Indoor environment and productivity in office environment

summary of the key contents of REHVA Guidebook no 6

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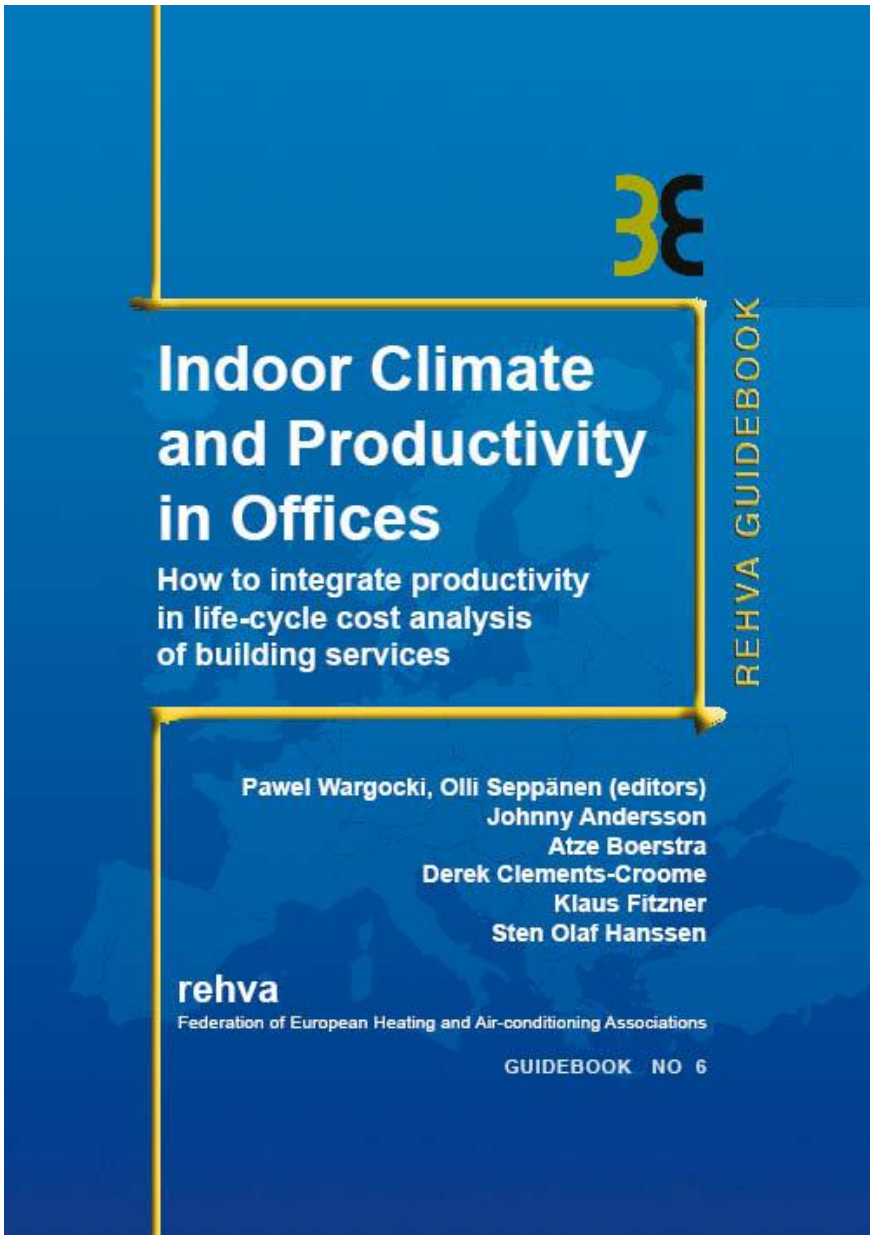
Federation of European Heating and Air-conditioning Associations (REHVA) = Professional organization with 28 member countries representing more than 100 000 HVAC experts in Europe



