatersysteem en het ventilatiesysteem. Rioleringen zijn niet onderzocht.

Het blijkt dat door sommige moderne verwarmingssystemen voor woningen, zoals stadsverwarming en vloerverwarming de temperatuur van het aangevoerde koude drinkwater langdurig tot boven de 25°C wordt verhoogd, zodat *Legionella* er goed in kan groeien en de kans op legionellagriep en veteranenziekte bij de bewoners toeneemt. Het toevoegen van monochlooramine aan het drinkwater op wijk- of gebouwniveau lijkt de beste bescherming te geven tegen dit risico. Hiermee zouden voor Nederland jaarlijks 1360 gezonde levensjaren (DALY's) gewonnen kunnen worden. Als de hiervoor benodigde investering over 5 jaar wordt afgeschreven, levert dat een acceptabele kostenpost op van €35 - €100 per woning.

In de komende decennia ligt een nieuwe vogelgriep pandemie op de loer, vergelijkbaar met de Spaanse griep van 1918-1920. Omdat het vogelgriepvirus gevoelig is voor vochtige lucht en mensen door inademen van het virus besmet worden, is de droge binnenlucht die ontstaat bij het stoken in de winter, de beste omstandigheid voor het vogelgriepvirus om infectieus te blijven. Boven een relatieve vochtigheid van 50% neemt de levensvatbaarheid van het virus snel af. Deze eigenschap van het virus kan gebruikt worden om een snelle verspreiding van de ziekte binnen een huishouden tegen te gaan. Onder Nederlandse wintercondities is het binnenshuis verdampen van 4 liter water, 4 maal per dag voldoende om de kans op verspreiding van de infectie als één van de huisgenoten al geïnfecteerd is, te verminderen van bijna 100% naar 82% in twee dagen, de incubatietijd van het virus. Deze terugdringing van de snelheid van infectieverspreiding, levert extra tijd op om medicatie toe te dienen en andere diensten beschikbaar te houden.

Het beperken van de gezondheisrisico's bij een bioterroristische aanval met miltvuursporen is onderzocht met een zogenaamde HACCP (Hazard Analysis of Critical Control Points), zoals die tegenwoordig in gebruik is om de veiligheid van ons voedsel te garanderen. Doel was de kritische punten van een gebouw te ontdekken voor wat betreft het inademen van lucht die met miltvuursporen vervuild was. Behalve de plaats waar de buitenlucht het gebouw binnenkomt, bleek ook de lift een belangrijk risico. De op- en neergaande beweging van liften werkt als een pomp om binnengebrachte verontreinigingen door het gehele gebouw te verspreiden.

Samengevat is het duidelijk dat deze nieuwe infectierisico's evenzoveel uitdagingen zijn voor de installateur en adviseur die voor de te plaatsen en te onderhouden HVAC (Heating Ventilation & Airconditioning) en drinkwatersystemen op basis van nieuwe criteria zullen moeten kiezen.

Het antwoord op chronische aandoeningen

Zoals bekend is een verbeterde kwaliteit van de binnenlucht het beste installatietechnische wapen in de strijd tegen astma, chronische bronchitis en longemfyseem, en longkanker. De veroorzakende afscheidingsproducten van huisstofmijten en tabaksrook kunnen hiermee namelijk worden aangepakt maar ook fijn stof van het nog steeds toenemende autoverkeer buiten, is een factor die te beïnvloeden is. Deze deeltjes zijn geassocieerd met hart- en vaat ziekten en longkanker. Helaas dringen stofdeeltjes met een diameter van 200-700 nm ook door een gesloten gevel binnen.

Een computersimulatie liet zien dat een verhoging van het ventilatievoud van 1.0 tot 2.1 luchtwisselingen per uur, de Nederlandse woningen verlost van 75% van de huisstofmijten en 50% van de tabaksrookdeeltjes. Hiermee is in deze simulatie de prevalentie van astma terug te dringen met 60%, die van chronische bronchitis en longemfyseem met 30% en van longkanker met 13%. Het fijnstof van de auto's buiten is niet meegenomen in deze simulatie.

