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Exploring the relationship between indoor air and productivity

by Riikka Antikainen, MSc(Econ),[1] Sanna Lappalainen, PhD,[2] Antti Lönnqvist, DSc(Tech),[1] Kati Maksimainen, MSc,[2] Kari Reijula, DMedSci,[2] Erkki Uusi-Rauva, DSc(Tech)[1]

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A lot of prior research has been done on the relationship between indoor environments and productivity, as well as on the measurement of the productivity impact of various improvement actions concerning indoor environments. Experience has shown that these studies are difficult to perform in practice. This paper identifies the pitfalls of designing such studies by examining several research projects. The methodological challenges include obtaining valid measurement data and taking into account the productivity impact of different components of indoor environments and other business factors, for example. As conclusions, solutions—such as choosing case organizations carefully and applying indirect productivity measures—are proposed to overcome the problems.

Key terms business performance; indoor environment; intervention; measurement; methodology; profitability; research methods.

Indoor-air problems can cause health hazards for people working on premises with indoor-air problems, and they may also affect the functioning of the whole organization. The connection between serious indoor-air problems and productivity is undeniable. For example, indoor-air problems can cause significant costs to companies. Another simple example is a situation in which an employee has to stay on sick leave due to health problems caused by indoor air. The result is a loss of workhours, higher medical costs, and increases in other employees' workloads.

In practice, the connection between indoor air and productivity is complicated. Several studies examining different elements of indoor air and their effects on productivity have been carried out. Even when the mechanism behind productivity has been known, the empirical assessment of productivity effects has been difficult. There has also been a lack of uniform methods for connecting productivity and indoor-air quality, and future studies are required to confirm the positive effects of investments in indoor air on productivity (1).

This paper examines the connection between indoor air and productivity from a methodological point of view. The objective is to discover pitfalls in designing such studies and to propose solutions for research design that would help overcome them. This paper is based on experiences gained in several research projects conducted by the authors. The relationship between work environments, such as increased temperature or noise control, and productivity has been studied in these intervention projects. In addition, experiences from other reported studies on the issue have been analyzed. Since productivity gains of indoor-air investments are of interest to both researchers and building managers and developers, the results of this study should provide valuable information for them.

Key concepts and their expected relationships

There are numerous biological (eg, allergens, fungi, bacteria, pollens, endotoxins), physical (eg, temperature, relative humidity of the air, air movement, noise, light), and chemical (eg, carbon dioxide and monoxide, volatile organic compounds, ammonia, formaldehyde, radon, ozone) sources in indoor-air environments. They may originate from construction materials, office machines, cleaning agents, and humans, for example. In addition, outdoor contaminants (like particles and bioaerosols) affect the quality of indoor air. The impact is connected with the filter efficiency and the volume of indoor air. The status of these factors determines the indoor air, and distortions in them can cause indoor-air problems. According to a recent questionnaire survey (2), the most

1 Tampere University of Technology, Tampere, Finland.
2 Finnish Institute of Occupational Health, Helsinki, Finland.

Reprint requests to: Dr A Lönnqvist, Institute of Business Information Management, Tampere University of Technology, PO Box 541, FI-33101 Tampere, Finland, [E-mail: antti.lonnqvist@tut.fi]

common environmental problems in Finnish offices are dry air (35% of the respondents), stuffy air (34% of the respondents), dust or dirt (25% of the respondents), and draft (22% of the respondents); the most common work-related symptoms are irritated, stuffy or runny nose (20% of the respondents) and itching, burning or irritation of the eyes (17% of the respondents).

Productivity is one of the key factors that define a company's ability to thrive in competition. A simple way of defining productivity is to describe it as a ratio between the output (eg, products, services, and activities) and the input (eg, material, labor, capital, and energy) that is used to generate the output. Productivity can be improved by making more output in relation to the amount of input and by making output with better quality (eg, less defective products). Productivity is closely related to profitability. The profitability of a company is affected by its productivity and also by the changes in input costs and output prices. While productivity deals with the amount and quality of input and output, profitability is examined in monetary terms.

