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PERSONAL CONTROL OVER INDOOR CLIMATE AND PRODUCTIVITY

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SUMMARY

A multilayer study was designed to investigate how having or not having control over one's indoor climate affects work performance in office buildings.
The study consisted of 2 stages. The HOPE database (with results from a large study in 64 European office buildings) was reanalyzed on correlations between perceived control and self-assessed productivity. Next a field study (that included an occupant questionnaire) was conducted in 9 Dutch office buildings with different kinds of control options.
The study showed that office workers that say to have a high amount of control over their indoor climate perceive to be significantly more productive than those that say to have a low amount of control. The quantitative effect of improving a no control situation towards a full control situation was estimated to be at least 6%.
More research is needed in this relatively new area before final conclusions can be made.

INTRODUCTION

Several studies (see e.g. REHVA, 2006) have shown that a suboptimal indoor climate (e.g. too high or too low temperatures or insufficient fresh air supply) has a negative impact on the work performance of building occupants. Some have interpreted these studies as if there exists one ideal productivity-boosting temperature, ventilation rate etc that will guarantee ultimate performance for all. We know from other studies (see e.g. Wyon, 1996) that people differ quite a bit in indoor climate preferences. Therefore one could ask oneself whether personal control e.g. over temperature, local air speed and/or fresh air supply also has productivity effects. Maybe it is with a good reason that Leaman & Bordass (2000) have identified personal control over the indoor environment as one of their top 4 'killer variables' for productivity enhancing buildings.
A multilayer study was designed to investigate how having or not having control over one's indoor climate affects work performance. The main focus was on the correlation between perceived control and (self-assessed) productivity. Even though obviously also other control aspects (like available control and exercised control, see Paciuk(1990)) are important.
Note that within this paper we define productivity in line with Leamen & Bordass (2000): 'By productivity we mean the ability of people to enhance their work output through increases in the quantity and/or quality of the product or service they deliver.' Perceived control in the context of this paper is defined (with a reference to Greenberger & Strasser, 1986) as 'an

individual's belief, at a given point in time, in his/her ability to effect a change, in a desired direction, on the environment.'
The main subject is control over indoor climate, so control over the combination of the thermal environment (heating, cooling) and indoor air quality (ventilation).

METHODS

The study consisted of two distinct stages.
First the original data of the European HOPE study (see Roulet et al, 2006) with over 6000 respondents (office workers) from 64 different European countries were reanalysed on correlations between perceived control over the indoor climate on the one hand and self-assessed performance on the other hand. See Boerstra et al (2013) for more background information on our re-analysis. Note that we conducted both a building-by-building, and a person(respondent)-by-person analysis. In this paper we only present the person-by-person outcomes.
The second stage of the study consisted of a field study (that included an occupant questionnaire) in 9 Dutch office buildings with different kind of control options. This field study enabled us to investigate correlations between e.g. quality of controls, perceived level of control and self-assessed productivity. For more information on the field study, see Boerstra et al (2013b).

RESULTS

Below the results of the two study stages are presented separately.

Reanalysis HOPE database

The HOPE questionnaires asked respondents to rate the amount of control they perceive to have on a 7-point scale (with as extreme answering categories 'no control at all' and 'full control'). They gave distinct scores for perceived control over temperature, over ventilation, over shading from the sun, over lighting and over noise. For this study we combined and averaged the scores for perceived control over temperature and ventilation into one (combined 7- point) score called 'perceived control over indoor climate'.
The respondents were also asked to estimate how their indoor environment affects their own productivity (performance) both in summer and winter (with as extreme answering categories 'productivity decreases by -30% or more' and 'productivity increases by +30% or more'. Also these scores were combined and averaged into one combined 7-point score (rounded up to 1 decimal after the comma) . They also answered questions (again on a 7-point scale) about how they rated their overall comfort in winter and in summer (with as extreme answering categories 'unsatisfactory' and 'satisfactory').

Respondents also rated the perceived comfort at their workplace on a 7-point scale, separately for the summer and for the winter season (with as extreme answering categories 'unsatisfactory' and 'satisfactory'). For the further analyses we combined and averaged the scores for summer and winter comfort into one (combined 7- point) score called 'comfort overall'.

