The Design of Building and Services Affects Indoor Environments and Impacts Productivity

Bohgard, Mats

2012

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Professor Mats Bohgard, Ergonomics and Aerosol Technology, Department of Design Sciences, Lund University, Sweden, 2012

We know that indoor environmental factors (such as noise, light, air quality and temperature) not only affect our well-being and perception of comfort and discomfort, but also our productivity and the quality of our work performance. This is true for both white and blue collar workers. Hence, the design and performance of workplace buildings, as well as the quality of building services and property management, are important in efforts to obtain highly efficient performance of work assignments.

Some environmental factors obviously affect productivity. For others there is solid scientific evidence of the effects, and for still others we just have hypotheses and speculations. We need to compile current knowledge and carry out further research to understand fully the economic consequences of building design and building services on productivity. There is reason to believe that we have significantly underestimated the impact of the design of good indoor environments on work performance. This is an issue for production economists, enterprise management, the construction industry and property management.

Thermal climate and noise affect work capacity
It is well established that the thermal climate affects our capacity to work, both physically and mentally. Many workplaces have technical means to regulate the effects of hot and cold climates. However, global warming tends to increase heat stress in many outdoor work situations as well as energy costs for air conditioning indoors. This in turn increases the need to design buildings that protect workers from heat stress. Worldwide, in cold climates there are demands to lower energy consumption to decrease carbon dioxide emissions and offset man's impact on global warming.

There is evidence that high noise levels (from mechanical sources, human voices and activities in open-plan offices) increase fatigue and lower our capability to concentrate, especially on complex work tasks. This noticeably affects work capacity. There is also clear evidence that low frequency noise affects the mental capacity of workers in sub-populations. However, more systematic investigations are needed to quantitatively measure these effects on work performance.

Allergies and hypersensitivities decrease work capacity during pollen seasons
We are well aware that the work capacity for people who are allergic or hypersensitive to pollen decreases seasonally if no measures are taken. Filtration of the outdoor air before it comes indoors is an efficient way to maintain high capacity in indoor environments for these sensitive groups. In many densely populated tempered regions, the pollen season tends to be longer, and pollen concentrations higher, due to global warming, which increases the benefits that can be achieved by means of technical building services.

Dampness and molds affect perception, health and the working capacity of sensitive individuals
A number of studies clearly show that damp and moldy indoor environments affect perception and work capacity for various work tasks and cause illness. It is a challenge in construction, building service design and property management/maintenance to keep the working environment free from dampness and mold. There is also considerable evidence that irritant odors affect have a negative impact on the working capacity of sensitive populations.

Buildings with visible dampness and mold are known to trigger and/or aggravate symptoms in people with asthma. There are no conclusive studies, though, as to whether these conditions can initially induce asthma in healthy adults. Research indicates that this may very well be the case for young children, however.

Seasonal infections can be affected by indoor environmental factors
Seasonal infections result in employees taking sick leave, which temporarily reduces the working capacity of a large part of the population on earth. It is possible to decrease these effects by the way we design buildings and their influence on the indoor environment. A prerequisite, though, is increased knowledge of the mechanisms underlying the impact of environmental factors on the occurrence and spread of seasonal infections. This is especially the case for the airborne transmission of certain infectious diseases. A problem that is likely to increase significantly in the future is the severe and sometimes deadly effects of resistant bacteria.

Airborne particles in general
Today, there is strong epidemiological evidence of the relation between airborne particles measured in the outdoor environment and increased

morbidity and mortality of exposed populations due to cardiovascular and lung diseases. Combustion from traffic, wood burning and other types of energy production are examples of sources of these particles. Many particle types have shown to be toxic. The World Health Organization has recently (2012) classified diesel as a carcinogen.

No specific studies clearly show the effects of exposure on work capacity. However, since hospital admissions increase at times of elevated particle concentrations, there is reason to believe that the effect on productivity is negative, resulting in sick leave and long-term illness. It is likely that high particle concentrations influence the work productivity of large populations as significant increases in mortality and morbidity have been observed. But we do not have sufficient conclusive evidence from studies designed to estimate the effects on productivity**.**

Particles and gases/vapors created indoors

A large fraction of the particles we are exposed to indoors are also generated indoors by our activities and emitted from equipment and materials. In industrial environments, a variety of thermal and mechanical appliances emit particles. In offices, nursing homes and hospitals there are gases/vapors from humans, furniture, chemical products, etc. There are also particles from cooking, human skin, textiles, printers and copiers, and chemical reactions between ozone and cleaning agents, for example. There are good opportunities to offset the exposures caused by these emissions through the pro-active design of buildings, building services, as well as the physical and organizational planning of workplaces.

