The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement

Article *in* Journal of Facilities Management · July 2002

DOI: 10.1108/14725960310807944

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Keywords:
productivity, performance, indoor environment, comfort level, thermal comfort

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The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement

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Received (in revised form): 27th August, 2002

Abstract

One of the fundamental human requirements is a working environment that allows people to perform their work optimally under comfortable conditions. Given that buildings and air conditioning systems are designed on the basis of a certain level of discomfort, this raises the key question 'What is the effect of the level of comfort on the productivity of people working in office environments?' The purpose of this paper is to quantify this relationship as an aid to making choices regarding the working environment at strategic level within the facilities management process, with particular emphasis on thermal conditions.

INTRODUCTION

For the assessment of the thermal indoor environment of offices, it is customary to start out from a certain level of discomfort. The criterion operated for this purpose is a permitted transgression of a certain percentage of dissatisfaction within the annual working hours. In practice, it has become clear that there is a need for a classification of buildings and installation concepts based on the level of comfort, in which the permitted transgression or the percentage of dissatisfaction per category differs. The concepts of category and (climate or comfort) class will be treated henceforth as synonyms.

A telephone survey conducted by the Building Owners and Managers Association International among 400 facility management and real estate managers in the US revealed that the indoor environment in particular is regarded as a major problem within the scope of building management, maintenance and design. The respondents also voiced their expectation that improving the indoor environment would lead to a significant rise in productivity in the organisation.[1] A recent article by Leyten and Kurvers contained a summary of the research (including Preller *et al.*, The Netherlands Organisation for Applied Scientific Research and Bluysen *et al.*) that underpins the conclusions drawn above.[2]

Extensive scientific research has also yielded indications suggesting that improving the working environment results in a reduction in the number of complaints and absenteeism and an increase in productivity.[3,4]

Working environment

Given that the personnel costs are substantially higher than the housing costs, investing in the quality of the working environment is the most effective way of combating loss of performance.[5,6] As opposed to sickness and accidents, fatigue and working reluctantly can affect a large number of people. This implies that the adverse effect on the performance of each individual does not have to be particularly substantial to result in a relatively high loss of productivity for the organisation as a whole. Research conducted by Rosenfeld, for instance, revealed that an additional investment in the climate systems of 10 per cent in a given office situation was justifiable if it resulted in a productivity increase of only 0.33 per cent.[7] Although this percentage will be barely quantifiable, it does indicate the relatively significant effect of the productivity aspects on the cost effectiveness of an additional investment.

Indoor environment

Considering the great importance of the workplace, it is surprising that most researchers have ignored the effects of the indoor environment on productivity and job satisfaction. It therefore seems that the design of the workplace is barely regarded as a strategy for productivity enhancement. This is especially the case regarding the office environment.[8]

PRODUCTIVITY, ABSENTEEISM AND HINDRANCE

Productivity

Productivity

Productivity is that which people can produce with the least effort.[9] Productivity is simply defined by Sutermeister as output per employee hour, quality considered.[10] Dorgan defines productivity as the increased functional and organisational performance, including quality.[11]

An increase in performance is expressed in a directly quantifiable reduction of absenteeism, such as a reduction in the number of employees that leave work too early or take long lunch breaks. The improvement in performance can, however, also be the result of an increase in the quantity and the quality of the production during the period that employees are actively working.

Absenteeism

Absenteeism

Research into people's satisfaction with the quality of the indoor environment in 61 Dutch office buildings (some 7,000 respondents) reveals that the employees questioned are absent on 2.5 days a year owing to complaints related to the indoor environment. This represents a quarter of the total average absenteeism of 10 days a year (absenteeism percentage 5 per cent of 2,000 workable days) per employee.[12]

Hindrance

Hindrance

As well as absenteeism, the hindrance aspect can also cause loss of productivity. Employees are present at the workplace but work less hard. The effect of quality improvement on the indoor environment yields an increase in performance varying from 5 to 15 per cent.[13–15]

FACTORS AFFECTING PRODUCTIVITY

As well as the working environment, there are also factors outside of the working environment that can have a positive or negative effect on a person's performance.[16] These factors cover areas such as domestic problems, personal relationships or the excessive consumption of food or drink, which affect a person's performance at work. These factors are, however, beyond the control of the organisation. Conversely, the working environment is the direct responsibility of the management.

