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# Climate change consequences for the indoor environment

Myriam B.C. Aries and Philomena M. Bluysen

Building Physics and Systems,

The Netherlands Organisation for Applied Scientific Research TNO,

P.O. Box 49, 2600 AA, Delft, Netherlands

Scientists warn us about climate change and its effects on the outdoor environment. These effects can have significant consequences for the indoor environment, also in the Netherlands. Climate changes will affect different aspects of the indoor environment as well as the stakeholders of that indoor environment. Buildings will require less heating in the winter and more cooling in the summer, resulting in an increase use of air conditioning systems. Increasing relative humidity indoors and rising moisture from the ground will cause significantly more mould problems resulting in further health risks. Additionally, effects on lighting and acoustical quality, but also several psycho-social effects seem likely to occur. It is concluded that possible adaptations, whether performed at the source of climate change effects, the building or by involving people, can only be executed properly when the possible effects of climate changes on occupant wishes and needs as well as the interactions of these occupants with their environment are well understood.

*Key words: Climate change, building envelope, durability*

## 1 Introduction

Despite the fact that the Earth always had a changing climate throughout its 4.5 billion years of history, today's climate changes seem different than before (e.g., Holmes & Hacker, 2007). Preceding evidence shows that humanity plays an important role with respect to climate change, as concluded by the Intergovernmental Panel on Climate Change [IPCC] (IPCC, 2007) in the Fourth IPCC Assessment Report 'Climate Change 2007'. Since the first measurements of CO<sub>2</sub> in 1958 by Revelle (Gore, 2006), scientists have warned us about climate change and possible consequences. The problem is named 'radiative forcing', which is defined as the change in average net radiation at the top of the troposphere (lower atmosphere). Positive radiative forcing warms up the Earth' surface to

keep the heat balance. Negative radiative forcing would cool down the surface of the earth (Houghton, 2004). In scientific literature, a debate and controversy exists about the actual cause of radiative forcing; in particular about the relative importance of anthropogenic or human induced sources versus natural influences such as the variability of the solar activity and radiation. Although it seems that something is happening with our climate, what exactly will happen in the next centuries is difficult to predict.

From the observed trends, altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems. The American National Research Council (NRC, 2001) concluded that climate change has the potential to influence the frequency and transmission of infectious disease, alter heat- and cold-related mortality and morbidity, and influence air and water quality. Depending on the scenarios occurring from now on, some health consequences related to climate change can be identified:

- Direct temperature effects: Particular segments of the population such as those with heart problems, asthma, the elderly, the very young, and the homeless can be especially vulnerable to extreme heat.
- Extreme events: Extreme weather events can be destructive to human health and well-being. An increase in the frequency of extreme events may result in more event-related deaths, injuries, infectious diseases, and stress-related disorders.
- Climate-sensitive diseases: Climate change may increase the risk of some infectious diseases, particularly those diseases that appear in warm areas and are spread by mosquitoes and other insects. Though average global temperatures are expected to continue to rise, the potential for an increase in the spread of diseases will depend not only on climatic but also on non-climatic factors, primarily the effectiveness of the public health system (WHO, 2003).
- Air quality: Respiratory disorders may be exacerbated by warming-induced increases in the frequency of smog (ground-level ozone) events and particulate air pollution. Ground-level ozone can damage lung tissue, and is especially harmful for those with asthma and other chronic lung diseases. Sunlight and high temperatures, combined with other pollutants such as nitrogen oxides and volatile organic compounds, can cause ground-level ozone to increase. Climate change may increase the concentration of ground-level ozone, but the magnitude

of the effect is uncertain. Climate change may indirectly affect the concentration of particulate matter [PM] pollution in the air by affecting natural or “biogenic” sources of PM such as wildfires and dust from dry soils.