De kosten om de bovengenoemde gezondheidswinst te behalen door een verbetering van de ventilatiesystemen in woningen bedragen €18.000 voor ieder te winnen gezonde levensjaar (DALY berekening). Dit ligt ruim onder het bedrag van 1-3 maal het Bruto Nationaal Product dat door de Wereldgezondheidsorganisatie als betaalbare bovengrens wordt gezien. Een gezonde opwaardering van de ventilatie in Nederlandse woningen is zowel economisch als technisch haalbaar.

Dus niet alleen de infectiebescherming maar ook het voorkómen van chronische aandoeningen vraagt om nieuwe uitgangspunten voor de installatietechniek.

Bevordering van welbevinden

De ervaren veiligheid en geïnstalleerde beveiliging zijn onderwerp van onderzoek in het derde deel van dit proefschrift: het bevorderen van welbevinden. Het betrof projecten met persoonsalarmering, inbraakpreventie en een videofoonverbinding met de voordeur, gefinancierd door de Nederlandse overheid met een subsidie ter bevordering van autonomie en sociale participatie. De betreffende technologiën waren bedoeld om de veiligheid van de oudere bewoners te vergroten. De verbetering in ervaren veiligheid bleek echter alleen te constateren bij alleenwonende oudere dames, niet bij de alleenwonende heren, of tweepersoonshuishoudens. Het waren ook alleen de oudere, alleenwonende dames die zich door de geïnstalleerde technologie wat vrijer voelden in hun sociale contacten. De overige groepen hadden geen extra veiligheidsbehoeften, wellicht wel extra sociale behoeften volgens de hiërarchie van Maslow. Van videofooncontacten met gezondheidscentra en familieleden zou dit meer verwacht kunnen worden maar tot onze verwondering was zo'n videofoon nergens geïnstalleerd. Men had zich in deze innnovatieprojecten beperkt tot oude, beproefde technologie. Ook waren de bewoners niet individueel gevraagd wat hun werkelijke behoeften waren.

Om in de toekomst het welbevinden tot op hoge leeftijd te ondersteunen, zullen opnieuw de uitgangspunten voor installaties gewijzigd moeten worden. Nog voor het eerste ontwerp is het noodzakelijk de actuele behoeften van de verwachte bewonerspopulatie te leren kennen, waarbij bovendien de daadwerkelijke installatie wordt aangepast aan de individuele behoeften van ieder huishouden.

Nieuwe 'uitdagingen voor de installatiebranche

De 21ste eeuw heeft de installatie-industrie nieuwe uitdagingen gebracht: gebouwinstallaties voor het beperken van nieuwe gezondheidsrisico's en het verhogen van het welbevinden in een vergrijzende samenleving. Uitdagingen die stuk voor stuk technisch en economisch haalbaar zijn. De branche zal deze kansen echter slechts kunnen benutten wanneer zij meer persoonsgerichte uitgangspunten gaat hanteren.

Dit resultaat is te danken aan een multidisciplinaire aanpak met onderzoeksmethodologiën uit de voedselindustrie (HACCP), de psychologie (Maslow's theorie) en de volksgezondheid (DALY).

CURRICULUM VITAE

Francesco Franchimon was born in Voorburg, the Netherlands on August 5 1975, as the son of Christiaan Franchimon and Antonia Wilhelmina Franchimon-Van der Pol. He was raised in Zoetermeer, a town in the western part of the Netherlands. After completing secondary school at the ONC College in Zoetermeer, he started Intermediate Vocational Education in Building Services at Haaglanden College, The Hague in the Netherlands. He completed this study programme in 1995 and moved to higher vocational education in Building Services at Hogeschool Utrecht, Department of Nature and Technology in Utrecht to attain a Bachelor's degree in Engineering in 1998. His Bachelor's thesis focused on Life Cycle Costing. In 2003, he attained his Master of Science degree in Building Services at the Eindhoven University of Technology. His Master's thesis addressed new daylight systems for high efficiency daylight penetration in offices. During this study programme he served as president of the Mollier (1999-2000) student association. Between 2003 - 2004 he was employed by BAM Techniek. His work field was fire safety engineering and he was an assistant planner and controller at construction sites. In 2004, he started his PhD in Performance Engineering for Built Environments, Department Architecture, Building and Planning, Eindhoven University of Technology, Eindhoven, the Netherlands. He was also a member of the board of the Department of Electrical Engineering of the National Professional Society TVVL (2005 - 2007). Between 2005 – 2008, he was the officer of the International Society for Gerontechnology responsible for subscriptions and advertisements. He became treasurer of the Dutch Chapter of ISIAQ (International Society of Indoor Air Quality) in 2007 and of the International Society for Gerontechnology one year later serving under two consecutive presidents Herman Bouma and Alain Franco.