Job stress

Job dissatisfaction

Motivation

Aspects such as job stress or job dissatisfaction also come under the responsibility of the management. Job dissatisfaction is related (among other things) to the question of motivation. This is a crucially significant factor regarding performance. It concerns basic motives, rewards, both tangible and intangible, and personality variables. Assuming that a clear and significant level of motivation is present and guaranteed, what is the relative role of the indoor environment on performance and productivity?[17]

Research is presently being conducted at the University of Reading into the effect of the working environment, management style, job satisfaction, job stress and personal factors on people's productivity and health.[18–20]

Performance

A pilot research project held among 170 people in six office buildings reveals that there is a clear relationship between job stress, job dissatisfaction and the indoor environment. Furthermore, a productivity increase of 10 per cent was observed following improvements to the indoor environment.

Using multiple linear regression analysis based on research results, the researchers made an equation for the worker evaluation of productivity (WEP) according to a nine-point scale, with dissatisfaction with the indoor environment, job stress and job dissatisfaction as variables according to a seven-point scale.

The equation is as follows:

$$WEP = 6.739 – 0.419E – 0.164JD – 0.048JS$$

Worker evaluation of productivity

where WEP is worker evaluation of productivity, E is dissatisfaction with the indoor environment, JD is job dissatisfaction, and JS is job stress.

It is clear from this equation that the indoor environment has a relatively substantial effect on productivity in relation to the other parameters. It is also clear that employees regard the indoor environment more critically in proportion to the extent to which the other parameters are comparatively unsatisfactory.

The WEP can be regarded as a measure of what the employee thinks, regardless of whether that opinion is correct. If employees feel that the physical and psychological conditions in the office affect their productivity, that view is important because it is likely to affect other areas of the work. Researchers regard the WEP as a suitable yardstick for productivity.[21]

PRODUCTIVITY AND THE INDOOR ENVIRONMENT

Sound level

The auditory indoor environment

It is known that sound levels above a critical limit can cause hearing damage. This limit must of course be respected, but there does not yet appear to be a significant effect on productivity below that limit.[22]

The visual indoor environment

Lighting

Lighting levels have a very minor effect on productivity unless the task is very visually demanding. That is not the case in most office complexes. The human eye can adapt to a very wide range of lighting conditions, even in situations that are far from ideal.[23,24]

Air quality

Air quality

Recent research results have demonstrated for the first time that air quality has a significant effect on the productivity of office workers, in both positive and negative terms.[25] In a normal office with good climate control, it was possible to produce two different air qualities. The percentage of dissatisfied employees was 15 per cent (Category A according to NPR-CR 1.752[26]) and 23 per cent respectively (roughly corresponding to Category B). The same test subjects worked for 4.5 consecutive hours on simulated office work. Their productivity proved to be 6.5 per cent higher with air of the highest quality, and they also displayed fewer symptoms of Sick Building Syndrome.[27] Later (unfortunately unpublished) studies confirm the positive effect of good air quality on productivity. These research results strongly justify providing office workers with good air quality in the future.[28]

Thermal environment

The thermal indoor environment

The thermal environment has a considerable effect on performance and is even measurable within the comfort zone. Unlike sound and light, the thermal environment affects all workers, regardless of the nature of their activities.[29]

Level of control

Level of control

Most users' complaints are about the temperature and draught and to a lesser extent about sound, lighting and air pollution (eg because of smoking). This holds especially true if the temperature and ventilation are only controlled centrally without the users being able to exert any control. Aspects such as sound, lighting and smoking, however, are often mainly influenced by changes at a level