## 2 Climate change scenarios

Generally, Global Climate Models [GCMs], driven by greenhouse gas emission scenarios, are used to construct regional climate scenarios. Global models are downscaled and completed by e.g., statistic data to give information on a regional scale. The climate change scenarios for the Netherlands are constructed differently from this general approach (Hurk et al., 2006a). For the Dutch situation, four scenarios of climate change have been developed by the Royal Netherlands Meteorological Institute [KNMI] (Hurk et al., 2006b). In all of the four possible New Climate Change Scenarios for the Netherlands (G, G+, W, and W+), similar effects of climate change will be experienced by the Netherlands and its surrounding regions (Hurk et al., 2006b). The majority of these effects will have significant consequences for the indoor environment of Dutch buildings. General tendencies, relevant for the indoor environment, in all four scenarios are:

- (Outdoor) temperatures will increase (see Figure 1), resulting in a higher frequency of more temperate winters and warmer summers;
- Winters will, on average, become wetter, and intensity of extreme rain will increase;
- Intensity of extreme rain in the summer will increase, however, in contrast, the number of rain days in summers will decrease (in two out of the four scenarios);
- Changes in wind regime are small compared to current natural variation. It is likely that wind speeds and frequency of storms will increase, however this scenario is uncertain.

The temperature increase over the previous decades was not globally equal. Temperature in the Netherlands has increased more rapidly than the global average temperature (PCCC, 2007), and most recent sources report the temperature to be increased even faster than forecasted previously (Oldenborgh et al., 2008). One of the causes is changes in atmospheric circulation, like e.g. the predominating wind direction. Southern and western winds have contributed strongly to the warmth record in autumn and winter. The atmospheric circulation naturally shows large changes. Global warming will most likely

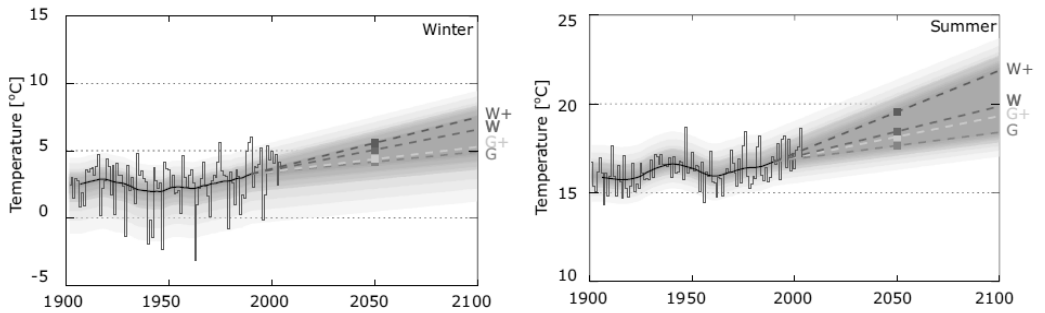


Figure 1. Temperature in De Bilt between 1900 and 2005: the four climate scenarios for 2050 (coloured points) for winter (left) and summer (right) (after Hurk et al., 2006b)

influence atmospheric circulation; however, the extent is not yet determined unambiguously.

Intensity of extreme rain in the summer will increase, although, in contrast, the number of rain days in summers will decrease. The relative humidity in summer remains high, which is ideal for different types of insects (anopheles and tiger mosquitoes). Related to temperature and humidity, it seems that eventually the Dutch climate may change into a type of climate that is currently seen in countries close to the equator. There is first evidence to suggest that part of the recent changes in the lichen flora of the Netherlands is attributable to an increase in temperature (Herk et al., 2002). (Sub)tropical types start to invade whereas the number of northern types decreases, clearly shown from the shifts in the composition of the Dutch lichens (see also Figure 2).

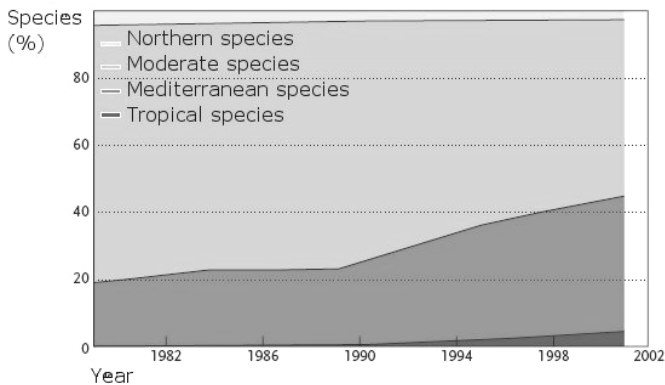


Figure 2. Recent shift in Dutch lichens species (after Herk et al., 2002)