Another key concept related to productivity is business performance. Business performance refers to a multiperspective interpretation of the success of an organization (3–4). In addition to profitability and productivity, other important components of business performance include customer satisfaction and loyalty, employee welfare, competencies, product quality, lead time, delivery efficiency, brands, corporate culture, and market share, for example.

Indoor air can affect productivity through many different routes. In order for the impact of indoor air on productivity to be determined, it is necessary to uncover the mechanism behind the relationship. In the workplace, there are several indoor elements (physical, chemical, and biological) that may sometimes cause health effects among workers (respiratory, skin, nervous, nasal, and related problems), and they can also hinder the fluency of work. In extreme cases, usually when serious indoor-air problems have occurred for a long time, they can also decrease employees' motivation. These effects on employees may, in turn, cause changes in business outcomes. These changes may be realized in various ways, in input usage, output quantities, work quality, expenses, for example, which are well-known factors of productivity.

Identification of the impact of indoor-air factors on productivity

Theoretical limitations

There are some theoretical limitations to the assessment of the effects of indoor air on productivity. First, when assessing productivity, we should be able to determine which factors cause alterations in the productivity level. In addition to the indoor environment, there are several different aspects that influence productivity—management and organization, job content, motivation, and training, for example (5–6). When the quality of indoor air is altered in real-life situations, other alterations may also take place. For example, changes in customer demand or the implementation of a new production technology may have a dramatic impact on productivity. In such cases, it may be difficult to determine which part of a productivity change is caused by indoor-air aspects and which is the result of other factors. Thus there is the problem of eliminating the other aspects when the effect of alterations on indoor air is evaluated. The most common method of dealing with this problem is the assessment of productivity effects in laboratory settings. They allow many of the affecting aspects to be controlled, such as environmental conditions, the work environment, workload, and, in some cases, also personal factors. In field studies, these factors are much more difficult to control (7). Another problem related to this situation is the inability to conduct studies in which several aspects of the indoor environment can be taken into account at the same time. It is argued that many studies focus on single aspects of the indoor environment, and, if they deal with multiple aspects, they are often too general and qualitative (8).

Second, it may take some time before the impact of an intervention is realized. An improvement in air quality (eg, reduction in detrimental particles in the air) may not take place immediately after the development actions. This delay may cause problems with productivity assessment, especially if it is done in real premises and not in laboratory settings. This lag may also lead to situations in which the observed alterations in productivity are caused by changes in some other factors, which are just not detected. On the other hand, the changes caused by improvements in indoor air may not have been realized before the assessment of its effects on productivity. Therefore the actual implications cannot be noted until later.

Third, differences in jobs can impose another problem for productivity measurement. The effects of changes in indoor air may vary in different jobs. For example, Kosonen & Tan (9) concluded that higher temperatures affect the jobs that include thinking (ie, knowledge work) more than "typing" jobs. On the other hand, productivity assessment cannot follow similar routes in dissimilar jobs. Therefore, the same methods cannot be automatically applied in all studies. This problem may make it difficult to compare research results between different jobs. In addition, the generalization of the results is limited in such studies because they are performed for too specific a population (8).

Empirical experiences

Several research projects have examined the connection between indoor air and productivity (10–12). Most of the studies have been conducted as field studies on the actual premises of an organization, and the applied productivity measures have been chosen individually in each organization. The most apparent problem with these studies has been the nonexistence of proper productivity measures. In many cases, the organization either did not monitor its productivity before the research project or it was impossible (given the resource constraints) to apply any objective measures. In these cases, a variety of subjective measures based on questionnaires has been used. In addition, certain surrogate measures, such as absence due to sickness, have been applied.

The nonexistence of productivity measures has been a result of many factors. Many of the case organizations have been nonprofit institutions, their output has been immeasurable, and the tasks under examination have been knowledge-oriented, or the tasks within the organization have differed. All these aspects have complicated the measurement and comparison of productivity assessments between different tasks, organizational units, or time periods.