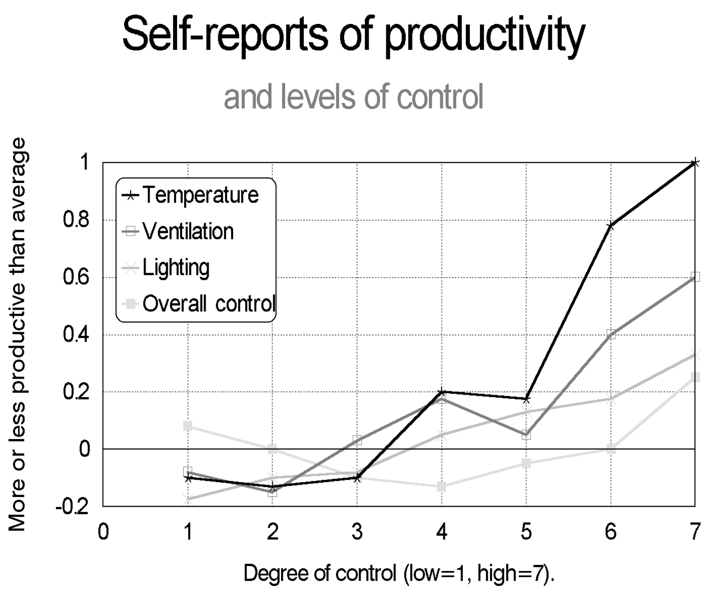

Figure 1: Relationship between self-reports of productivity and levels of control

in the building that can be influenced by the user (eg the internal layout, the work station set-ups that are partly determined by the users). There are indications that if users are able to exercise greater control over the indoor working environment, there is an improvement in performance, involvement in the work and morale. This implies an increase in productivity within the organisation (Figure 1).[30,31]

PRODUCTIVITY AND THE THERMAL ENVIRONMENT

The thermal environment is important both to the building design (including installations) and the building management. The relation between the thermal environment and productivity makes it possible to design the building and the installations on the basis of productivity improvements. Creating a comfortable working environment can give the organisation a consistent financial advantage.

Financial advantage

Various thermophysiological human models[32–35] and building simulation models (eg VA 114) are available for the assessment of existing working environments in thermal terms or the design of new, comfortable working environments. Thermophysiological human models are mathematical models based on the heat balance of the human body.

Human models

One of the human models (the two-layer model of Gagge) makes it possible to relate the loss of performance to the thermal load.[36,37] Research conducted by the Loughborough University of Technology reveals that the above-mentioned relation is suitable for comparative studies concerning the productivity change in relation to the thermal environment.[38] A direct relation can be made

Comparative studies

Table 1: Regression coefficients in the loss of performance equation

Regression coefficients	For the cold side of the comfort zone	For the warm side of the comfort zone
b_0	1.2802070	−0.15397397
b_1	15.995451	3.8820297
b_2	31.507402	25.176447
b_3	11.754937	−26.641366
b_4	1.4737526	13.110120
b_5	0.0	−3.1296854
b_6	0.0	0.29260920

Regression analysis

between the loss of performance and the predicted mean vote (PMV) on the indoor climate by incorporating the calculations of equal thermal situations with the model of Gagge[39] and that of Fanger[40] by means of a regression analysis.

This relation is therefore as follows:

$$P = b_0 + b_1 PMV + b_2 PMV^2 + b_3 PMV^3 + b_4 PMV^4 + b_5 PMV^5 + b_6 PMV^6$$

where P is the loss of performance (per cent) ($P >= 0$), and b_0–b_6 are regression coefficients, which are given in Table 1.

NEN–EN–ISO–7730

This relation is in line with the method generally used in the Netherlands for assessing the indoor climate in accordance with NEN-EN-ISO-7730[41] on the basis of the PMV index, and is shown in graph form in Figure 2.

Thermal comfort

THERMAL COMFORT

To predict the thermal perception and the extent of dissatisfaction with the climate, use is made of the method described in NEN-EN-

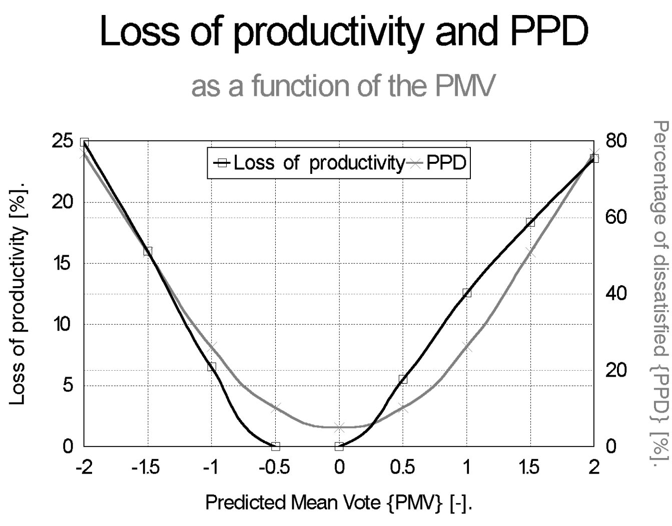

Figure 2: Relationship between the loss of productivity, PPD and the PMV

ISO-7730.[42] This standard employs the concepts PMV and PPD, which, for the sake of clarity, are explained below.

