AVERAGE AND VARIATION OF THE INDOOR TEMPERATURE IN SWEDISH OFFICES

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Abstract

To investigate if the indoor temperature distribution calculated with the theory for indoor temperature as a collective factor of production coincide with the distribution of measured indoor temperatures. A collective factor of production is the same to everybody and the cost for producing the factor do not change if more uses the factor. An occupant does not have a loss of production when the temperature is above a threshold temperature for that occupant. The threshold temperatures for the occupants in an office are the same as for the households in Swedish single unit dwellings. It is the members from the households who work in the offices.

The theory uses economic data such as the price of a work hour 250 SEK/h, the price of heat 0,5 SEK/kWh and the specific heat demand 73 W/°C pers. (7 SEK = 1 USD)

The measured temperatures follows a distribution between the theoretical distributions for zone size 5 and zise 10 workplaces. In zones with 5 or 10 workers there are 20 or 10 % disturbed. If only one worker in every zone is disturbed. This coincides with earlier estimates of the percentage dissatisfied. The theory also predicts that smaller temperature control zones will get a lower average temperature and a higher variation between the zones.

Keywords: offices, temperature, economics, factor of production

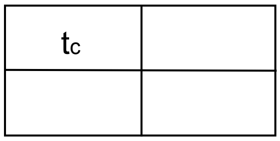
1 Introduction

A collective factor of production is the same to everybody and the cost for producing the factor do not change if more uses the factor. An occupant does not have a loss of production when the temperature is above a threshold temperature for that occupant. The threshold temperatures for the occupants in an office are the same as for the households in Swedish single unit dwellings. It is the members from the household who work in the offices. The theory explains why it is economically optimal to use an indoor temperature that disturbs only the most sensible occupant in the temperature control zone. If a temperature control zone has between 5 or 10 occupants then 20-10 % are disturbed by the indoor temperature.

The theory for collective goods was developed before 1920. Friedman (1986) used it to find the optimal collective temperature for two households. Jönsson (2006) found the optimal collective temperature for a collective of households with normally distributed thresholds. Jönsson (2009) applied the theory of collective goods for indoor temperature to an indoor temperature as a collective factor of production. The factor is produced in the office with heat or energy, the heating system and with the insulation in the building.

2 Indoor temperature in a temperature control zone

The heating system in an office building is divided into zones with a temperature control system in every zone. A zone can be a floor or a group of rooms. A zone has its own collective temperature t_c in Fig. 1.



Figur 1. Building with four temperature control zones and the temperature t_c in one zone.

It the temperature t_c in a zone is higher then heat is lost out and to the rest of the building. The heat to the rest of the building replaces heat for the heating there since all temperature control zones have temperature control. The net loss for the building is for the heat loss out. If one firm owns the building and runs the office then it pays for the heat loss out for every zone. If the zone is rented then the cost for the owner of the building is the heat loss out. If the tenant of the office wants a higher temperature the owner needs to charge the cost for the increased heat loss out.

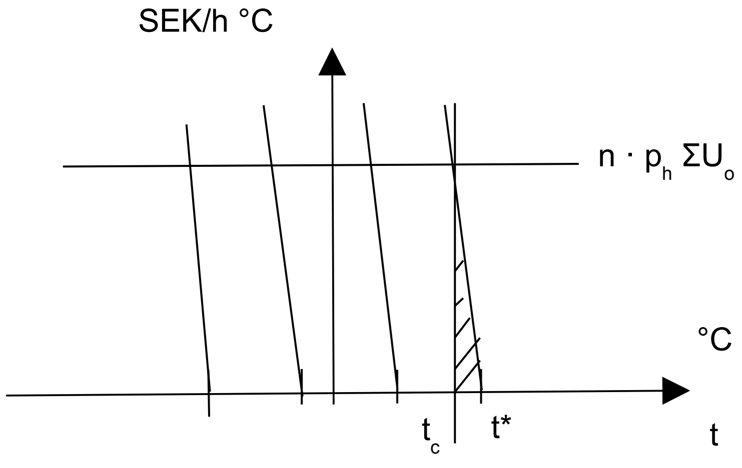
ΣU_o is the heat demand per unit temperature difference indoors and outdoors during work hours, during heating season for a workplace in a modern Swedish office with heat recovery ventilation, efficiency 0,7. The outdoor air rate is 20 l/s pers. The transmission heat demand last 4,4 times longer than the work hours. Ventilation is only operating during the work hours. Eq.(1).