To get an idea of the individual incidence of building related symptoms they were also asked whether in the past 12 months they had more than 2 episodes of the following symptoms: dryness of the eyes, itchy or watery eyes, blocked or stuffy nose, runny nose, dry throat,

lethargy and/or tiredness, headaches, dry or irritated skin. This resulted in a Personal Symptom Index (8) varying from 0 (0 out of 8 symptoms) to 8 (8 out of 8 symptoms).

With SPSS 20 correlations between the variables described above were studied.

The reanalyses showed (see also Table 1) that there is a positive and significant correlation between the amount of control that building occupants perceive to have over their indoor climate and self-assessed productivity (Spearman's rho = 0.183; p = 0.001). For 1 point that perceived control goes up on the 7 point scale, the self-assessed productivity goes up by about 1% (see Figure 1) and the difference in self-assessed productivity between those that perceive to have full control is about 6% higher than for those that perceive to have no control at all.

Perceived control over the indoor climate is not just significantly correlated with self-assessed productivity but also with comfort overall as perceived by the respondents (Spearman's rho = 0.268; p=0.001) and with (negatively) individual Personal Symptom Indexes (8) (Spearman's rho = -0.208; p < 0.001). So those that say to have more control over their indoor climate not just perceive to be more productive, they also are more comfortable and have less building related symptoms.

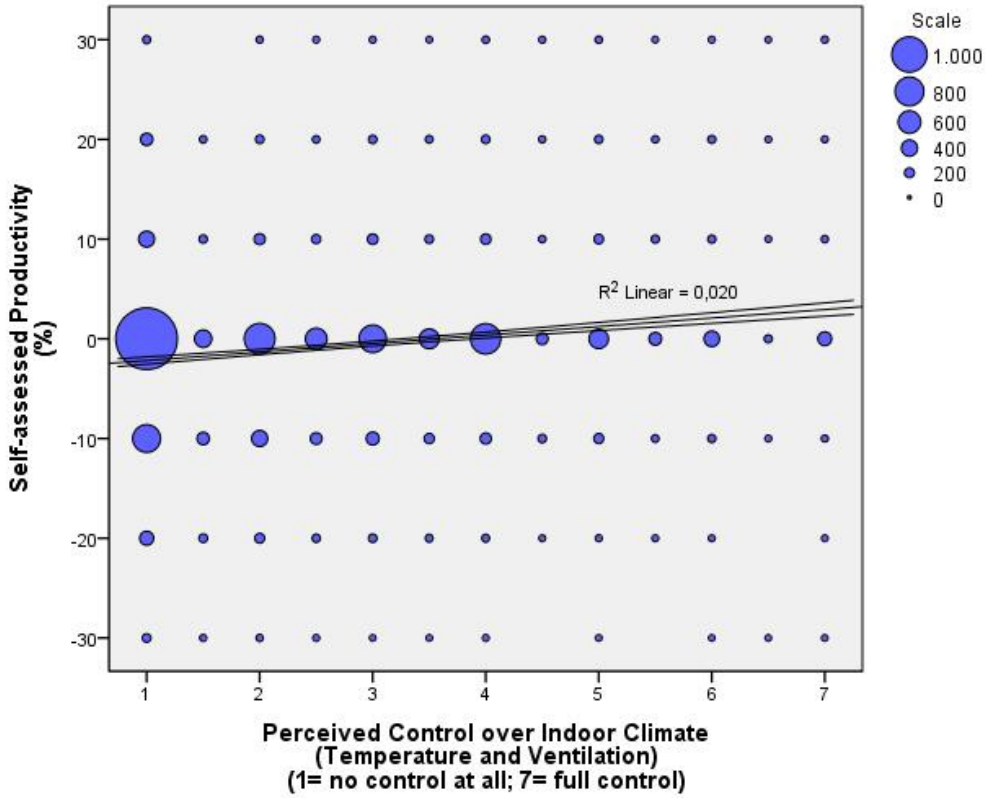

Figure 1. HOPE database correlation between individual Perceived Control over Indoor Climate and self-assessed productivity (n=5736); note that not just the correlation line is presented, but also the 95% confidence intervals (lines).