How can we achieve indoor environments that promote health and productivity?

Existing knowledge and practices provide a basis for the design of buildings to avoid harmful exposure to many indoor environmental factors. This is true for emissions from building material and furniture and problems due to dampness and mold. However, we do not have sufficient experience and data as yet to estimate the economic losses we can avoid and the increase in productivity we can gain in different types of work.

Even though we currently lack sufficient knowledge about exactly how airborne particles affect productivity, there are examples of technical solutions that can significantly decrease particle concentrations. One is the novel office building produced and maintained by Skanska in the center of Malmö, a city in southern

Sweden. The design of the building and ventilation system has resulted in concentrations of PM10 (particles less than 10 micrometer) that are approximately eight times lower than outdoor/ambient levels, and two times lower for PM1 (particles less than 1 micrometer) concentrations. Our group at Lund University performed the measurements of different modes of airborne particles. Figure 1 shows estimated mass concentrations over three days for particles larger than 0.5 micrometer. Figure 2 illustrates the mass particle size distributions of these particles. The results show that it is possible to achieve a very low baseline concentration and that a majority of the exposures to larger particles emanate from indoor activities. This means that the people working in the building are to a high extent prevented from exposures to particles from the city air (pollen, particles from wear between tires and pavement, and a significant fraction of traffic emissions from car exhaust). By increasing the ventilation filter efficiency to capture sub-micron particles, it should be possible to even further increase the protection against ambient particles that negatively affect the health of the population.

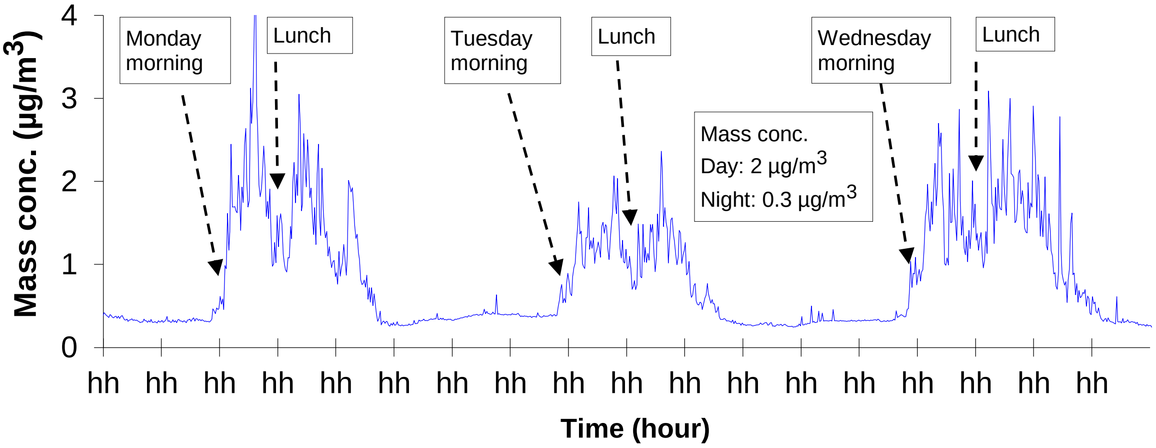

Figure 1. Mass concentrations over three working days for particles larger than 0.5 micrometer in a novel office building produced by Skanska in Malmö, Sweden (from a 2007 study by Gudmundsson, Dahl and Bohgard at Lund University).

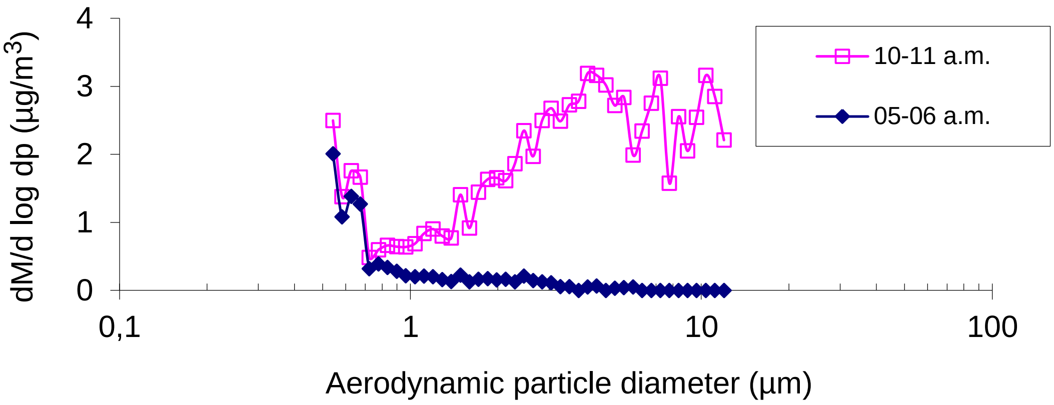

Figure 2. Example of mass particle size distributions of particles in Figure 1. Particles in this size range is dominated by emissions from indoor sources due to the high degree of filtration of the supply air (i.e., subjects in the building are protected to a high degree from exposure to outdoor particles).