$$\Sigma U_o = (15 \text{ W/°C} * 4{,}4 + 0.02 \text{ m}^3\text{/s} * 1{,}2 * 1000 * (1 - 0{,}7) * 1) = 73 \text{ W/°C pers} \qquad (1)$$

The reduction of temperature at the marginal cost for the zone with n workers is balanced against the loss of production for one worker, Eq.(2). k = 0,004 /°C^2. The price of heat 1992 was p_h = 0,5 SEK/h (incl. tax). (1 USD = 7 SEK) The average cost of a work hour in a Swedish office 1992 was p_{wh} = 250 SEK/h (incl. tax), Jönsson (2005)

$$t_c = t^* - \frac{n \cdot p_h \cdot \Sigma U_o}{k \cdot p_{wh}} \qquad (2)$$

The loss of production from a low temperature SEK/h is represented by the area of the marked triangle in Fig. 2. It is Loss in Table 1. The relative loss, Rel loss is the loss divided by the value of all work hours in the zone. The Loss/yr is the loss of production during 1600 h/yr in the zone. This is the loss for the most sensible worker.



Figur 2. Loss of production, area of marked triangle from indoor temperature t_c for a sample of four office workers, n = 4.

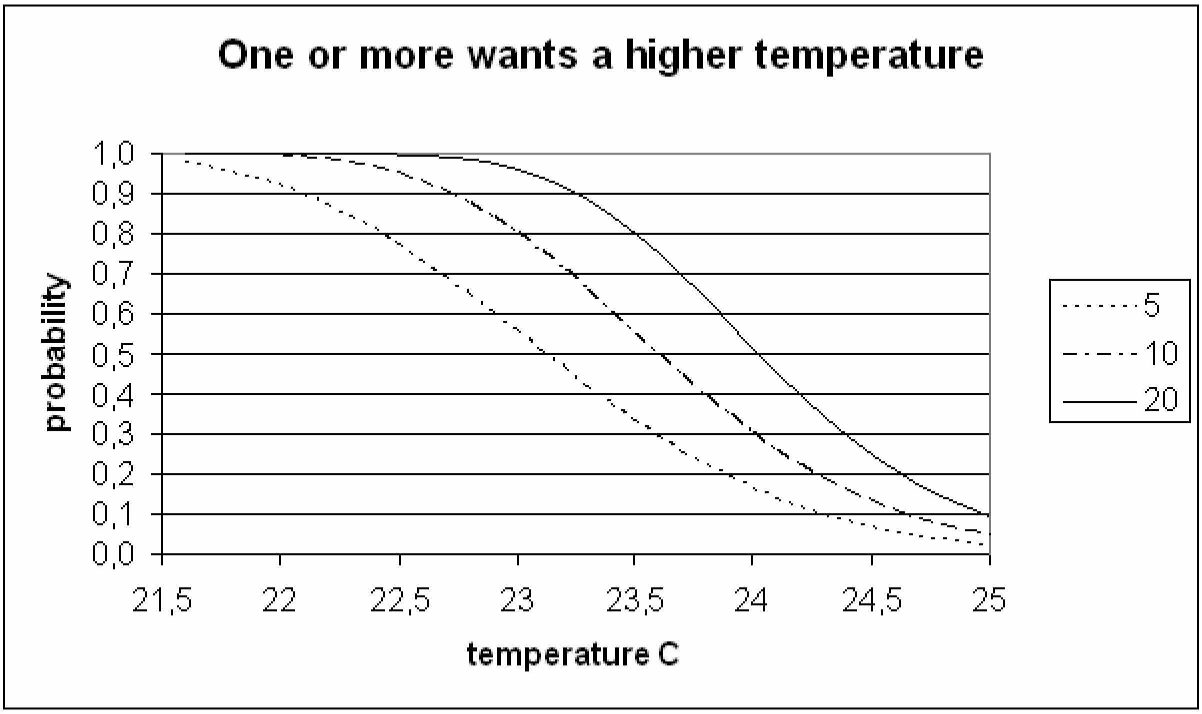
If there are only 5 persons in the zone the probability is small that more than one will be disturbed by the indoor temperature. At 20 workers in the zone the reduction of temperature is bigger and more persons are present so the probability that more than one will be disturbed is higher.