### 3 Possible climate change consequences for the indoor environment

Changes in the outdoor environment have impact on the indoor environment. Cities are probably the worst case scenario. It has long been recognized that the built environment can have so called 'Urban Heat Islands' [UHI]. An UHI refers to the tendency for a city to remain warmer (up to 5–6°C) than its surrounding countryside (Wilkinson et al., 2007; Oke, 1982). Vegetation and soil moisture normally use much of the absorbed sunlight to evaporate water as part of photosynthesis. Due to a lack of vegetation and soil in most present-day cities, sunlight is absorbed by manmade structures like roads, parking lots, and buildings instead.

Before describing the possible effects of climate change on the indoor environment, we will first describe 'indoor environment'; keeping in mind this worst case scenario in cities.

#### 3.1 *Indoor environment*

The indoor environment can be described by the so-called indoor environmental factors or (external) stressors:

- Indoor air quality: comprising odour, indoor air pollution, fresh air supply, etc.
- Thermal comfort: moisture, air velocity, temperature, etc.
- Acoustical quality: noise from outside, indoors, vibrations, etc.
- Visual or lighting quality: view, illuminance, luminance ratios, reflection, etc.

All together, these factors outline the indoor environmental quality. They provide the environmental stimuli that form the input for our physical sensations, which are the data of perception upon which we react in the form of behaviour and/or evaluations (Taylor, 2006). They can influence our sensations via the three major regulation and control systems of the human body (nervous system, immune system and endocrine system), resulting in both mental (e.g., memories, anxiety) and physical effects (e.g., escape, fight, protect). Stimuli can cause changes in our psychological state, of which we do not know the cause (no conscious experience), and can also be harmful to our physical state of well-being (for example, invisible radiation, gases, chemical compounds, etc.). Besides these direct stimuli, a number of interactions take place that eventually determine how well you will feel, how healthy you will be and how comfortable you will be at a certain moment in time, and determine your interaction with your environment over time (see Figure 3):

- Interactions at human level: physical, psychological and interhuman.
- Interactions at indoor environmental parameter level: between and in.
- Interactions at building level: between elements of the building and between the building and the environment.

### 3.2 Direct consequences

Despite the scenario occurring from now on, some indoor environmental aspects will change (or have to change) in order to be able to cope with the climate change consequences. Not all variables contained in the KNMI scenarios correspond directly to those needed for indoor environment design, but relevant parameters may be derived. Largely consistent with the implications in the UK (CIBSE, 2005), the main implications of the climate change scenarios on Dutch buildings may be on thermal comfort and air quality through:

- changes in the need for space heating;
- the risk of summertime overheating;
- the occurrence of the need for comfort cooling;
- performance of mechanical air conditioning systems.

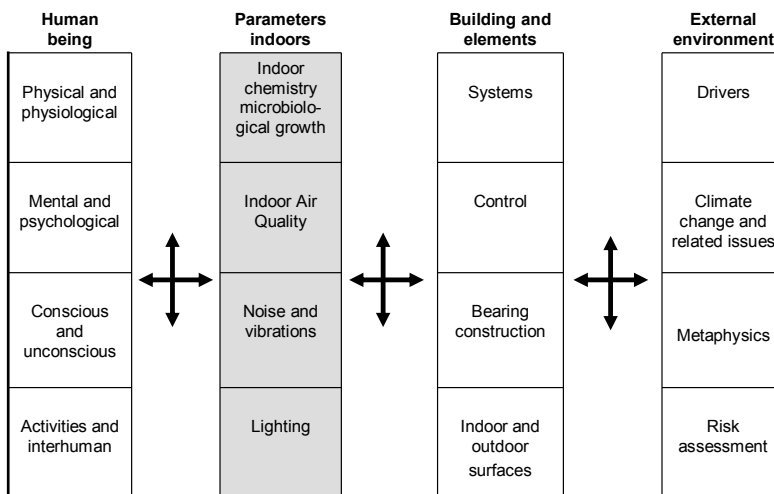


Figure 3. Interactions at different levels with examples of factors in each column (after Bluysen, 2008)