Table 1. HOPE database correlation between Perceived Control over Indoor Climate and i. comfort overall, ii. Personal Symptom Index (8) and iii. self-assessed productivity

			Perceived Control over Indoor Climate	Comfort overall	Personal Symptom Index (8)	Self-assessed productivity
Spearman's rho	Perceived Control over Indoor Climate (temp + vent)	Correlation Coefficient	1.000			
		Sig. (1-tailed)				
		N	6140			
	Comfort overall	Correlation Coefficient	0.268**	1.000		
		Sig. (1-tailed)	0.000			
		N	5834	5864		
	Personal Symptom Index (8)	Correlation Coefficient	-0.208**	-0.391**	1.000	
		Sig. (1-tailed)	0.000	.000		
		N	6139	5863	6188	
	Self-assessed productivity	Correlation Coefficient	**0.183****	0.490**	-0.239**	1.000
		Sig. (1-tailed)	0.000	0.000	0.000	
		N	5736	5698	5763	5764
** Correlation is significant at the 0.001 level (1-tailed)						

Field study

After the HOPE database analysis a field study was carried out in nine office buildings located in different cities in the Netherlands. The buildings were visited at different times between November 2011 and March 2012. Inside the buildings relevant building and HVAC system characteristics were mapped with the help of a checklist. In each building also several measurements were conducted (on average 10-15 per building). The measurements involved interventions that consisted of an active control action by the researchers and measurement of the effects (e.g. in terms of temperature and CO_2 concentration change).
Also an inventory was made of the building occupants' perceptions. In each building between 20 and 30 people were asked by the lead researcher to manually fill in a questionnaire. The total number of respondents for the nine buildings was 236. The respondents were selected at random. Purposely we looked for respondents spread out over different floors, different departments, different facades etc. The response rate was > 95%: more or less everybody that was approached agreed to fill in the questionnaire. After the respondents filled in the questionnaire they were asked to participate in an extra 10 minute face-to-face interview. A total of 161 building occupants agreed to participate in this part of the research.
For more detailed info on the field study and e.g. the measurement outcomes, see Boerstra et al (2013b).
In this paper we focus on the field study results related to self-assessed productivity as reported by the respondents.

The field study respondents were asked to rate the amount of control they perceive to have on a 7-point scale (with as extreme answering categories 'no control at all' and 'full control'). They gave distinct scores for perceived control over temperature in winter, over temperature in summer, over ventilation, over air speed, over shading from the sun, over lighting and over

noise. For this study we combined and averaged the scores for perceived control over temperature in winter, perceived control over temperature in summer and perceived control over ventilation into one combined 7-point score (rounded up to 1 decimal after the comma) called ‘perceived control over indoor climate’.
The respondents were also asked to estimate how their indoor environment affects their own productivity (performance); with as extreme answering categories ‘productivity decreases by -30% or more’ and ‘productivity increases by +30% or more’.

Respondents also rated the perceived comfort at their workplace on a 7-point scale, separately for thermal comfort in winter, thermal comfort in summer and olfactory comfort for the whole year (with as extreme answering categories ‘very dissatisfied’ and ‘very satisfied’). For the further analyses we combined and averaged the 3 scores into one (combined 7- point) score called ‘comfort overall’.

To get an idea of the individual incidences of building related symptoms respondents also were asked whether they have health symptoms that they associate with being at their workplace. They could choose amongst 5 different kinds of standard building related symptoms: dry eyes/eye irritation, blocked nose, dry throat, lethargy and headache. This resulted in a Personal Symptom Index (5) varying from 0 (0 out of 5 symptoms) to 5 (5 out of 5 symptoms).

With SPSS 20 correlations between the variables described above were studied.

The reanalyses showed (see also Table 2) that there is a positive and significant correlation between the amount of control that building occupants perceive to have over their indoor climate and self-assessed productivity (Spearman’s rho = 0.200; $p < 0.001$). For 1 point that perceived control goes up on the 7 point scale, the self-assessed productivity goes up by about 1.5 % (see Figure 2) and the difference in self-assessed productivity between those that perceive to have full control is about 10% higher than for those that perceive to have no control at all.

