

HOW DO raised temperatures, AFFECT PERFORMANCE?



Indoor environment experts **David P Wyon** and **Pawel Wargocki** answer 30 key questions on indoor air quality and its effect on a person's mental and physical capacity

As experienced researchers in the effects of thermal comfort and indoor air quality (IAQ) on performance, we are often asked to give our best estimate of how, and to what extent, performance is affected by different aspects of indoor climate. Here we answer 30 frequently asked questions on the topic. Our answers are based on the results of behavioural experiments conducted to date.

Q Why should we be interested in thermal and air quality effects on performance?

There are four main reasons:

- It is the added value of occupant performance that pays for indoor environmental quality¹
- Performance is affected in the short-term by the combined effects of all indoor environmental factors, while subjective and physiological responses are usually selected because they are a function of one specific factor
- It turns out that thermal and air quality effects on performance can be observed even when there are no observable effects on comfort or on health-related symptom intensity^{2,3,4}
- The primary purpose of factory, office and school buildings is to provide an optimal indoor environment for work and for learning to work

Effects

Q What effects do raised temperatures and poor air quality have on performance?

We have found that they usually reduce the rate of working, with little or no effect on accuracy.^{3,4}

Q Why is that?

In our experience, people tend to reduce their rate of work until they are again able to achieve an acceptable error rate.

Q What aspects of mental work are affected?

In general, tasks that require concentration (clear thinking and symbolic manipulation), memory and original thought.^{3,5,6}

Q Are all kinds of performance affected to the same extent?

Most mental work involves concentration and is likely to be similarly affected.

Q What are the exceptions?

Excessive concentration can impair recognition memory and creative thinking, so as moderate warmth leads to lowered arousal, it can paradoxically improve the performance of work that includes such tasks.

Mechanisms

Q How do raised temperatures affect performance?

Raised temperatures have been found to increase end-tidal CO₂ (ETCO₂). This is an indicator of mild 'acidosis', which is an increase in the concentration of CO₂ in the blood and decreases oxygen saturation in blood (SpO₂), both of which are likely to be detrimental for mental work.⁶

Q How does poor air quality affect performance?

Poor air quality may lead to mild acidosis, exactly as raised temperature does, because



WHAT EFFECT DOES
**poor air
quality**
HAVE ON OCCUPANT
PERFORMANCE?



it has been found to reduce CO₂ emissions from occupants.⁸ If so, this may be why both factors have such similar effects. Satish et al⁹ have recently shown that increasing the ambient CO₂ concentration artificially can decrease performance, suggesting that ambient CO₂ may have to be regarded as a pollutant instead of as an indicator of a low outdoor air supply rate.

Magnitude

Q What is the magnitude of the negative effects of the indoor environment on performance?

For adults, up to 5% in the laboratory³ and up to 10% in the field.² For schoolchildren, it's more than 20%.⁴

Q Is work in transportation environments similarly affected?

It would seem so. Driver vigilance was found to be reduced by up to 30% by warmth in field intervention experiments lasting only one hour.¹⁰

Q What are the estimated costs of allowing poor indoor environmental quality (IEQ) to reduce performance?

As staff costs per unit of floor area exceed operating costs by 100:1, the effects observed are seldom negligible.¹

Q Surely, children are less affected than adults because they are young and healthy?

We have found that their performance is more affected, not less. We believe that this is because children in school, by definition, are doing work that is new to them, while adult workers are usually very familiar with the work they do and are better able to cope with environmental effects that make their work more difficult.

Q Is factory work likely to be less affected by thermal and IAQ effects than office work?

We believe not, as most workers in modern factories have to interact with computers, just as office workers do.

Methodology

Q Does laboratory research really predict what happens in practice?

Many field studies have found that the negative effects of poor working conditions are greater in real workplaces than would have been predicted from

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laboratory experiments.^{2,5} This may be because laboratory experiments use paid subjects, who tend to exert more effort in the course of a necessarily brief laboratory exposure to poor IEQ than they would routinely experience in their workplace.

Q Why do some laboratory experiments show no effects on performance?