### 3.2.1 *Effects on thermal comfort*

Due to the consistent increase of the average global air temperature near the Earth's surface, - causing mild winters and hot summers -, buildings will require less heating. Depending on the scenario, the number of heating degree-days around 2050 will decrease between 9 and 20% (Hurk et al., 2006b). Van Dongen and Vos (2007) found in their study of 1240 Dutch homes that the average indoor temperature is likely to be higher as houses are of a more recent date, mainly caused by less temperature decrease at night. Relatively warm night temperature can cause problems for the night's rest. A small (short term) skin temperature change of less than 1°C has already a large impact on sleep quality, especially for the elderly (Raymann et al., 2008). Long term changes in environmental temperature can result in an adjustment of the basal metabolic rate and heat production by altering hormone secretion (Kapit et al., 2000).

The fact that temperature in winter will go up, combined with increased insulation of Dutch buildings due to energy saving policies, will reduce the demand for space heating. Therefore, not only energy consumption will slightly decrease, also indoor comfort will increase during milder outdoor temperatures during winter. Conversely, the increasing average temperature will make cooling a more crucial and energy consuming issue. The potential increase in winter comfort is to some extent in contrast with the situation in summer. Well-insulated and reasonably air-tight buildings slowly warm up due to entering solar energy and indoor heat sources. The heat remains trapped in the construction, causing an uncomfortable warm indoor climate after a couple of hot days. Therefore, air conditioner use will increase during hot summers. This will affect the power use significantly. The effects of electricity shortfall during hot days in (rich) countries with warmer climates like the US and Canada are already noticeable. However, electricity shortfalls not only happen during the cooling season. Meier (2006) found that a shortfall in Arizona was mostly driven by air conditioning, but an electricity shortage in Norway was caused by drought and a Swedish utility required electricity conservation for very cold days in the winter. The causes of the shortages include many severe weather events, such as droughts, heat or cold waves. Intentional cut-backs in electricity consumption without fully understand all consequences, will not automatically lead to less problems and more energy efficiency. For example, allowing the temperature to float somewhat upwards during warm periods means that certain zones of buildings will raise in temperature faster than other zones. These procedures can seriously disturb the balance of a building's Heating Ventilation and Air Conditioning [HVAC] system and result in uneven delivery of services, reduced efficiency, and of course discomfort. In winter, temperature set-backs



may lead to cold spots and localized thermal discomfort for the occupants. Condensation may appear on unexpected surfaces and water pipes are more likely to freeze if a cold wave arrives (Meier, 2006).

### 3.2.2 *Effects on air quality*

As a result of possible increased storms and wind speed (scenario G+ and W+), air pollution comprising of dust particles (from fine to the more heavy) are most likely to be transported more easily from one area to the other. For example, the orange dust coming from the Sahara covering cars after a rain fall will be a more frequent sight. This increase in outdoor air pollution can require buildings to be more airtight than usual, relying more on air conditioning systems which clean the air before it enters the building. In that case, attention should be paid even more to the cleaning and maintenance of air conditioning systems, as these have proven to be a major source of health and comfort problems indoors (Bluyssen, 2003).

Ozone is another pollutant of concern. Increased ozone outdoor concentrations (smog) can lead to an increase in secondary pollution indoors. An increase in temperature and primary emissions combined with solar radiation will lead to secondary air pollutants. In two of the four scenarios, the smog situation in winter may improve due to mainly westerly winds with relatively clean air. High temperatures and UV-radiation stimulate the production of photochemical smog as well as ozone precursor biogenic Volatile Organic Compounds [VOCs] (Wilby, 2007). Organic compounds that react with ozone on the surface of a used filter are transformed to more highly oxidized species. If thus oxidized chemicals are released fast enough compared with the airflow through the filter (organic compounds diffuse through the filter to the surface), they can influence the air quality downstream of the filter. In one study formaldehyde was found (Hytinen et al., 2003).