Perceived control over the indoor climate is not just significantly correlated with self-assessed productivity but also with comfort overall as perceived by the respondents (Spearman’s rho = 0.222; p , 0.001). On the other hand, perceived control over the indoor climate was not significantly correlated with the Personal Symptom Indexes (5) (Spearman’s rho = -0.073; p =0.137). So those that say to have more control over their indoor climate perceive to be more productive and are more comfortable. But there is no difference (with those that perceive to have no control at all over their indoor climate) in terms of incidence of building related symptoms.

Note that the field study furthermore showed that access to operable windows and access to adjustable thermostats (available control in itself) also positively impacts both perceived control over the environment and self-assessed productivity. The details around available control correlations are beyond the scope of this article.

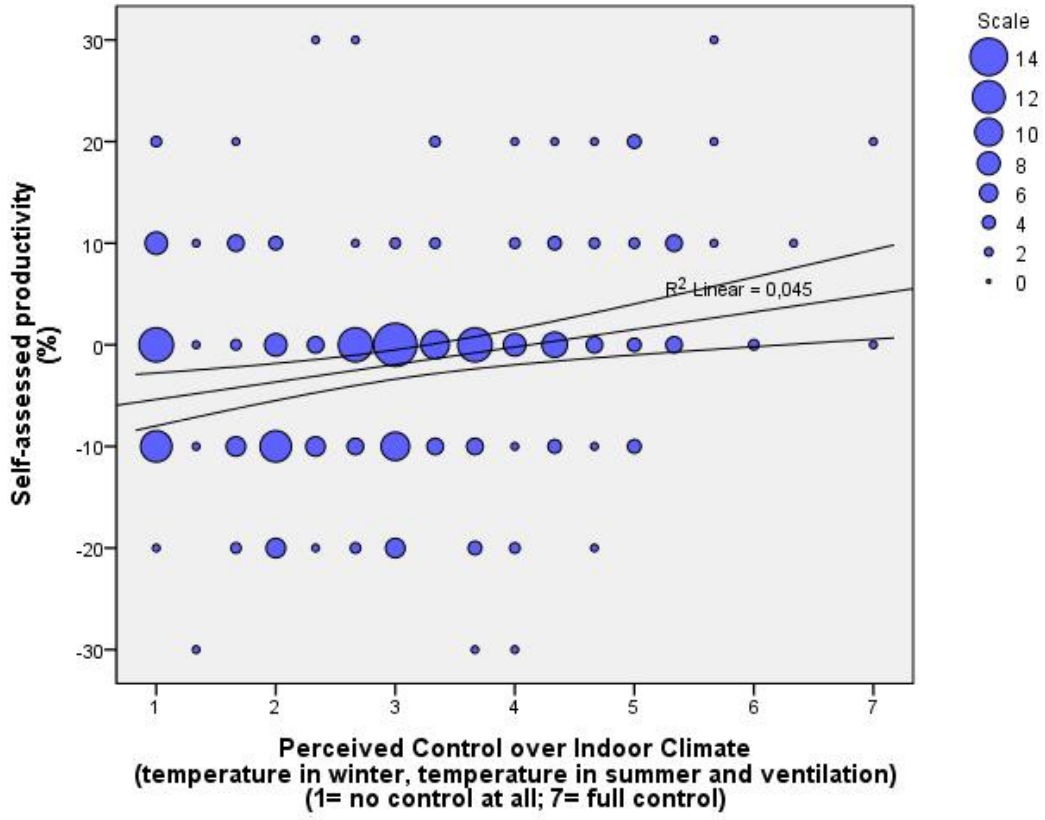

Figure 2. Field study correlation between individual Perceived Control over Indoor Climate and self-assessed productivity (n=5736); note that not just the correlation line is presented, but also the 95% confidence intervals (lines).

DISCUSSION

If one combines the results from the HOPE database reanalysis with the results from the field study than the first conclusion is that in general building occupants that perceive to have a high amount of control over their indoor climate are 6 to 10% more productive than those that perceive to have no control at all. At least, as long as one assumes that self-assessed performance (using the standard -30 to +30% 7-point scale) gives an adequate estimate of actual performance effects.