In most studies, subjective measures have been applied to overcome the problems with objective productivity measures. These measures have worked rather well, although there is only limited experience from their use and many researchers are critical towards their reliability. However, they seem to offer a rather good means with which to examine employees' perceptions about surrogate factors of productivity and, especially, their comfort in the workplace (13). On the other hand, the information they provide may not indicate sufficient evidence of productivity effects, since it may be difficult to separate productivity effects of indoor-air improvements from other factors when subjective methods are also used.

Seppänen et al (7) analyzed several studies that examined the effect of ventilation on performance. They concluded that, in only a few cases, objective measures have been used. It seems to be easier to use them when clerical-type work is studied, but subjective methods seem applicable to more diverse work. They also stated that relevant objective measures are rare. The most used of them seems to be speed of work (eg, average time per certain task), but it does not fit jobs in which tasks regularly differ from each other. However, they argued that the use of subjective methods expose productivity measurement to expectations or biases and, therefore, deliver more unreliable data.

Another problem in several of the empirical studies reported was related to the laboratory settings, in which certain imaginary and mostly mechanical tasks were used to imitate real work situations (8–9, 14–16). The observation of such mechanical tasks provided information about indoor-air effects on them but not necessarily data on the work processes, which consist largely of brainwork. For example, noise is known to impede brainwork (16). However, these effects may not be observable if we measure productivity in laboratory conditions with predefined tasks instead of in real work situations, where tasks may differ, sudden changes are probable, and the like.

Discussion

Studying the effects of indoor air on productivity at work has proved to be of interest to both researchers and building managers. The problems with these projects have been discussed in this paper in terms of our experience. We propose that the following four sets of actions be taken in such projects in order to avoid the most common mistakes being repeated.

First, the research frame has to be carefully planned. In order for productivity effects to be studied, there has to be applicable productivity measures on which the comparisons can be based. Many of the problems faced in research projects have been related to the fact that there has been no real experience with productivity measures, and, therefore, the application of suitable methods has proved impossible in practice. In an ideal situation, the organization already has a tradition in productivity measurement and uses certain measures for continuous measurement. These measures have proved to be applicable in the organization under study and will provide the productivity information required to enable comparison between different time periods.

Second, each project should be started by defining the presumed path from indoor-air improvement to employee's perception, and, from there, to improvements in productivity or performance. Interventions related to indoor factors have a different impact, and the impact may vary in different situations. Solving an indoor-air problem may, for example, increase an employee's motivation, while solving another problem may prevent the employee from getting sick. Furthermore, the employee's organization may benefit from these interventions in terms of improved efficiency and creativeness (due to improved motivation) or in terms of savings in sick-leave costs and improved labor productivity (in case the employees become healthier). The defined path of causes and effects can assist with the recognition of factors for which a positive impact of indoor-air improvements is most likely seen. These relationships can be visualized using strategy maps or similar tools (17). Defining the relationships can further

be utilized when the surrogate factors that should be monitored are determined.

Third, it can often be easier to detect the effects of indoor-air improvements by monitoring surrogate factors (eg, absence due to sickness, motivation) than by traditional direct productive measures. It may even be impossible to detect a direct effect on productivity because it may be relatively small in the short run, and thus other factors that affect productivity or performance can overshadow them. Indoor-air factors are known to first affect the perceived comfort of employees, and only when problems are very serious or prolonged do they gradually affect the performance of employees also. Therefore, the surrogate factors should highlight changes in factors of productivity even before they have caused irreversible reductions in productivity. Examples of possible surrogate measures include (18–21) (i) process problems (high defect rates, machine defects, unused capacity, high material scrap, unnecessary transports, and long waiting times), (ii) work habits (absenteeism, tardiness, and safety rule violations), (iii) work climate (number of grievances, employee turnover, and job satisfaction), (iv) feelings or attitudes (attitude changes and perceived changes in performance), and (v) initiative (number of suggestions submitted and implemented, successful completion of projects).

Fourth, from the indoor-air measurement perspective, technical indoor-air measurements are not unambiguous. Therefore, it is recommended that subjective methods with psychosocial aspects be developed and tested to evaluate the quality of indoor air in the future. The results of technical indoor-air measurements and subjective evaluation may also offer more clarification with respect to the connection between indoor-air quality and productivity.

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