Predicted mean vote

Predicted mean vote

Thermal comfort is quantified in the PMV value. The PMV is the calculation variable, based on the heat balance of the human body, which predicts the average value of the assessment of a large group of healthy people who make a pronouncement on the thermal perception of the environment on the basis of the following seven-point scale:

- +3 hot
- +2 warm
- +1 slightly warm
- 0 neutral
- –1 slightly cool
- –2 cool
- –3 cold.

Predicted percentage of dissatisfied

Predicted percentage of dissatisfied

The individual assessments result in a certain spread around the average value. It is therefore useful to predict the percentage of people that will normally experience the thermal environment as uncomfortable, ie the predicted percentage of dissatisfied (PPD). This PPD can be derived from the PMV. The PPD provides a quantitative prediction in percentage terms of the number of people that are dissatisfied with the climate.

Criterion

CRITERION FOR THERMAL COMFORT

The choice of the limits set for the indoor climate can be derived from the following:

Working Conditions Act

(1) The Netherlands Working Conditions Act (Arbo-wet; art. 3) obliges the employer to promote safety as effectively as possible, to offer as much health protection as possible and to promote wellbeing as well as possible. The term 'as well as possible' is further substantiated by the stipulation that this has to be based on the generally recognised rules of technology, the prevailing standard for industrial health, the prevailing standard for ergonomics and the prevailing standard for labour or business administration. The Dutch standard NEN-ISO-11399 'Ergonomics of the Thermal Environment'[43] and the Dutch code of practice NPR-CR 1752,[44] including the recommendations in the annexes, are regarded as documents in which the prevailing standard of ergonomics in the area of the indoor climate are laid down.

NPR-CR–1752

(2) Article 3 of the Arbo-wet stipulates that only what can reasonably be expected is required. The minimum requirement for the indoor climate is in any event that which is generally

Table 2: Three categories of thermal comfort

Category	Thermal comfort	
	PPD (%)	PMV (–)
A	<6	–0.2<PMV<0.2
B	<10	–0.5<PMV<0.5
C	<15	–0.7<PMV<0.7

accepted. What is generally accepted for the office situation is facilities with which the PMV value can be kept between –0.5 and 0.5. A lower value is permitted for a maximum of 5 per cent of the working hours, and a higher value for a maximum of 5 per cent. This is subject to the understanding that account must be taken of the seasons (weather conditions) when the PMV area ± 0.5 is fallen below or exceeded. Possibly acceptable deviations from this starting point, depending for instance on the function of the area, the work situation and the practical alternatives, are laid down in the Dutch code of practice NPR-CR 1752[45] and the Building Services Research Institute ISSO/SBR-publications 300[46] and 354.[47]

Code of practice

THE DUTCH CODE OF PRACTICE NPR-CR 1752

The Dutch code of practice NPR-CR 1752 *Ventilation of Buildings — Design Criteria for the Indoor Environment*, dated January 1999[48] makes a distinction between three categories for the indoor environment in buildings (categories A, B and C), in which the limits within the PMV value have to be different for each category as regards the thermal environment. Table 2 provides an overview of this categorisation.

Dutch situation

VERIFICATION AND CATEGORISATION FOR THE DUTCH SITUATION

According to Appendix D of NEN-EN-ISO 7730, during working hours the thermal environment has to be within the comfort limits $-0.5 < \mathrm{PMV} < 0.5$.[49]

For the assessment of the thermal environment, it is customary in the Netherlands to verify this in accordance with the directives of the Dutch Government Buildings Agency Department.[50–52] These directives are in principle based on the above comfort limits, subject to the understanding that under extreme meteorological conditions and during malfunctions in the installations the recommended values may be deviated from:

— during heating season: max. 5 per cent of the annual working hours $\mathrm{PMV} \leqslant -0.5$ (100 h/y)
— outside heating season: max. 5 per cent of the annual working hours $\mathrm{PMV} \geqslant +0.5$ (100 h/y).