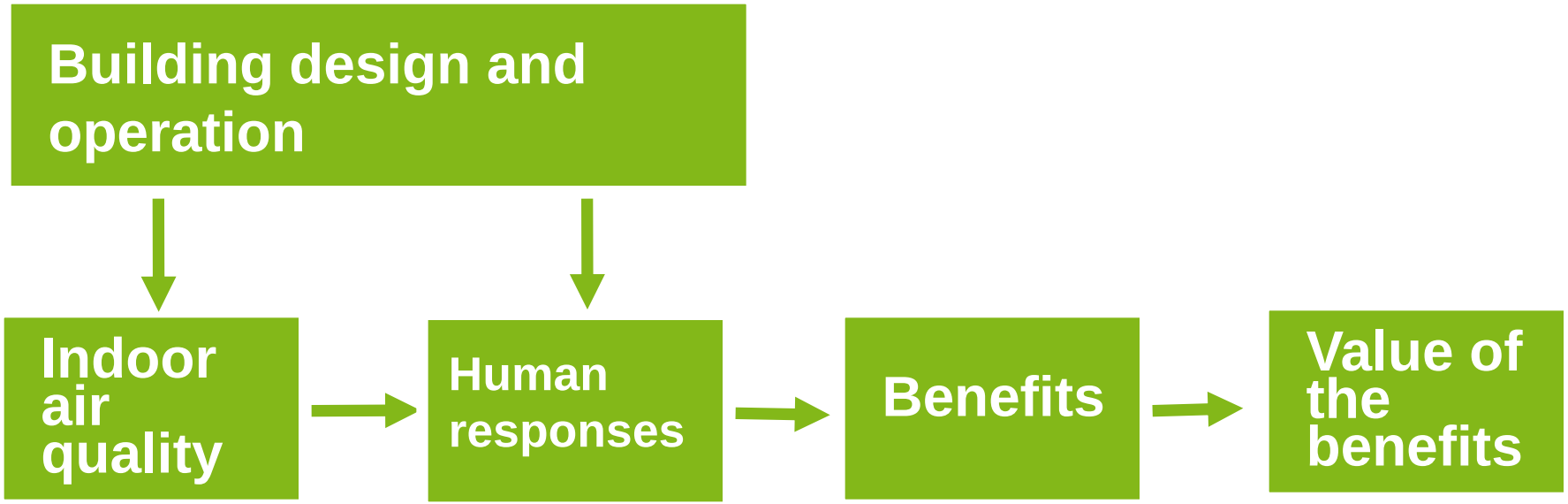
Procedure to include indoor environment in calculations is needed

- **for engineering analysis to compare alternative technical systems**
- **to convince the employers to invest on better indoor environment**
- **to motivate building owners to invest on better indoor environment and**
- **to justify higher rents of high quality leased buildings**

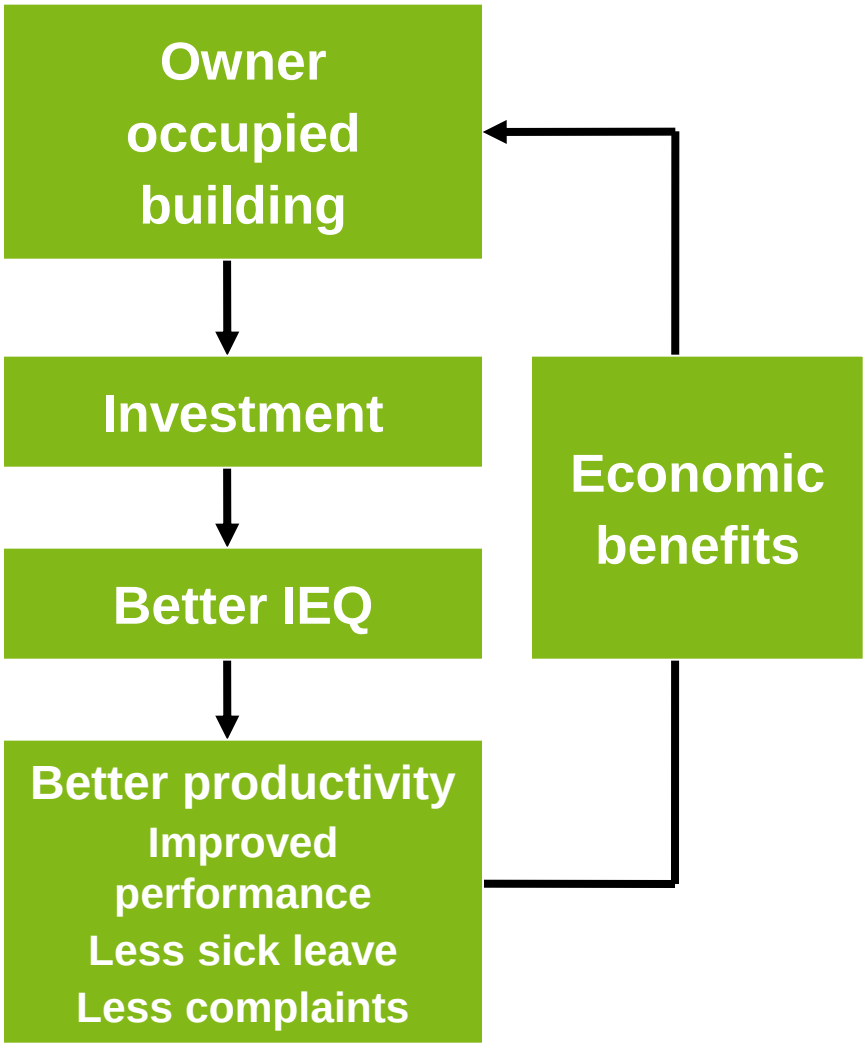
Economic calculations in design and operations stage should include

