# ECONOMIC VALUE OF HIGH QUALITY INDOOR AIR CLIMATE

Kim Hagström[1], Risto Kosonen[1], Jarmo Heinonen[2],Tuomas Laine[2]

[1] Oy Halton Group Ltd, Finland
[2] Olof Granlund Oy, Finland

## ABSTRACT

In the building process it is common that comparison between different systems is made based on the initial costs. Low investment can turn out to be costly from the whole life-cycle viewpoint, if the costs of operation and maintenance are not understood. Today the role of life-cycle costs (LCC) is increasing its importance in the decision-making process. However, also an LCC analysis may lead in the wrong selection, if the difference in indoor environment quality (IEQ) and its impact on the workers productivity is not accounted for.

The information of the Indoor environment parameters' influence on the workers productivity is limited. Also the link between LCC and productivity is currently missing. This paper presents a sensitivity analysis methodology for LCC and non-productivity costs comparison. It is also demonstrated that an investment to a better HVAC system is profitable already with modest profitability improvements of only a few minutes per day.

## KEY WORDS

Productivity, Air Quality, Life-cycle costs, Ventilation Strategy

## INTRODUCTION

In the building process it is common that the initial costs are the main criteria when making choices between different systems. Low investment can turn out to be costly from the whole life-cycle viewpoint if the costs of operation and maintenance are not understood. Nowadays the role of life-cycle costs (LCC) has increased its importance little by little in the decision-making process. With an LCC calculation tool covering initial installation costs as well as operation and maintenance costs it is possible make comparisons between alternative systems. [1]

However, the primary objective of commercial building system is to provide an environment that will foster tenants productivity and increase the profitability of business. Though being a step forward, LCC analysis is missing the link between life-cycle costs and resulting indoor environment level. Thus, it is not a valid tool to compare air conditioning systems resulting in different level of indoor climate and may lead in the situation, when an air-conditioning system providing lower quality environment causing reduced productivity is chosen due to budget reason. The true valuation and comparison of the ventilation systems is possible only, when we know both system LCC-costs and system's impact on the productivity.

The information of the Indoor Environment parameters' influence on the workers health and productivity is yet limited. However, the existing literature contains some significant evidence of such dependency. The costs of lowered quality of the indoor environment for the employer realize in two ways: through workers impaired performance on daily bases and from adverse health effects causing absence of the workers. Based on the review of a current literature Fisk and Rosenfeld made crude estimates of the potential savings of the improved indoor environment in the U.S. For example the potential gains in productivity improvement alone was estimated to be $12 billion to $125billion.[2]

The air conditioning system has effect on two indoor environment parameters namely thermal environment and indoor air quality. Wyon has reported the thermal environment having a great influence on the workers performance in different types of work. [3] As an example the influence on the mental tasks requiring concentration (thinking) is reproduced in Figure 1.

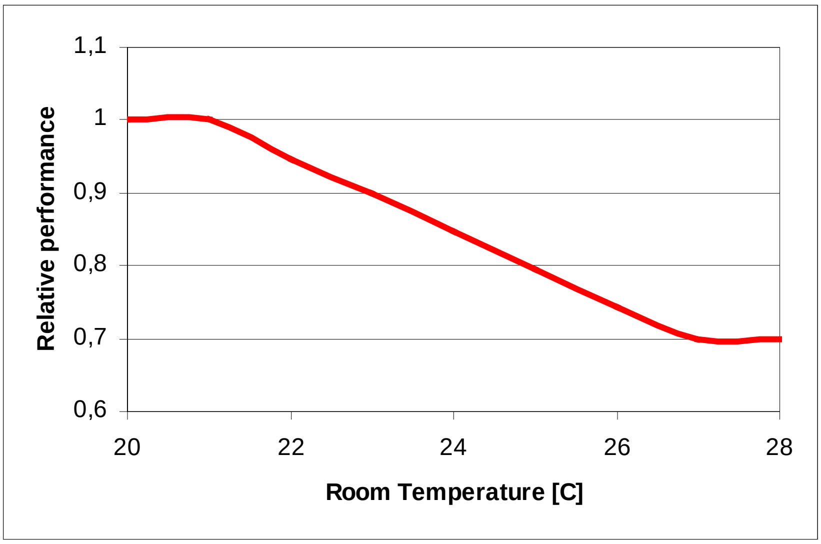

Figure 1. Group average performance in thinking work as a function of the room temperature.[3]

Sources impairing indoor air quality have been reported to have a great influence on the workers productivity. Wargocki et al reported a productivity decrease of 6,5% among typists, when a pollution source, old carpet, was introduced into the office space. [4] The indoor air quality level in the room is affected by many factors, such as: used construction materials, cleaning practices, and cleanliness and cleanability of the ventilation system. When the correlation of these factors with the productivity is known the cost of non productivity can be calculated. In the calculation example of this paper the indoor air quality factor is not considered, thus impaired air quality would be an additional source of non productivity costs.