This is based on an operating time of nine hours a day, including a one-hour break (2,000 h/y).

Dutch Government Buildings Agency

To rule out the possibility of excessively high temperatures in the national government's offices, the Dutch Government Buildings Agency and the former National Medical Department have set a requirement that PMV must not exceed the value 1.[53]

Based on the comfort-determining parameters in normal office situations, the verification criterion for the *summer period* can be translated as follows:

— For a maximum of 5 per cent of the annual working hours (100 h/y), an indoor air temperature of 25°C may occur or be exceeded.
— for a maximum of 1 per cent of the annual working hours (20 h/y), an indoor air temperature of 28°C may occur or be exceeded.

This Dutch Government Buildings Agency criterion (which has somewhat fallen into disuse) was previously often used in practice to assess the thermal indoor temperature.

Weighting hours

These days, increasing use is made of the 'weighting hours criterion' for the assessment, where the number of hours during which the PMV is greater than 0.5 or less than –0.5 are weighted. This weighting factor is determined in such a way that an hour with twice the number of predicted dissatisfieds is also doubled in the calculation. The sum of the weighted transgressions and shortfalls is designated as the 'weighting hours' or 'weighted temperature transgression hours' (WTH). The Dutch Government Buildings Agency has set the verification value for a standard office situation as 150 weighting hours/WTH hours, for both the winter and the summer periods. In the approach adopted by the Dutch Government Buildings Agency, PMV values exceeding 1 are in principle permitted in the weighting hours criterion.

Weighted temperature transgression hours

The current performance specifications of the Dutch Government Buildings Agency propose verifying on the basis of the weighting time. To bring this in line with the developments at national and European level, the Dutch Government Buildings Agency, ISSO (Building Services Research Institute) and NOVEM (The Netherlands Agency for Energy and the Environment) propose (eg in ISSO/SBR publication 300)[54] basing the categorisation of buildings on:

— a maximum of 100 weighting hours
— a maximum of 150 weighting hours
— a maximum of 200 weighting hours.

Legal requirements

The requirements operated here do not conflict with the viewpoint laid down in the Working Conditions Information Sheet AI-7,[55] which can be regarded as a substantiation of the Working Conditions Act. If this categorisation is adhered to, in the

Table 3

Category	No PMV transgressions		Minimum 90% of the working hours per year within the PMV limits mentioned[a]
	PPD (%)	PMV (–)	PMV (–)
A	<6	−0.2<PMV<0.2	−0.2<PMV<0.2
B	<10	−0.5<PMV<0.5	−0.5<PMV<0.5
C	<15	−0.7<PMV<0.7	−0.7<PMV<0.7

[a]A transgression of the PMV limits for a maximum 5% of the working hours.

judgement of the Ministry of Social Affairs and Employment, the indoor climate meets the legal requirements.

PRODUCTIVITY IN RELATION TO THE CRITERION OPERATED

Starting points

Starting points

To ascertain the extent to which the criterion operated for the thermal indoor environment affects productivity, a number of calculations for a standard office are made in accordance with the insights described above. Table 3 contains an overview of the criteria operated for the thermal indoor environment.

Calculation results

Calculation results

Figure 3 provides an overview of the calculation results when mechanical cooling is used and when mechanical cooling is not used (the installation is only prepared for cooling). In the latter case, a substantial increase in the loss of productivity is perceivable.