Table 1: *The reduction of temperature in a zone with n workers if the loss of production is taken by one worker and Loss of production.*

Pers in zone	t^*_i - t	Loss	Loss	Loss
n	°C	SEK/h	Rel	SEK/yr
5	0,1825	0,0167	0,000013	27
10	0,365	0,0666	0,000027	107
20	0,73	0,2665	0,000053	426

3 Distribution of the most sensible workers threshold temperature

The population of office workers is assumed to have the same temperature preferences t^*_i and k as the households in Swedish single unit dwellings. Average t* is 21,65°C and the standard deviation is 1,3°C from Jönsson (2006) that refers to temperature measurements in Swedish single unit dwellings. The possibility that someone think the temperature is to high is neglected. The distribution of threshold indoor temperatures t* for the most sensible worker in a temperature control zone was calculated in Jönsson (2009).



Figur 3. The probability that one or more of the workers in a temperature control zone with 5, 10 or 20 workers wants a higher temperature than t, Eq.(3).

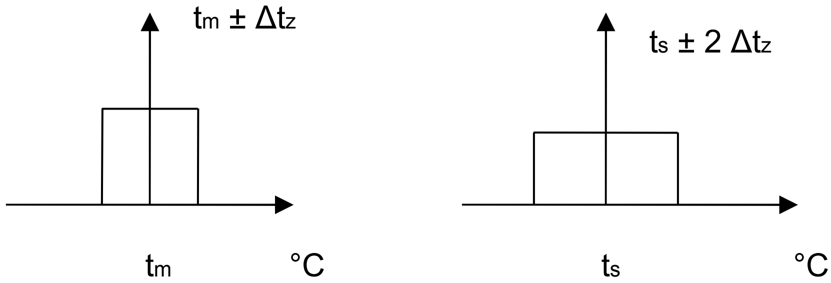
Since it is the most sensible workers in the zone that determines the indoor temperature it is interesting to calculate the probability that workers with different sensibility for indoor temperature is present in a zone with n workers. The probability p that one or more worker wants a higher temperature than t comes from Eq.(3).

$$p = 1 - (1 - N(t))^n \quad (3)$$

N(t) is the normal distribution for t* with an average 21,65°C and a standard deviation 1,3°C. The result is shown in Fig. 3. It shows that small zones will get a lower average indoor temperature and there will be a bigger variation in temperature between small zones than if there are more workers in the zone. If there are 5 workers in the zones and if heating is almost free then the probability of having one or more workers who wants a higher indoor temperature than 23,1°C is 50%. With 10 workers in the zone the probability of having one or more workers who wants a higher indoor temperature than 23,6°C is 50%. With 20 workers in the zone it is 24,0°C at 50%.

4 Distribution of temperatures in a zone

If the measured temperatures at the workplaces in all temperature control zone are rectangular distributed with $\pm \Delta t_z$ then the temperatures in a temperature control zone with average temperature t_m will be within $t_m \pm \Delta t_z$. The temperatures in many temperature control zones where the most sensible person in all zones have t_s will be within $t_s \pm 2\Delta t_z$. In a zone where the most sensible person has the coldest workplace the warmest workplace has the temperature $t_s + 2\Delta t_z$.



Figur 4. Frequency function of temperatures round t_m in one temperature control zone, left and in all temperature control zones where the most sensible occupant demands t_s