The link between LCC of the air conditioning system and productivity is currently missing. This paper presents a methodology of a practical sensitivity analysis for LCC and non-productivity costs comparison. It is also demonstrated that an investment to a better HVAC system is profitable already with modest profitability improvements of only a few minutes per day.

## METHODS

In following the methodology and background for LCC and non-productivity costs comparison is explained. The analysis results are summarized in a diagram, see Figure 2, which can be used for comparison during design. It must be noted that the diagram is site and case specific and made for the calculation example in this paper.

The LCC costs were calculated using the same calculation tool as explained in [1]. LCCs of different system options are drawn on the bottom right corner of the diagram.

The thermal environment is mainly created by air conditioning system. The quality of the thermal environment depends on the system capacity and the control system performance. A following method is used for productivity loss evaluation:

(1) The time period, when air conditioning system is not capable in maintaining optimum conditions is calculated and quantified as degree-hours, Kh. Kh is the sum of degree-hour, when the indoor air temperature diverge from the optimum temperature, equation (1).

$$Kh = \sum \left| T_{in,\,i} - T_{opt} \right| \times h \ , \tag{1}$$

where $T_{in,i}$ is an indoor air temperature at time period i, $T_{opt}$ is The optimum indoor air temperature and h is a time period.

In this paper it is assumed that the optimum temperature is 21° C as was presented by Wyon for ”thinking” work.[3] Currently only simple hours are used. A more sophisticated method could be to integrate a productivity correlation, like in Figure 1, thus differentiating the influence of different levels of excess temperature. The results of this part is shown on the right top corner of the diagram and the calculation principles are presented below.

(2) The 100% working time loss is calculated multiplying the degree hours with the average percentage of productivity loss. Lines of different productivity loss levels are drawn on the top left corner of the diagram from where an appropriate level can be used.

(3) Productivity loss is quantified into currency with the aid of the expected net turnover of an employee. The use of net turnover is argumented by the fact that an employer both pay employees salary and loses the income from the lost work due to decreased productivity. Lines of different salary levels are drawn on the bottom left corner of the diagram.

(4) Finally LCC and non productivity costs can be compared at the negative y-axis.

## Cooling capacity

A common practice in dimensioning the maximum cooling capacity of a building air conditioning system is to use a somewhat higher indoor air temperature than the optimum. By selecting this dimensioning summer design temperature one accepts a certain loss of productivity due to increased temperature level during summer. Higher dimensioning temperature means reduced air conditioning installation costs, but it also increases the time period, when the optimum temperature is exceeded and, thus, higher productivity loss among workers during usage. Daily and annual variation of the room temperature can be evaluated using energy simulation software. This time period can be calculated from annual temperature constancy from energy simulation.

## Control system performance

The problems of the thermal environment arising from insufficient control system are:

- Incapability to compensate the differences of external and internal cooling loads, thus creating temperature uniformity between rooms. As an example the percentage of the rooms not meeting the desired temperature with centralized and zonal contol principles is reported by Kosonen.[5] He found out that centralized control system results in 2° C temperature difference and zonal control system 1° C temperature difference between rooms in South and North facades even in situation, when the difference in cooling loads between facades is taken into account during design and the internal loads are the same.