The remaining calculations are based on mechanical cooling so that one of the above-mentioned criteria is met in accordance with NPR-CR 1752.[56]

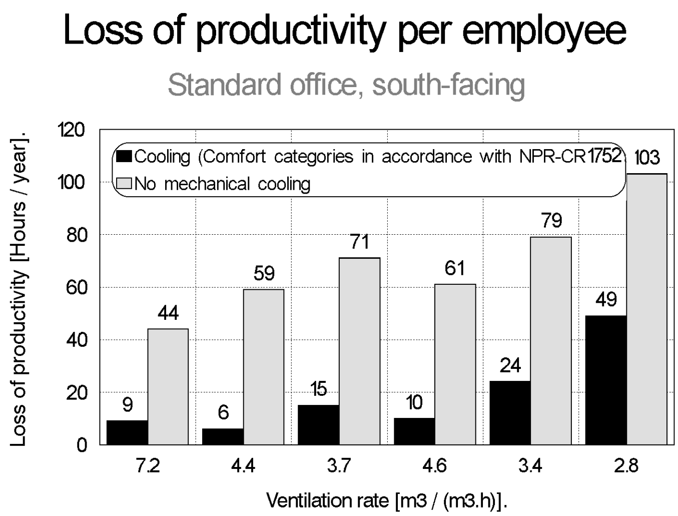

Figure 3: Loss of productivity per employee

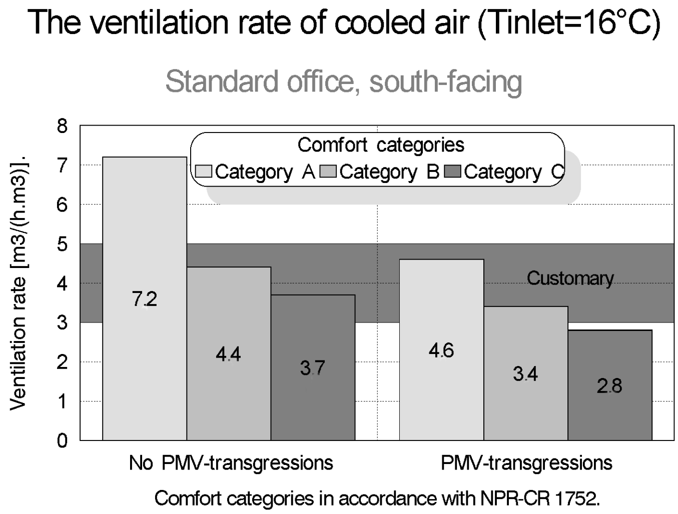

Figure 4: The ventilation rate of cooled air

Ventilation rate

Figure 4 shows the ventilation rate in relation to the comfort categories (with or without PMV transgressions). The figure also shows a bandwidth within which the ventilation rate is usually found in office complexes. The ventilation rate in category A (no PMV transgressions) and C (with PMV transgressions) falls outside that bandwidth in this situation; in practice, this will usually mean that a different installation concept has been chosen or that the starting points for the installation design have been adapted. The effect of the experienced air quality on productivity is left out of consideration.

The fact that, contrary to expectations, the loss of performance in hours per year (Figure 5) proves to be slightly more favourable than category A (no PMV transgressions) is because the average