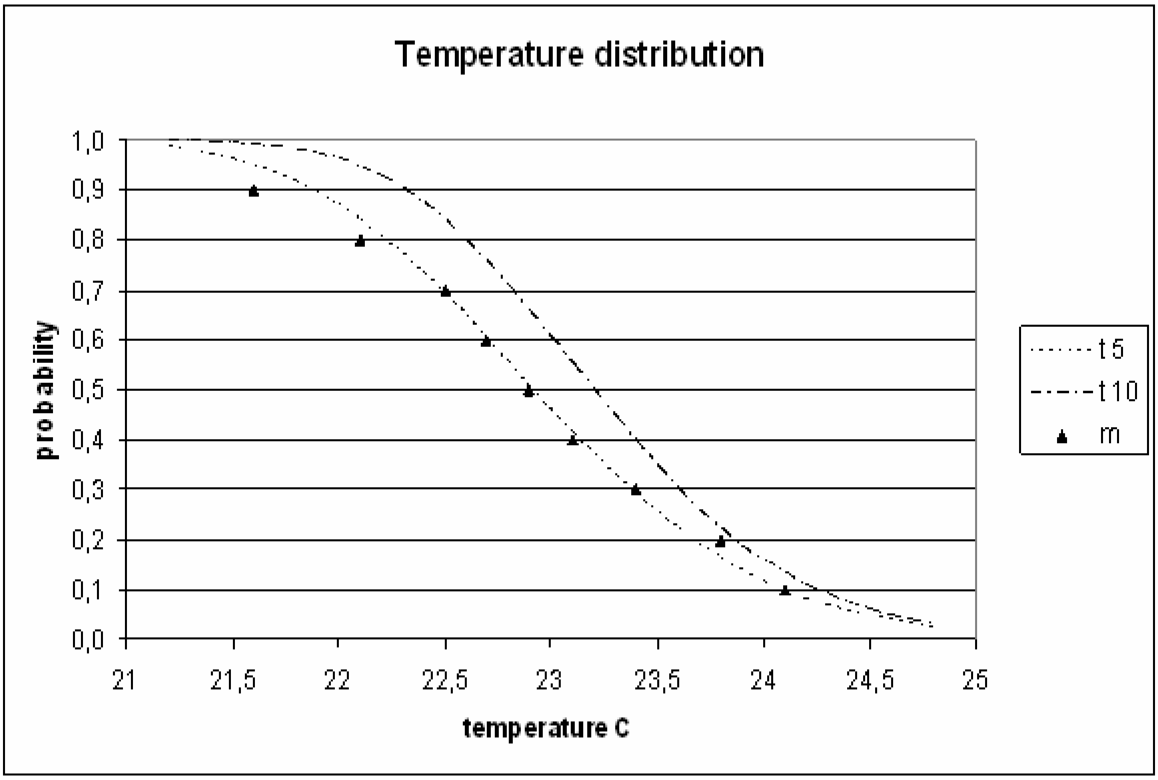
The variation of the temperature in the zones is neglected. It does not affect the average temperature for all workplaces.

5 Conflicting demands of temperature

If one worker in a temperature control zone wants a higher and one worker wants a lower temperature then there are conflicting demands. If there are conflicting demands then the probability curves in Fig. 3 will meet curves for the probability that one ore more wants a lower temperature. The conflicting demands will reduce the average indoor temperature in a temperature control zone from the curve in Fig. 3. It must be possible to see this on the distribution of measured temperatures as a deviation left down to zero at high indoor temperatures.

6 Measured temperatures in Swedish offices

Sundell et al. (1994) measured the indoor temperature in 540 office rooms during the heating season when the outdoor temperature was -10 - 12°C. The rooms where situated in 160 buildings with between 1 - 12 levels and an average of 3 levels. Some rooms had 2 workplaces. The distribution of measured temperatures m is shown in Fig. 5. Since the zone sizes for the measured workplaces are not known the sizes are assumed to be between 5 and 10 workplaces.



Figur 5. Temperature distribution in Swedish offices according to theory, t 5 and t 10, with 5 and 10 workers in a zone and measured temperature distribution, m.

7 Comparison of theory and measurements

From the distribution of temperatures t* for the most sensible worker in a zone Fig. 3 is drawn the reduction of the temperature due to the marginal cost of temperature in Table 1. The temperature is reduced because it costs to heat. The reduction is 0,2°C for zone size 5 and 0,4°C for zone size 10 workers. This gives the distributions of temperatures t_c in the zones with 5 and 10 occupants, t 5 and t 10 in Fig. 5. To get the reel distribution of temperatures at workplaces the variation of the temperature in the zones should have been included.

The measured temperatures, m in Fig. 5 follows the theoretical distribution for zone size 5, t 5. In zones with 5 or 10 workers there are 20 or 10 % disturbed. If only one worker in every zone is disturbed. This coincides with earlier estimates of the percentage dissatisfied.

8 Conclusion

The theory for indoor temperature as a collective factor of production explains the measured temperatures from 1994 in 540 rooms in Swedish offices, if the zones have approximately 5 workers. The theory uses economic data from 1992 such as the price of a workhoure 250 SEK/h and the price of heat 0,5 SEK/kWh. The theoretical calculation assumes 5 – 10 workers in a temperature control zone and the temperature variation between the workplaces in a temperature control zone is neglected. The distribution for measured temperatures is slightly inclined downwards, in relation to the theoretical; witch indicates conflicting demands in zones with high indoor temperatures.

The theory for a collective factor of production gives the low number of dissatisfied 10 – 20 % known from the thermal comfort theory.

9 References

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