If subjects are highly motivated they can sometimes maintain performance during short exposures to poor IEQ. Negative effects on fatigue may then be found instead. Additionally, some studies may have missed the subtle changes in performance that are caused by slightly suboptimal indoor environmental conditions.

Q Do performance tests really predict productivity?

Logically, yes. Although environmental effects on component skills have yet to be validated as predictors of overall productivity, call-center results use 'bottom-line' measures of the call volume achieved in practice,^{2,5} and schoolwork is what children do in school.^{4,11,12}

Q Does a decrease in the performance of schoolwork indicate reduced learning?

Not proven. But surely schoolwork is assumed by teachers to promote learning? Test scores used by teachers and regulators to observe progress in learning have been

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dust
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DOES LOW RELATIVE
humidity
AFFECT PERFORMANCE?

➤ found to correlate with spot measurements of ventilation.¹¹

Q Are research findings on performance from Northern Europe valid in warmer climates?

Yes. Very similar results were obtained when the same experiments were repeated in Singapore.⁵

Indicators

Q What seems to be the most reliable indicator of IAQ effects on productivity?

Until we know which pollutants are causing the negative effects on people, the outdoor air supply rate per person seems to be the most reliable indicator.¹³

Q Can subjective assessments of IAQ by occupants be used to predict performance effects?

No. Sensory habituation ensures that increasingly poor air quality may be underestimated, except by visitors.³

Q Can occupants reliably assess their own productivity?

So far there is no reliable evidence that they can. Self-estimated productivity may simply indicate the effort they are aware of exerting,³ and/or wishful thinking and a desire to placate management.

Q What is the most reliable indicator of thermal effects on performance?

Air temperature is not a reliable indicator in any absolute sense, because performance is a function of the heat balance of the body,

which is affected by clothing, metabolic rate, air velocity, and so on. But in a given work situation it is a very useful basis for comparison. In the cold, manual dexterity is progressively impaired as the body actively reduces finger temperature to conserve heat, while in slightly warm conditions, mental performance has been found to decrease when finger temperatures approach their maximum value of about 36°C and sweating must be initiated to maintain the body's heat balance. Finger temperatures in the 30°C to 34°C range are, therefore, a reliable indicator that thermal conditions are optimal for most kinds of performance.

Q Do occupants' assessments of thermal discomfort predict effects on performance?

Not always. They may be able to avoid discomfort by working less. This implies that the adaptive model of thermal comfort should *not* be used in isolation to justify energy conservation measures, because that could lead to conditions that cause suboptimal performance and productivity.⁶

Q Can we use sick building syndrome symptoms to predict effects on productivity?

Yes, in theory, because they do co-vary. But the data is still too meager to create a robust relationship.⁵

Q Is absenteeism a useful indicator of effects on productivity?

Poor ventilation does increase absenteeism,¹⁴ but so do many other factors.

Mitigation

Q Could openable windows, giving children access to fresh air, provide an alternative to going outside?

No. They will not be opened spontaneously unless it is also warm. Also, opening windows will often be seen as a waste of heating or cooling energy.

Q Does increased outdoor airflow always improve performance?

No. It can even have the reverse effect if it passes through particulate filters that are full of dust.⁴

Q Does airborne dust affect performance?

There is no evidence that it does, even though dust is expected to have negative effects on chronic health problems. ➤

ARE
factory workers
MORE SUSCEPTIBLE TO
poor indoor,
AIR QUALITY?

CAN WE ALLOW INDOOR temperatures TO DRIFT upwards TO CONSERVE ENERGY IN BUILDINGS?

► Short-term effects of poor air quality on the performance of schoolwork remained after airborne dust had been removed, so the negative effects observed were attributed to gas-phase air pollutants.¹⁵

Going forward

Q What are the most commercially important questions for future research?

We have identified the following 10 high priority research topics:

- Are the combined effects of temperature and IAQ additive?
- How does performance vary with self-estimated performance?
- Which component skills are affected by indoor temperature and air quality effects?
- Is high-level work involving decision-making and creative thinking similarly affected?
- Are leisure activities negatively affected by poor IEQ?
- Is sleep affected by temperature and IAQ, and if so, does this affect next-day performance?
- What is the economic impact of all these effects on different kinds of productivity?
- What is the most cost-effective way to reduce the negative effects of poor IEQ?
- How can energy be conserved without affecting performance?
- How do energy certification schemes affect productivity?