Many esters are used in indoor products/materials, such as plasticizers (phthalate esters, phosphates, sebacates, etc.) and flame retardants (halogenated phosphate esters, aryl phosphates, etc.), and therefore become part of the indoor environment (Weschler, 2004). These esters are susceptible to hydrolysis, especially under basic (high pH) conditions, a reaction which is slower than oxidation reactions and therefore insignificant in the gas phase (too little time for the reaction to occur before the molecules are ventilated from the space). But, on the surface these reactions can occur and occur more likely when the

surfaces are moist. Moisture also facilitates the disproportionation of NO<sub>2</sub> in aqueous surface films, leading to increased levels of nitrous acid (HONO) in indoor air.

The primary pollution of building products indoors can be influenced by an increase in indoor air temperature, but this effect will be small. For most pollutants, temperature increases of only a few degrees do not influence the emission rate significantly.

The KNMI climate scenarios forecast humidity and ferocity of precipitation to increase during winter months. Higher precipitation, both in summer and winter, combined with increased wind effects could result in wetter walls. Wet wall areas can become a pleasant living environment for fungi and moulds. In general, locations, with long or short term exposure to high amounts of water in combination with organic material, are ideal spots for growth of mould and bacteria (Rylander, 1998; Samson et al., 1994; Adan, 1994).

### 3.3 *Indirect consequences*

#### 3.3.1 *Effects on lighting quality*

Since the introduction of electric lighting, a large part of the population is spending time inside buildings during daytime. The consequences of the move from a bright and dynamic outside to a relatively dark and static indoor environment are incalculable. Light controls the human biological clock and is therefore an important regulator of the human physiology and performance (Duffy and Wright, 2005). During the day, it is important for humans to receive enough light at the eye for entrainment of the biological clock. Insufficient light levels could cause lower concentration, reduced performance, decreased well-being, sleep disturbance, or trends of (winter) depression. One of the consequences of climate change effects might be that people stay inside even more than they already do. In an attempt to shut out the sun, blinds and curtains will be used, decreasing daylight exposure even more. Additionally, the effect of storms and cloud forming may influence the quality of daylight.

#### 3.3.2 *Effects on acoustical quality*

Possible increased wind speeds and frequency of storms can influence the acoustical quality indoors through the noise and vibrations perceived. Vibration is in general experienced by fewer people than noise. However, where significant vibration occurs, it can be a cause of nuisance (or disturbance, or complaint); and/or a cause of health effects

(e.g., sleep disturbance) (Bond, 1996; DEFRA, 2007). The increase in use of air conditioning systems may cause more people to complain about noise originating from these systems. In a study performed by van Dongen and Steenbekkers (1993) with 4072 respondents, about 30% of occupants were disturbed by noise from a fan in their own house, when mechanical ventilation is applied. A smaller fraction was seriously annoyed. It was not clear how many were not annoyed because they turned the system down or off, thus preventing the disturbance (Dongen & Steenbekkers, 1993).

### 3.3.3 *Effects on psycho-social aspects*

The indoor environment can cause physical stress, such as too warm or too cold, and the indoor environment can limit a person in coping with this stress. For example, not able to control the temperature in their office, open the window to get outdoor (fresh) air or have the possibility of a view. Additional to that, psycho-social factors such as fear for storm, flooding, mental well-being, etc., can influence the perception of those physical and coping stressors (mostly negatively). And, the amount of time spent indoors might well be increased as a consequence of climate change effects, causing more stress and probably an increase in mental disorders and obesity, as this relation has been indicated by Bonnefoy et al. (2004).

## 4 **Adaptation possibilities**

Adaptation is 'the action taken to cope with a changing climate and may need to tackle present problems or anticipate changes in the future, aiming to reduce risk and damage cost-effectively, and perhaps even exploiting potential benefits' (EU, 2008). Actions include adapting building codes to future climate conditions and extreme weather events. The European Union (2008) emphasized that adaptation includes both national or regional strategies and practical steps taken at community level or by individuals (home or installation level). Adaptation planning will be more effective if it is systematic and strategic and even though it may require special focus, it also has to fit into existing practices, policies, and strategies.