For buildings situated in areas with high road traffic intensity, it is particularly important to reduce particle concentrations before the air is supplied to the interiors. Increased concern about the toxicity of diesel exhaust particles stresses this importance. Figure 3 displays an image from transmission electron microscopy of diesel particles. If no precautions are taken these particles will penetrate extensively into the interiors of buildings and, after inhalation, be deeply deposited in human airways.

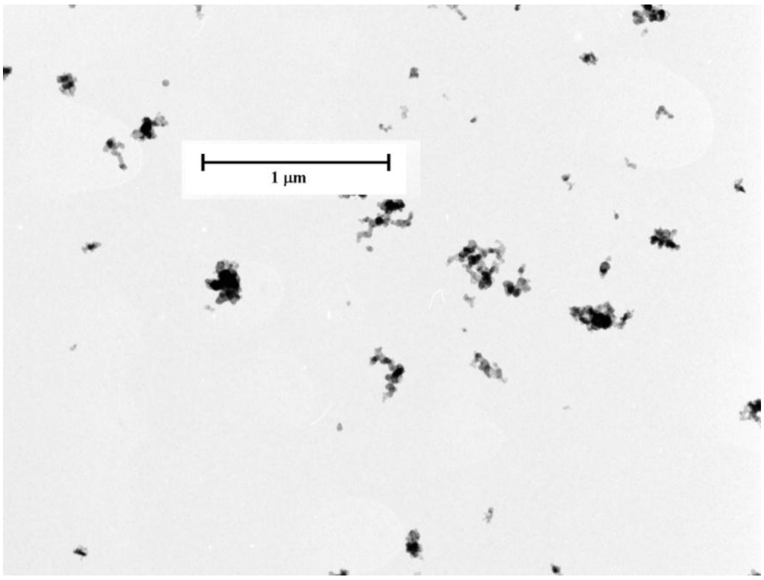

Figure 3. Diesel exhaust particles (image from Patrik Nilsson, Ergonomics and Aerosol Technology and Dr. Erik Carlemalm, Lund University Bioimaging Center).

Intensive research activities are taking place worldwide to increase our understanding of how the indoor environments affect health and perception. An example is that of the experiments going on at Lund University's Division of Ergonomics and Aerosol Technology (Figure 4). Extensive studies are examining the extent to which humans are affected by different environments. Both objective measures of physiological factors and subjective ones of how people perceive such environments are used.

Figure 4. Left: a walk-in chamber at Lund University, Sweden, where extensive studies are performed on how indoor environmental factors affect humans. Right: one of the test persons is examined after being exposed to airborne particles in the chamber.

Our knowledge is rapidly increasing on how various indoor environmental factors affect populations, sensitive sub-populations and individuals with respect to health perception and how we perform. Bad indoor environments result in production losses due to illness and sick leave, but also due to a decrease in work capacity. Productivity most likely could be even more increased by improving the environment beyond the measures considered necessary to avoid direct unhealthy exposures. This can be done by creating workplace environments that are positive for human well-being and effective work performance.

In addition to the environmental factors mentioned in this paper, the design of construction and building services also affects light environments, occupational safety, physical workload and how we can organize work, all of which certainly affect productivity.

What we need are better methods that improve the quantitative predictions of productivity losses and gains in order to economically justify increased investment in healthy and productive environments.

Acknowledgements
The author is grateful to the following individuals for valuable suggestions and comments on the manuscript: Dr. Maria Albin, Occupational and Environmental Medicine, Lund University; Dr. Aneta Wierzbicka and Dr. Anders Gudmundsson, Ergonomics and Aerosol Technology, Department of Design Sciences, Lund University.

Professor Mats Bohgard is head of the Division of Ergonomics and Aerosol Technology (www.eat.lth.se) at the Department of Design Sciences, Lund University, Sweden. He has long and extensive experience in research and teaching on air quality and on how environmental factors affect work environments.