On February 1, 2009 he started a new carreer at BAM Techniek.

ACKNOWLEDGEMENT

This work could not have been completed without the support of many colleagues, friends and family members; some of them are mentioned below.

The Stichting PIT financed the study. I hope that the aim of Stichting PIT, to encourage technical, economical and scientific development for the Dutch Building Services Industry, has been materialized in this dissertation, and am grateful for the support.

The firm Deerns gave me the opportunity to discuss results of my work with their experts. I learned about the work flows inside a consultant agency. I truly appreciate their patience.

Cor Pernot and Wiet Koren gave me the faith I needed to start the research. They laid an important fundament for my further scientific development.

I interfaced with and supervised also a number of master students: Froukje van Dijken, Joost van Hoof, John van Deursen, Martijn Janssen, Tamara Derksen, Jeroen Knies, Ton Verblackt, Niek van Erk, Chao Ming, Coen Hoogervorst, Stefan Bours, Lester van Ree, Jan van Hout, Jaap Balvers, Roel Loonen, Michiel Brink, and others. You kept me sharp and I hope I have not complicated your life too much!

Bachelor students have also contributed to this dissertation with the fake bio-terroristic attack on the Vertigo building. Thanks!

During my doctoral work my life has been enriched with new international friends. I met Jim Fozard at the ISG conference in Nagoya in 2005. Jim taught me fine details of science and the life in scientific community. I have visited him three times in Palm Harbor where he not only supported me in my work, but also shared his swimming pool with me. Jim, I experienced you as my scientific father!
During a conference on Persuasive Technology in 2006, I met Bill Kearns who I visited at the University of South Florida and I will never forget the Tarek's hamburger. Bill is a warm person that showed me interesting technological topics.
The last international friend I want to acknowledge is Claudia Oppenauer. We met at the 2nd ISG Masterclass in Eindhoven in 2007. Since then we kept in touch, and she motivated me to continue my work in hard times, and tried to stop me when I stressed too much. Thank you for being so empathic!

I am grateful to both Bill Kearns and Sharron Dubbelman-Sibeijn who revised my dissertation and any of the remaining mistakes are my own responsibility.

Ger Maas served as the mirror. In times of PhD depression, he told me that it was my own fault since I freely chose to be a PhD student. He always confronted me with my own ideas and habits and that taught me well.

Don Bouwhuis, my second supervisor, introduced me to the social sciences that are so different from technology and engineering. Het not only gave me methodologies, but also humor in explaining things.

Annelies van Bronswijk, my first supervisor, has also been my inspirator. Annelies, you believed in me from the beginning; even more than I believed in myself. When you asked me to consider a doctoral study, I started laughing. However, my mind changed, as you already expected and I decided to take the challenge. I have not been bored. I never met a person who is more devoted to her work and expects the same of her students. In the beginning this was hard to accept, but later I started to believe that doing a doctoral study is comparable with performing at top sport level. Actually this is one of the most important lessons I have learnt. Annelies I admire your devotion to science and appreciate your interest in people. I will never forget how proud you are when one of your students achieves a good result. Maybe that is the best example to describe your devotion.

Last but not least, I want to thank my parents. You were not very happy when I decided to start a PhD track. Nevertheless, you have supported me at every single step. I am lucky to have enjoyed a carefree youth during which you taught me social skills as well as perseverance. These virtues were essential in the completion of my doctoral work. Thank you for being there when I needed you!

NOTES