GOOD THERMAL COMFORT IN OFFICE BUILDINGS WITHOUT AIRCONDITIONING
THE IMPORTANCE OF AN ADAPTIVE MODEL OF THERMAL COMFORT

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ABSTRACT

A secondary analysis of the Dutch prevalence study by Zweers et al shows that office buildings without artificial cooling and with operable windows have a lower risk for health symptoms and comfort complaints than office buildings with artificial cooling and sealed windows. Temperature simulations of various office buildings show that in the Dutch climate zone thermal comfort during summer conditions is secured without the use of artificial cooling if a number of essential design criteria are met. Furthermore a financial analysis is presented in this paper which shows that construction costs, maintenance costs and energy costs of an office building without artificial cooling are lower than that of an airconditioned building.

However it is often not considered feasible to implement these measures consistently. Furthermore there is a tendency to reduce temperature transgressions more than would be necessary to comply with the Dutch thermal comfort standard for various (inadequate) assumptions. As a result of this most new office buildings in the Netherlands are designed with artificial cooling.

The ASHRAE Transaction Technical Paper "Developing an adaptive model of thermal comfort and preference" by De Dear and Brager shows that the “static” PMV model predicts thermal comfort judgements in HVAC buildings accurately enough, but that occupants in naturally ventilated buildings are tolerant of significantly higher temperatures than the PMV model predicts.
A new thermal comfort standard based on the results of De Dear and Brager will result in less reliance on artificial cooling, thus reducing complaint rates and reducing construction costs, maintenance costs and energy costs.

INTRODUCTION

There is a growing consensus that compared to artificial cooling in offices a combination of free cooling and heat source control may offer great advantages. These include lower occupant complaint rates and lower energy consumption. In practice however most newly designed office buildings are fitted with artificial cooling, even in regions with a moderate climate like the Netherlands. The purpose of this paper is to investigate the causes of this discrepancy. Is artificial cooling mandatory in office buildings to avoid unwanted temperature transgressions, even in moderate climates? Does the combination of free cooling and heat source control lead to unacceptable costs or is it unfeasible in modern offices? Or are there other reasons for the adherence to artificial cooling, like conservatism or unfounded assumptions? These are the questions that this paper will try to answer.

METHODS

To stress the importance of avoiding artificial cooling to lower occupants complaints this paper will not only reiterate the published results of various field studies relevant to this subject, but also the results of a secondary analysis of a Dutch field study. The secondary analysis will focus on the combined effects of artificial cooling and sealed windows.
To evaluate the arguments concerning costs a financial analysis is presented of the construction costs, maintenance costs and energy costs of building variants with and without artificial cooling.
To investigate whether a good thermal comfort is achievable without artificial cooling both the traditional Dutch thermal comfort standard and the adaptive model of thermal comfort proposed by De Dear and Brager [1] are discussed.

RESULTS

A large number of field studies show increased complaint rates in office buildings equipped with artificial cooling ([2], [3], [4], [5], [6], [7], [8], [9], [10]). This relation is consistent and is also found if a multivariate design is used. Although the statistical relation itself does not prove causality, the consistent statistical relation plus the fact that there are plausible causal mechanisms to explain it (e.g. an increased risk of air pollution due to condensation on the coils, an increased risk of local thermal discomfort due to lower supply air temperatures and higher supply air velocities) in the authors' view warrant it to regard artificial cooling as a risk factor that should be avoided if possible (see also [11]).
Later in this paper the distinction between naturally ventilated buildings (without artificial cooling and with operable windows) on the one hand and buildings with artificial cooling and sealed windows on the other hand will turn out to be of special importance. Therefore a secondary analysis has been carried out on the data also used in [8] to investigate the effect of exactly this distinction on the complaint rates. The results are shown in table 1. It turns out that sealed windows plus artificial cooling show higher complaint rates than operable windows without artificial cooling.

Table 1. Occupants complaint rates in HVAC buildings and naturally ventilated buildings

Symptoms/complaints in %	HVAC (cooling plus sealed windows)	Naturally ventilated
Thermal complaints	63	46
Dry air symptoms	48	36
Eye irritation	24	14
Throat, nose irritation	26	15
Headache, lethargy	28	17

(All differences between building categories: $p<0.05$)

Now the question is: Is a good thermal comfort achievable without artificial cooling? The Dutch thermal comfort standard demands a Predicted Mean Vote (PMV) between –0.5 and +0.5. To allow for meteorological influences a PMV value greater than +0.5 is allowed for 5% of office hours and a PMV value greater than +1.0 is allowed for 1% of office hours. Computerized temperature simulations of various types of office buildings show that in the Dutch climate zone, and without artificial cooling, the indoor climate just complies with the Dutch thermal comfort standard if the following measures are taken:

- maximum glass percentage in facade: 35%
- outside sunshading or sunshading with comparable effectiveness
- energy efficient lighting
- ventilation exhaust through the lighting fixtures
- energy efficient office equipment
- intelligent software that puts unused office equipment in stand by mode
- thermally open ceilings
- night ventilation

Although these measures are far from standard in modern day offices, they are certainly feasible. They require certain design constraints and a sensible and consistently applied strategy for the purchase of office equipment and software. The demand for thermally open ceilings may appear to be the most controversial. It is often assumed that thermally open ceilings decrease the flexibility of an office building. This need not be so. If the layout of the bays and the ceiling structure are adjusted to one another thermally open ceilings can provide all the flexibility that is practically needed in an office building. Furthermore greater flexibility is also precluded by the existing layout of the HVAC-system, the artificial lighting, windows, sunshading etc.