Q Which underlying mechanisms are worth investigating?

We believe that the following four topics should be addressed by future research:

Do thermal and IAQ effects on acidosis decrease performance?

Is acidosis caused by shallow breathing or by decreased gas exchange in the lungs?

Which gas-phase indoor air pollutants have this effect, and can it be prevented?

Are any other mechanisms involved? **CJ**

References

- 1 Fisk, W.J., D. Black, and G. Brunner. 2011. 'Benefits and costs of improved IEQ in U.S. offices.' *Indoor Air* (21):357–367.
- 2 Wargocki, P., D.P. Wyon, P.O. Fanger. 2004. 'The performance and subjective responses of call-centre operators with new and used supply air filters at two outdoor air supply rates.' *Indoor Air* (14) Supplement 8, 7–16.
- 3 Wyon, D.P. 2004. 'The effects of indoor air quality on performance and productivity.' *Indoor Air* (14) Supplement 7, 92–101.
- 4 Wargocki, P., D.P. Wyon. 2006. 'Effects of HVAC on student performance.' *ASHRAE Journal* (10):22–28. (From ASHRAE 1257-TRP).
- 5 Tharn, K.W., H.C. Willem. 2005. 'Temperature and ventilation effects on performance and neurobehavioral symptoms of tropically acclimatised call centre operators near thermal neutrality.' *ASHRAE Transactions* 111(2), DE-05-10-7.
- 6 Lan, L., P. Wargocki, D.P. Wyon, Z. Liam. 2011. 'Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses and human performance.' *Indoor Air* (21):376–390.
- 7 Wyon, D.P., L. Fang, L. Lagercrantz, P.O. Fanger. 2006. 'Experimental determination of the limiting criteria for human exposure to low winter humidity indoors (RP-1160).' *HVAC&R Research* (12):201–213 (From ASHRAE 1160-TRP).
- 8 Bakó-Biró, Z.S., P. Wargocki, D.P. Wyon, P.O. Fanger. 2005. 'Poor indoor air quality slows down metabolic rate of office workers.' In *Proceedings of Indoor Air 2005*, Beijing, Vol. 1 (1):76–80.
- 9 Satish U., et al. 2012. 'Is CO₂ an indoor pollutant? Direct effects of low-to-moderate CO₂ concentrations on human decision-making performance.' *Environ Health Perspect* (120):1671–1677.
- 10 Wyon, D.P., I. Wyon, F. Norin. 1996. 'Effects of moderate heat stress on driver vigilance in a moving vehicle.' *Ergonomics* (39):61–75.
- 11 Haverinen-Shaughnessy, U., D. Moschandreas, R.J. Shaughnessy. 2010 'Association between substandard classroom ventilation rates and students' academic achievement.' *Indoor Air* (21):121–131.
- 12 Bakó-Biró, Z., et al. 2012. 'Ventilation rates in schools and pupils' performance.' *Building and Environment* (48):215-223.
- 13 Seppänen, O., W. Fisk, Q.H. Lei. 2006. 'Ventilation and performance in office work.' *Indoor Air* (16):28–35.
- 14 Milton, D.K., P.M. Glencross, M.D. Walters. 2000. 'Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints.' *Indoor Air* (10):212–221.
- 15 Wargocki P., D.P. Wyon, K. Jensen, C.G. Bornehag. 2008. 'The effects of electrostatic filtration and supply air filter condition in classrooms on the performance of schoolwork by children.' *HVAC&R Research* 14(3):327–344. (from ASHRAE 1257-TRP).
- 16 Kolarik, J., J. Toftum, B.W. Olesen, A. Shitzer. 2009. 'Occupant response and office work performance in environment with moderately drifting operative temperatures (RP-1269).' *HVAC&R Research* 15(5): 931–960. (From ASHRAE 1269-TRP).

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