In fact, the adaptation process can be engaged at three levels:

- Take away or adjust the **source** of climate change effects
- Adjust the **building** to the changing outdoor climatic conditions
- Involve **people** (occupants and other stakeholders)

At the first level, mitigation - taking actions to reduce greenhouse gas emissions - will be necessary to reduce the global temperature increase, assuming that human induced sources are the actual cause. Consequently, the impact in the long run will be less severe and adaptation possibilities improve. Efficient lighting and daylighting, more efficient electrical appliances and heating/cooling devices, improved insulation, passive and active solar design for heating/cooling, alternative refrigerant fluids are all examples of mitigation technologies and practices that are currently commercially available. Technologies and practices projected to be fully commercialised before 2030 (Cassar et al., 2007) are the integrated design of commercial buildings including technologies such as intelligent meters and controls including feedback options, and solar photo-voltaic [PV] cells integrated in buildings.

However, amongst others, experts of the British Royal Society fear that it is already too late to prevent climate change by reducing the emission of CO<sub>2</sub> (Lauder and Thompson, 2008). Humanity must possibly take more extreme measures. Crutzen (2006) called for active scientific research of the kind of geo-engineering. Geo-engineering is any large scale intervention or manipulation of the environment to help modify the Earth's climate, such as blocking sunlight through mirrors, increase precipitation, or removing carbon dioxide from the environment by injecting iron in the oceans or spreading dust in the stratosphere (Schneider, 2008). Therefore, to reduce the greenhouse gas emissions, possible adaptation measures may range from the development and use of new, innovative materials, which consume CO<sub>2</sub> and other green house gases, and can be used both indoors and outdoors to the design of façade or roof systems that bounce back sunlight into space.

For the second and the third level, it is important to realise that the indoor environment comes into existence as a consequence of the building process. Therefore, solutions for adaptations for the indoor environment should not be found in the building adaptation only, but should be part of the whole life cycle of the building and the processes involved, including technical as well as social (communicative) aspects. The lifecycle of a building comprises of initiation, design, realisation, occupation and renovation/demolition and reuse. Already at the initiation of a building, requirements for the indoor environment should be included in the brief in order to be taken on board. For existing buildings, the renovation also starts with a brief, followed by the detailed design and realisation of the intended adjustments and alterations.

#### 4.1 *Adjust the building (technical aspects)*

Temperature increase will most likely have the largest effect of climate change on the indoor environment in the Netherlands. It means that summer time overheating in buildings and urban areas next to moisture damage to buildings will be the main issues that have to be tackled and both issues have considerable health implications. Overheating is a slightly more serious problem in more modern buildings; moisture is often more applicable to older ones. Over the years, energy saving has been an important focus of the building world, meaning that Dutch homes lose less and less energy due to better insulation and energy recovery systems. However, with increasing temperatures outside, the inside temperature will increase accordingly, and mainly in summer periods when the sun remains heating homes, the temperature will rise to unacceptable levels.

Direct and indirect heat gains can be decreased by adopting a cooling strategy based on the 'switch off', 'absorb', 'blow away', and 'cool' principles (CIBSE, 2005). With '**switch off**', the reduction of heat gains due to needless use of electrical equipment of devices is meant, next to the use of sun shading as those can 'switch off the sun'. With regard to indoor lighting quality and climate changes consequences, adaptation measures may range from the use of foliage as an environmental friendly and effective way for sun shading to the development of lighting installations that are a combination of daylight, daylight dependent dimming installations, and energy efficient lighting technologies (e.g., CFL or LED), without losing the attention for lighting quality and visual comfort aspects. One step further will be climatically-sensitive buildings and façade systems that do not limit the adaption to building installations only, but mean wisely designed buildings and facades that react to the outdoor circumstances as required by the indoor user. The next step in the cooling strategy will be '**absorbing**'. By increasing the thermal mass of a building, (undesirable) heat gains can be distributed to reduce the peak. If the thermal mass cannot easily be changed (e.g., if the only way is to replace the building structure), adaptation measures have to go further by means of innovative solutions like e.g. phase change materials. Besides, increasing the thermal mass cannot be achieved without due attention to all the principles of low-energy and sustainable design, including proper appeal to the present-day and likely future climatic context of the site (Holmes and Hacker, 2007). In case excluding or absorbing gains are not reasonable adaptation options, solutions have to be found by means of installations. The strategy steps involving installations are '**blow away**' and '**cool**'. In case of installation use extra attention has to be paid to avoiding installation noise and vibrations. The 'blow away' strategy means the introduction of an

intelligent and properly ventilation strategy, with night cooling for example. Possible adaptation measures may range from the development and use of new, innovative energy recovery systems that are outdoor temperature dependable to climate-sensitive façade systems. In winter time, heat recovery systems recycle as much energy as possible while in summer they either discontinue working completely or operate in reverse. Incoming fresh air can should not only be warmed during the winter by means of an (earth) heat exchanger, but also cooled down during periods of high temperatures in the summer (Werner, et al., 2008).