- Lack of individual control compensating different needs of the people. Based on his studies Wyon has suggested that ±3 °C individual control range would be necessary to satisfy 99% of the occupants.[3]

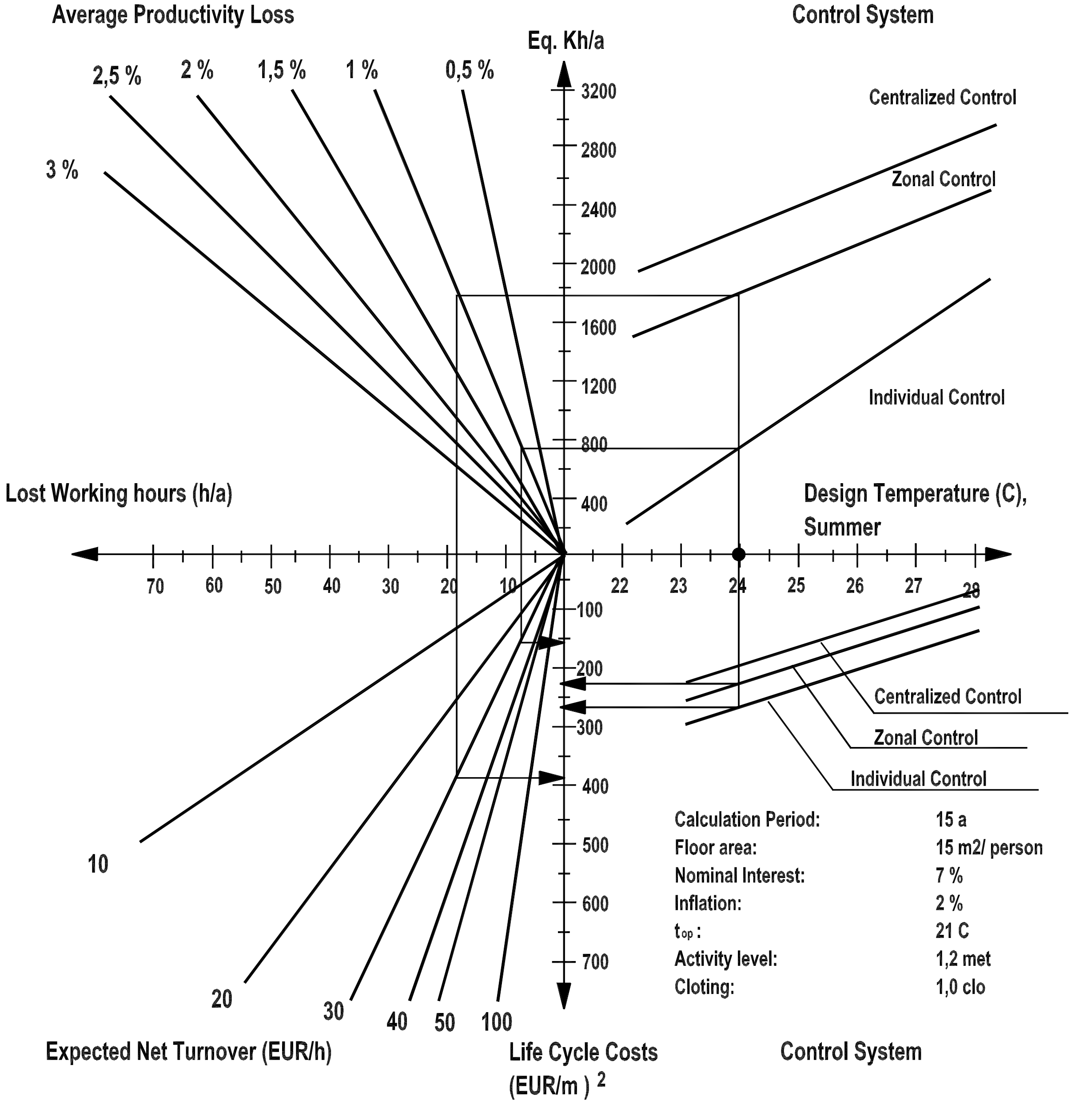

Figure 2. Diagram linking LCC of ventilation systems, thermal environment and productivity effects.

Studied control systems were individual control, zonal control and centralized control:

- With individual control system it is possible to control indoor air temperature of each rooms individually. This can be carried out either with Variable Air Volume (VAV) system or cooled-beams system.
- Zonal control system is normally used with Constant Air Volume (CAV) system, where control of indoor air is based on control of supply air temperature. Supply air temperature is controlled zone by zone either by exhaust air temperature or indoor air temperature at certain point in the zone. Buildings are normally divided into zones based on direction of facades.
- Indoor air temperature is also controlled by supply air temperature, when centralized control system is used. The difference between centralized and zonal control system is, that in centralized control system supply air temperature of whole ventilation system is controlled based on either average exhaust temperature or indoor air temperature at certain point in the building.