Comparing these findings to the literature;

Kroner et al (1992) investigated during a year-long field study what the effect was of the introduction of ERW's or Environmentally Responsive Workstations (microclimatisation systems that allow for direct control at the workstation over the thermal environment) on the productivity of insurance company workers housed in an open office landscape. At the same time other measures were taken to improve the physical work environment and to upgrade the general workplace. After analyzing the results of the experiment, that involved turning a no-control over the indoor climate situation into a some-control over the environment situation, Kroner et al concluded that the objectively measured performance had increased by 16% of which at least 3% point could be attributed to the introduction of the ERW's. This range (min. 3%, max. 16%) is comparable to the range found based on the HOPE analysis and the field study (6 to 10%).

Table 2. Field study correlation between Perceived Control over Indoor Climate and i. comfort overall, ii. Personal Symptom Index (8) and iii. self-assessed productivity

			Perceived Control over Indoor Climate	Comfort overall	Personal Symptom Index (8)	Self-assessed productivity
Spearman's rho	Perceived Control over Indoor Climate (temp winter + temp summer + vent)	Correlation Coefficient	1.000			
		Sig. (1-tailed)				
		N	230			
	Comfort overall	Correlation Coefficient	0.222**	1.000		
		Sig. (1-tailed)	0.000			
		N	222	223		
	Personal Symptom Index (8)	Correlation Coefficient	-0.073	-0.578**	1.000	
		Sig. (1-tailed)	0.137	0.000		
		N	229	222	234	
	Self-assessed productivity	Correlation Coefficient	**0.200****	0.651**	-0.376**	1.000
		Sig. (1-tailed)	0.001	0.000	0.000	
		N	223	216	227	228
** Correlation is significant at the 0.001 level (1-tailed)						

The results are also, at least partial, in agreement with Leaman & Bordass (2000). They presented a summary of the outcomes of a reanalysis of field studies in 11 UK buildings by Building Use Studies in the years 1996 and 1997. The found that self-assessed productivity is significantly associated with perception of overall control in 7 out of the 11 buildings studied. The strength of their correlation (a Spearman's rho of 0.29) was comparable with our correlations, respectively: 0.183 and 0.200).

Another relevant study in this context is that conducted by Wyon (1996) based on a general analysis of lab and field experiments that involved objective measurements of productivity. Wyon analyzed how providing an ideal control range to building occupants in an office environment would affect overall group performance in comparison with a situation in which no personal control options are present and all are exposed to the group average neutral temperature.
He came to the conclusion that providing individual control equivalent to +/- 3 K will increase group performance by 2.7 % for logical thinking, by 7.0 % for typing, by 3.4 % for skilled manual (office) work and by 8.6 % for repetitive manual work that involves (finger) speed. Wyon came to an average productivity effect (related to the introduction of ideal personal control over the thermal environment) of 5.4 % (assuming that office workers divide their time equally over the 4 different task types).
Wyon later on (see Wyon, 2000) later on also calculated how the introduction of ideal personal control over the thermal environment affects group performance when the reference situation is not (as assumed above) the group average neutral temperature (e.g. 24.5^{o}C in summer according to EN-ISO 7730) but situations varying from 3 K below group average

neutral temperature till 6 K above this group average neutral temperature. Than the overall productivity effect varies from +3 till about +12 %.
Also the quantitative effects calculated by Wyon (that relate to objectively measured performance, not self-assessed performance) are in line with the numbers that came out of the HOPE analysis and the field study in the 9 Dutch buildings.

CONCLUSION

The outcomes of this multilayer study imply that offering adequate options for personal control over one's indoor climate has a positive impact on productivity.
Productivity is estimated to be at least 6% higher when building occupants perceive to have full control over their indoor climate (thermal environment and indoor air quality), than when they perceive to have no control at all. For every step upwards on the standard 7 point control scale (with 'no control at all' and 'full control' as extreme scores) performance is estimated to go up by about 1%.
More research is needed in this relatively new area before final conclusions can be drawn.

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