As a consequence of indoor temperature increase, many air conditioning systems (primarily meant for cooling) will be introduced in homes, following the trend in increased air conditioning in non-domestic buildings. As stated before, attention must be paid to cleaning and maintenance of air conditioning systems. Although the first possible solution for this problem may be to avoid the use of air conditioning systems, especially in homes, adaptation strategies for pollution air conditioning systems may be range from the development of self-cleaning systems to systems which transform air pollution material into harmless components. Besides, Holmes and Hacker (2007) stated that HVAC systems will be replaced several times during the life of the building and therefore, a building and associated systems may take a number of different forms throughout the life of that building. According to the researchers, it is probably impossible to predict the changes that that will be made to the HVAC systems (Holmes and Hacker, 2007), but systems that can be easily changed and/or modified may contribute to effective climate adaption.

#### *4.2 Involve people (social, communication aspects)*

Either buildings, or occupants, but in many circumstances both, have to endure smaller or bigger changes to adapt to the changing situation outside. Management of the indoor environment is an issue for many stakeholders at different scales. It is a dynamic issue which has to take into account changes over time at those scales and of the stakeholders. The real occupants of a building can comprise of several kinds: occupants of dwellings, employees in an office building, employers, labour workers, personnel in a shop, etcetera. What they have in common is that they all like to be in a state of well-being that they can accept. This state of well-being can influence their productivity in the tasks they are performing and their state of mind and body.

Besides the occupants, the direct stakeholders of the indoor environment are the parties that initiate, create, build and maintain the indoor environments, in which we all live, work and play. These parties all have their own stakes for taking part in the life-cycle of the indoor environmental spaces. The parties involved are:

- the party who pays: the investor
- the party who initiates: the project initiator (often also the investor)
- the party who designs: design team including an architect and several consultants (systems, construction, etc..)
- the party who builds: the contractor and sub-contractors
- the party who owns/buys the building: the building owner (can be different from end-user)
- the party who maintains: facility manager
- the party who regulates: the regulator provides regulation and rules to keep
- the party who produces the products: construction, furnishing and HVAC system components producers
- the end-user who has his/her basic needs

The parties mentioned can have double functions, such as the project developer can also be the investor and the builder, and even the facilitator. The party who owns the building can be the end-user. Etc.

In the traditional process the project developer initiates a new project. From the acquisition of a construction location until the deliverance the regulator, the contractor, the design team (normally only the architect) and the owner are involved. After the first phases also the investor is involved, who is normally approached by the developer.

The communication between the stakeholders involved is crucial to make technical adaptations feasible and to make certain that end-users needs in a changing environment are translated in the appropriate way. Unfortunately, in the traditional building process, the so-called 'over the bench methodology' is often used; a real team is not formed. Parties do not understand each other, stakes or products and occupants' wishes and demands are only incorporated on an individual basis. Next to the communication process, understanding the needs and requirements of the occupants, before thinking about the solutions, is crucial for incorporating adaptations (Blyussen, 2008).

Fortunately, some “innovative” methods are available that do focus on the occupants requirements and the communication process between stakeholders, to incorporate the occupant requirements in the total building life-cycle via technical requirements in all the phases of the life-cycle. Communication i.e. interaction between supply and demand, and knowledge and/or technology transfer between sectors and stakeholders, is hereby of utmost importance. Several forms have been made available through communication, design, and even cooperation forms to make this interaction possible and more clear. Examples are the ‘Open building approach’ ([www.habraken.com](http://www.habraken.com)), the ‘value-domain model’ (Rutten and Trum, 1998), the ‘PPC [Public-Private-Cooperation]’ (Bergsma, 2007), and the ‘BriefBuilding Tool’ (Ree et al., 2007). But perhaps the most complete approach is the system engineering approach, a holistic top-down approach in which occupants’ requirements form the starting point (Blanchard, 2004).