## CASE-STUDY

### Design Criteria

Case study calculations were carried out for LVIS 2000 office building, which has been designed as a reference building for system simulations. The use of reference building improves the repeatability of simulations and makes it easier to compare the results of different researchers. The building was located in Helsinki, Finland. The occupation in building was 15 floor-m²/employee. The building life cycle calculation period was 15 years.

All ventilation and control systems were dimensioned to meet two summer design temperatures (24 and 26 $^{o}$C). After dimensioning the temperature dependent equivalent degree-hours for air conditioning systems were defined.

### LCC analysis results

The LCC of different ventilation and control systems defined with dimensioning temperatures are presented in figure 3.

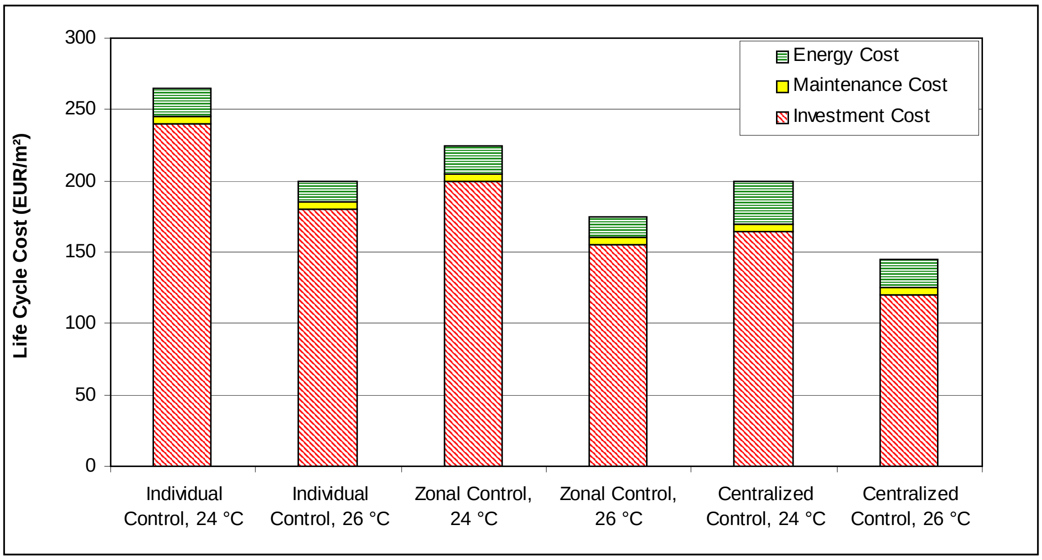

Figure 3. Life cycle costs of different ventilation and control system with two target values.

### Sensitivity analysis results

The comparison results are summarized in Figure 2. One can see the productivity effects of different air conditioning systems are big, whereas LCCs don't differ much from system to system. For example, if we compare individual and zonal controls and make a modest assumption of 1 % average productivity loss with design indoor temperature 24 °C and of expected turnover 30 EUR/h. The difference between system life cycle costs is about 50 EUR/m², and between costs of lost working hours is 250 EUR/m². Thus, the payback time of an additional investment for individual control instead of zonal is in this case only 1,8 years and the total income for the company will be 200 EUR/m² in 15 years.

Similarly the same diagram can be used for desing temperature optimization as well. If we compare summer design temperatures 24 and 26 $^{o}$C, the diagram shows that it is still profitable to dimension the system using lower temperature, although LCC is much higher in that case.

## DISCUSSION

A methodology was introduced for the evaluation of the economic value and profitability of the good indoor climate. Based on the method it will be possible to develop a suitable tool for the sensitivity analysis and reasoning of the good indoor air climate during design. For the moment the information of the Indoor Environment parameters' influence on the percentage productivity lost is limited, thus it is left open for subjective estimation. When more accurate information is available in the future, it will be easy incorporate that into analysis.

Presented method links together LCC and productivity. Looking at LCCs only would have lead to the selection of lower quality air conditioning system. However, through the case study it was possible to demonstrate that an investment to a better HVAC system is profitable already with very modest productivity improvements of only a few minutes per day. Applying Wyon's findings would make it still more profitable. The results of the analysis are supported by the results presented in references.

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For more information, please contact Kim Hagström, Tel. +358 9 825 40023