The next question to ask is: do the measures necessary to avoid artificial cooling lead to higher overall costs?

A cost analysis was carried out. Three building variants were defined:

- variant 1: without artificial cooling and with the measures necessary to comply with the thermal comfort standard
- variant 2 : a standard office building with simple cooling of the supply air
- variant 3: an office building with a lightweight facade and full airconditioning

An exact definition of the variants is given in table 2, as are the results of the cost analysis.

Table 2. Integral construction costs and yearly maintenance and energy cost per standard office room (4.1 x 5,3 x 2.7 m) for three office building variants

	No cooling	**Central cooling**	**Airconditioning**
Facade	Heavy, stonelike	Heavy, stonelike	Light
Window area	35%	50%	50%
Sunshading	External	Sunshading glass	Sunshading glass
Ceiling	Thermally open	Thermally closed	Thermally closed
Internal walls	Heavy, stonelike	Light	Light
HVAC-system	Radiating panels + mechanical ventilation	Radiating panels + mechanical ventilation + supply air cooling	Airconditioning (heating, cooling + ventilation)
Construction costs	$ 12,790	$ 12,880	$ 19,780
Maintenance costs/y	$ 159	$ 203	$ 242
Energy costs/y	$ 115	$ 145	$ 168

It turns out that both building costs and maintenance costs are lowest for variant 1, as is energy consumption. The costs for the extra measures, like thermally open ceilings, were outweighed by the savings made possible by using a simpler ventilation system. (The extra costs concerning office equipment and software are not included in this analysis because they are subject to rapid decreasing. At present, assuming a normal devaluation rate, they are low enough to be outweighed by the extra maintenance costs of variants 2 and 3, even if the energy savings that these measures bring are ignored.)

DISCUSSION

Thus far the result have shown:
- artificial cooling increases the risk of occupants complaints
- artificial cooling is not necessary to ensure compliance with the thermal comfort standard (in a moderate climate)
- artificial cooling causes higher construction and maintenance costs
- artificial cooling causes higher energy consumption

Despite all this most newly designed office buildings in the Netherlands (and other moderate climates) are fitted with artificial cooling. As far as the authors can conclude from their experience as consultants, the reasons for this are the following (see also [12]):
- Lack of knowledge about the health and comfort risks of artificial cooling.
- Inadequate motivation to minimize energy consumption. In the case of artificial cooling this is even promoted by Dutch legislation. There is an Energy Performance Standard, by which all Dutch buildings must comply and which puts a maximum on the energy consumption of a certain building. But the standard contains a correction factor for buildings with artificial cooling in such a way that the decision to fit or not to fit artificial cooling is of no consequence for compliance with the Standard.
- Assuming too high internal heat loads. This may be caused by using unrealistic values for energy consumption of office equipment or by incorporating an unnecessary headroom in the assumed internal heat load. It is the authors' opinion that a low but realistic design value for the internal heat load should be assumed and that building management should see to it that compliance with this value is maintained.
- The assumption that the present thermal comfort standard is barely tight enough to prevent thermal comfort problems and that the standard should actually be tightened and that this will increase thermal comfort. In the authors' opinion there are no data to support this assumption. In the remainder of this paper it will be argued that in some situations the standard may actually be loosened.

In [1] DeDear & Brager report the results of a meta-analysis of a large number of thermal comfort field experiments. The results show that the PMV-model, given the correct assumptions, very accurately predicts thermal comfort in buildings with artificial cooling and sealed windows. But it turns out that occupants of naturally ventilated buildings are tolerant of a much wider range of temperatures. This is especially relevant in the case of high outdoor temperatures. In naturally ventilated buildings the acceptable indoor operative temperature is up to 3 or 4K higher than the PMV-model predicts. The reasons for this greater tolerance for higher indoor temperatures are:
- behavioral adaptation of the clothing insulation (works also in HVAC buildings)

- behavioral adaptation of the air velocities (probably works less in HVAC buildings)
- psychological habituation to higher temperatures caused by recent thermal history and/or concurrent outdoor temperatures

Because of this DeDear & Brager refer to their model for naturally ventilated buildings as an adaptive model. (They also show that the PMV-model instead of being a static model is actually a partially adaptive model. It takes account of the behavioral adaptations, but not of the psychological adaptation.)

These results allow for a thermal standard that permits higher temperatures during summer in naturally ventilated buildings. This will increase the possibilities to provide for a acceptable indoor thermal climate without artificial cooling in several ways:

- In cases where omission of artificial cooling is already possible, but designers and consultants are hesitant because they are unfamiliar with this approach, the extra headroom that a new standard will provide may take away their hesitations.
- In cases where artificial cooling is considered unavoidable on the basis of the currant standard (e.g. a higher internal heat load) the extra headroom provided by a new standard may change the situation.
- A new standard may also allow for avoiding artificial cooling in warmer climates, on the condition of course that external and internal heat load are properly minimized.
- A new standard based on the results of DeDear & Brager will hopefully also be a strong antidote against the recurrent suggestions that further tightening thermal comfort standards will improve thermal climate as experienced by the occupants.

It is also important to note that the building category that allows for higher indoor temperatures is also the one that shows the lowest complaint rates, as was shown in table 1. So it looks like we are in a situation where benefits can be combined instead of traded off.

CONCLUSION

De results of DeDear & Brager allow for the development of a thermal comfort standard that permits higher indoor temperature in naturally ventilated buildings during the summer. Such a standard will encourage avoiding artificial cooling in a large number of situations all over the world, thus contributing to:

- lower occupant complaint rates
- lower construction and maintenance costs
- lower energy consumption

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