For each of those can be said that they make use of an underlying structure (organisational structure, model, or even a contract) to accommodate the communication process, making it more effective and efficient whilst reducing the risks that overall project goals are not achieved.

Additionally, Cassar et al. (2007) stated that occupants will have to change their behaviour in relation to how they use and interact with buildings as the future climate changes. The change of occupant behaviour is – in theory – the quickest and most flexible adaptation strategy. However, in practice occupants have very little understanding of their interaction with the built environment. For example, many occupants let the heat into buildings during the hottest part of the day by opening windows. Issues like overheating need better designed solutions to cope with occupant behaviour. Other researchers like Cole et al. (2008) advised to engage occupants or inhabitants in the adaptation process. Also Chappells and Shove (2005) proposed several opportunities for behavioural and technological changes that promote adaptive (comfort) standards:

- People may become used to greater seasonal variety due to climatic variation;
- New clothing and furniture technologies could be developed to provide for insulation and environmental control;
- Institutional flexibility that includes variable work hours.



- Approximately 20% of the European population is allergic to mites and fungi and the prevalence of asthma and allergies in domestic buildings is increasing (Institute of Medicine, 2000). A meta-analysis of health effects of dampness, suggests that building dampness and moulds are associated with increases of 30-50% in a variety of asthma-related health outcomes (Fisk et al., 2007).
- Most countries suffer from 5-25% winter mortality. In the UK, this involves an estimated 20-40.000 death (Clinch and Healy, 2000). There are clear indications that excess winter mortality is connected to poor thermal insulation, and to fuel 'poverty'. The same accounts for an increase in respiratory and cardio-vascular ailments. Similar effects of cold stress have been pointed out in a Harvard study (Levy et al., 2003).
- Sleep disturbance, linked to a multitude of indoor physical parameters, increases the risk of household accidents by at least 46%. Some 350 million Europeans complain regularly about sleeping problems. (Bonnefoy et al., 2004)
- In 1998, more than 10 million accidental injuries in and around the house occurred in the Europe-15 countries. This resulted in more than 1 million hospital admissions and more than 42.000 deaths. The most common interior causes appear to be inadequate lighting, insufficient working space in kitchens and staircases. (Bonnefoy et al., 2004)
- It is estimated that in general 25% of families has one member at least suffering from mental disorder, which is the leading cause of disability worldwide. Depression affects 19 % of adults, and increases strongly with age. Antidepressant prescriptions have more than tripled the past 10 years (Bonnefoy et al., 2004). Rise in obesity is leading to increase in diabetes and risk for cardiovascular disease. Obesity reduces life expectancy (EU, 2007a). Both obesity and mental disorder seem to have a relation with the conditions of homes and neighbourhood's people are living together with the increasing time they spend indoors. (Bonnefoy et al., 2004).
- In 2000 about 350000 people died in the EU prematurely due to outdoor air pollution caused by fine particulate matter (PM2.5) alone. 11.5 % of children suffer from asthmatic symptoms in Europe. (EU, 2007a).

Figure 4. Some facts and figures on (un)healthy buildings (Bluyssen, 2008)

## 5 Conclusions

When Global warming is indeed inescapable, adaptations are necessary to reduce the impact also on the indoor environment. Bluysen (2008) reported in her literature review a limited overview of facts and figures on (un)healthy buildings (see Figure 4). In case the adaptation process is not implemented at all three levels (source, buildings, and humans), health consequences due to the indoor environment will be as mentioned in Figure 4 or even worse.

Adaptation strategies focused on health and comfort of people in the indoor environment should involve all stakeholders responsible and involved in the realisation of an indoor environment, using the appropriate communication processes.

Even though several adaptation possibilities have been sketched above, it should be reminded that, adaptation strategies cannot be executed properly until we:

- Understand the possible effects of climate changes on occupant wishes and needs both present and in the future, making modelling or predicting human behaviour under different environmental conditions possible and thus defining actions easier and straight forward.
- Understand the interactions at all interfaces of human being, indoor environment, building (elements) and outdoor environment.

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