Investment costs

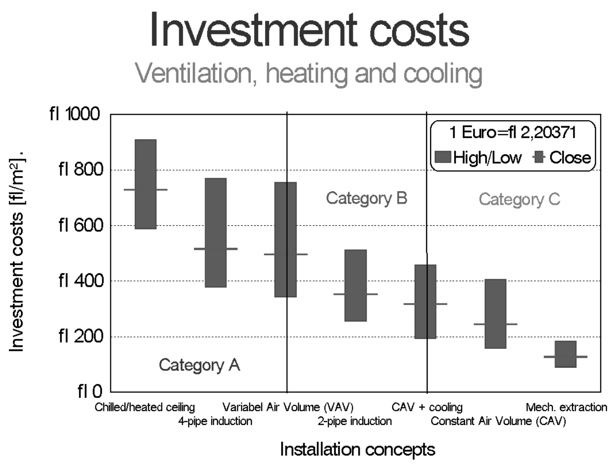

Figure 5: Investment costs

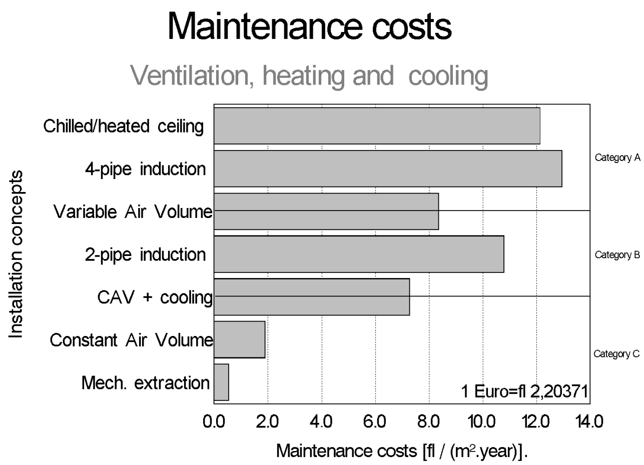

Figure 6: Maintenance costs

PMV value in the given period is on the cold side of the comfort area in category B and on the warm side in category A.

Figure 2 and the calculation results in Table 3 therefore justify the conclusion, on the grounds of the loss of productivity, that it is more expedient to place the PMV limits for category A at –0.5 and 0 than at –0.2 and 0.2 as presently given in NPR-CR 1752,[57] after all, within the PMV limits –0.5 and 0, there is no loss of performance. The preference for the cool area of the comfort zone is also referred to by Clements-Croome.[58]

Costs

Maintenance costs

The indexed key investment figures for the various installation concepts for office complexes[59,60] and the costs of preventative maintenance[61] are given in graph form in Figures 5 and 6 respectively.

Both figures also contain a global categorisation of the installation concepts that are most suitable in practice for applying a certain category.

Energy costs

The energy costs are given in graph form in Figure 7.

Profitability

Profitability

On the basis of a certain hourly wage, the overview of costs referred to above and the calculated productivity improvements, a profitability calculation can be made in order to ascertain whether the productivity improvement weighs up against the additional investment for a better climate and less discomfort. The calculation results are given in Table 4, based on the average costs for heating, ventilation and cooling per category (with PMV transgressions; Figures 5–7) and an average hourly wage of *ƒ*125.00 (not including value added tax).

Clearly, all sorts of variants on the above profitability calculation are conceivable, but this example in any event clarifies the fact that an additional investment in a better climate with less discomfort

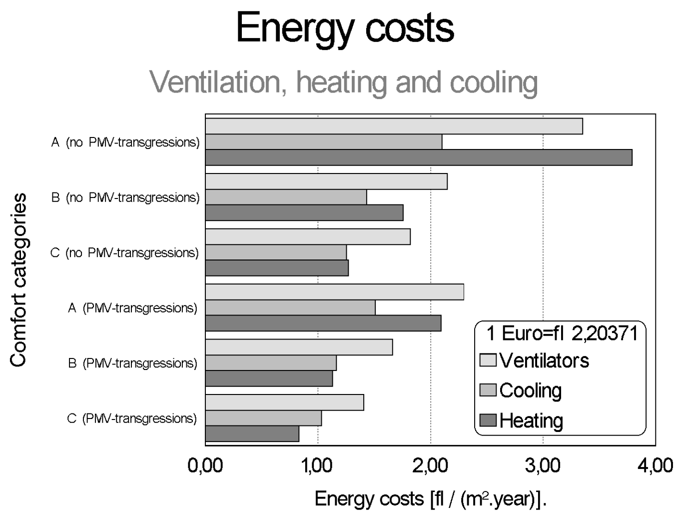

Figure 7: Energy costs

Performance improvement

can be regarded as profitable, because the annual benefits of productivity improvement exceed the additional investment within 1 or 2 years.

Table 4: Overview of calculation results regarding loss of performance per category

Item	No PMV transgressions			Minimum 90% of the working hours per year within the PMV limits mentioned		
	A	B	C	A	B	C
Maximum loss of performance (%)	1.4	5.6	8.2	5.2	9.9	12.7
Average loss of performance (%)	0.5	1.0	1.8	0.7	2.3	2.8
Standard deviation (%)	0.4	1.0	1.8	0.7	2.3	2.9
Perc. Working hours with loss of performance (%)	76.5	27.5	36.2	57.9	44.2	75.0

CONCLUSIONS

The following conclusions can be drawn from this study:

- Research has revealed that the indoor environment has the biggest effect on productivity in relation to job stress and job dissatisfaction.[62]
- Stricter requirements have to be set for the indoor environment because the WEP is not adversely affected if the parameters job and job stress are not to the satisfaction of the employees.[63]
- Various studies indicate that improving the quality of the indoor environment improves performance by between 5 and 15 per cent.[64–66]
- Given that the personnel costs are considerably higher than the

accommodation costs, investing in the quality of the working environment is the most effective way of combating loss of performance.[67,68]

- Within the indoor environment, in addition to the air quality,[69,70] the thermal environment has a considerable effect on performance.[71]

Temperature control

- The ability individually to control the temperature and the ventilation in a room has a relatively substantial effect on the WEP and is therefore desirable.[72,73]
- For categories A to C (with PMV transgression), in accordance with NPR-CR 1752,[74] the difference in loss of performance between the various categories is a good 100 per cent.
- Depending on the category chosen (A, B or C; whether or not with PMV transgression), the maximum loss of productivity attributable to the thermal indoor climate varies between 1.4 and 12.7 per cent, and there may be loss of productivity during approximately 28–77 per cent of the working hours on an annual basis.

Cost effective

- An additional investment into a better climate with less discomfort can virtually always be regarded as cost effective, because the annual benefits of productivity improvement exceed the additional investment in one or two years.
- There is a small difference between category A and B in terms of productivity only if there are no PMV transgressions.
- In view of the loss of productivity, it makes sense to set the PMV limits for category A at –0.5 and 0 instead of –0.2 and 0.2 as stipulated in NPR-CR 1752.[75]

Financial advantage

- The relationship between the thermal environment and productivity makes it possible to design on the basis of productivity improvement, resulting in a comfortable working environment and a consistent financial advantage for the organisation.
- Given the great importance of the workplace, it is surprising that until now most researchers have largely ignored the effects of the indoor environment on productivity and wellbeing. The design of the workplace is barely regarded as a strategy for productivity enhancement. This is particularly the case with regard to the office environment.[76]

Quality of the workplace

- If the indoor environment is henceforth assessed in the context of comfort and productivity, the participants in the housing process who are generally less interested in the aspects mentioned above will eventually incorporate investments in the quality of the workplace in their objects (in connection with the ability to sell and lease real-estate).[77]

RECOMMENDATIONS

Empirical model

It is becoming increasingly important to develop an empirical model that simulates people's comfort, wellbeing and productivity under realistic, dynamic working conditions.[78,79]

Table 5: Overview of costs and the simple pay-out time (SPOT)

Costs	Of category C→B	Of category B→A
Additional investment	Approx. ƒ159.00/m^2	Approx. ƒ192.00/m^2
Productivity improvement	Approx. ƒ196.00/(m^2 a)	Approx. ƒ110.00/(m^2 a)
Maintenance costs	Approx. ƒ5.6 /(m^2 a)	Approx. ƒ2.3/(m^2 a)
Energy costs	Approx. ƒ0.7 /(m^2 a)	Approx. ƒ2.0/(m^2 a)
SPOT	0.8 year	1.8 years

NB: 1 euro (€)=ƒ2.20371.

The recent research results of Fanger concerning productivity and air quality are a powerful incentive to provide office workers with good air quality in the future.[80]

The combination of experimental research results in the field of performance with thermophysiological human models and building simulation models is a rational method for determining loss of performance, depending on the person-related and environment-related parameters within the working environment.[81] An approach along these lines could apply to possible adaptive mechanisms (ie behavioural changes and psychological adaptation) which would manifest themselves in (among other things) a relation between the prevailing accepted/appreciated indoor temperature and the prevailing outdoor temperature.[82,83] This method provides a sound basis and a guideline for further studies in this field.[84]

Further studies

Within the indoor environment, the thermal environment and the air quality have the biggest influence on people's productivity.[85–87] The way in which people experience the air quality does depend, however, on the thermal environment.[88] It would therefore make sense to develop, in the near future, a validated human model in which at least the thermal environment in combination with the air quality can be evaluated in terms of comfort and loss of productivity.

ACKNOWLEDGMENTS

This research was performed within the scope of the FMH Facility Management educational programme for Senior Facility Manager. The assistance of E. N. 't Hooft MScEng, consultant of Technical Management Consulting Engineers, is gratefully acknowledged. Thanks are due to Professor J. Bekker MScEng for his interest and help during this work.

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