- **investment cost**
  - euros per occupant/employee
- **operation cost**
  - including energy
- **productivity and health benefits/decrements**

From improved building performance to benefits



Economic benefits as a driving force for better IEQ



Simplified definition of productivity

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

Productivity, building investment and cost

$$\text{Productivity} = \frac{\text{Work performance}}{\text{Investment and operational cost}}$$

Factors affecting productivity

(Clements-Croome 2000)

IAQ-factors with quantitative effect on productivity

- **Ventilation and sick leave**
- **Ventilation and work performance**
- **Temperature and performance**
- **Perceived indoor air quality and task performance**
- **SBS-symptoms and performance**

Ventilation rates affect

- **Concentration of pollutants from indoor sources and outdoor sources**
- **Pollutants from air handling system itself**
- **Humidity etc.**

- **Perceived air quality**
- **Sick building syndrome symptoms**
- **Dryness etc.**

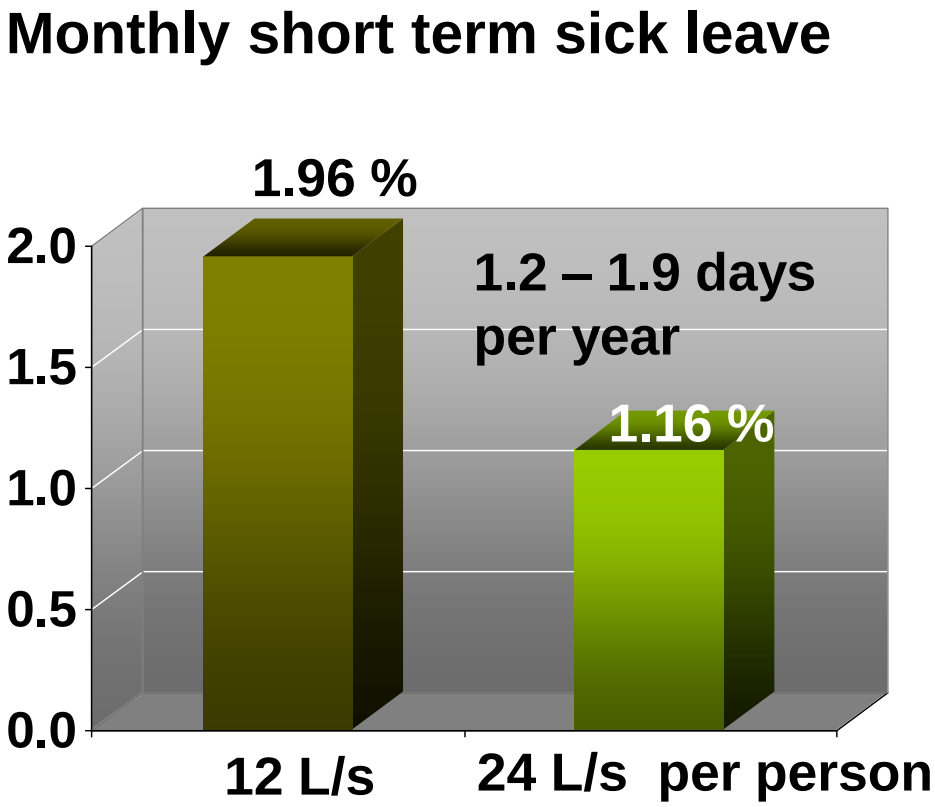
What about objectively measured sick leave and performance ?

Ventilation rates and sick leave

An example of data on ventilation and short term sick leave

(Milton et al. 2000)

Relative risk for short term sick leave was 1.53 with lower estimated ventilation rate of 12 L/s compared with ventilation rate of 24 L/s



Short term sick leave or illness inflicted by infectious diseases vs. ventilation rate (ach) (Adapted to Wells-Riley-model)

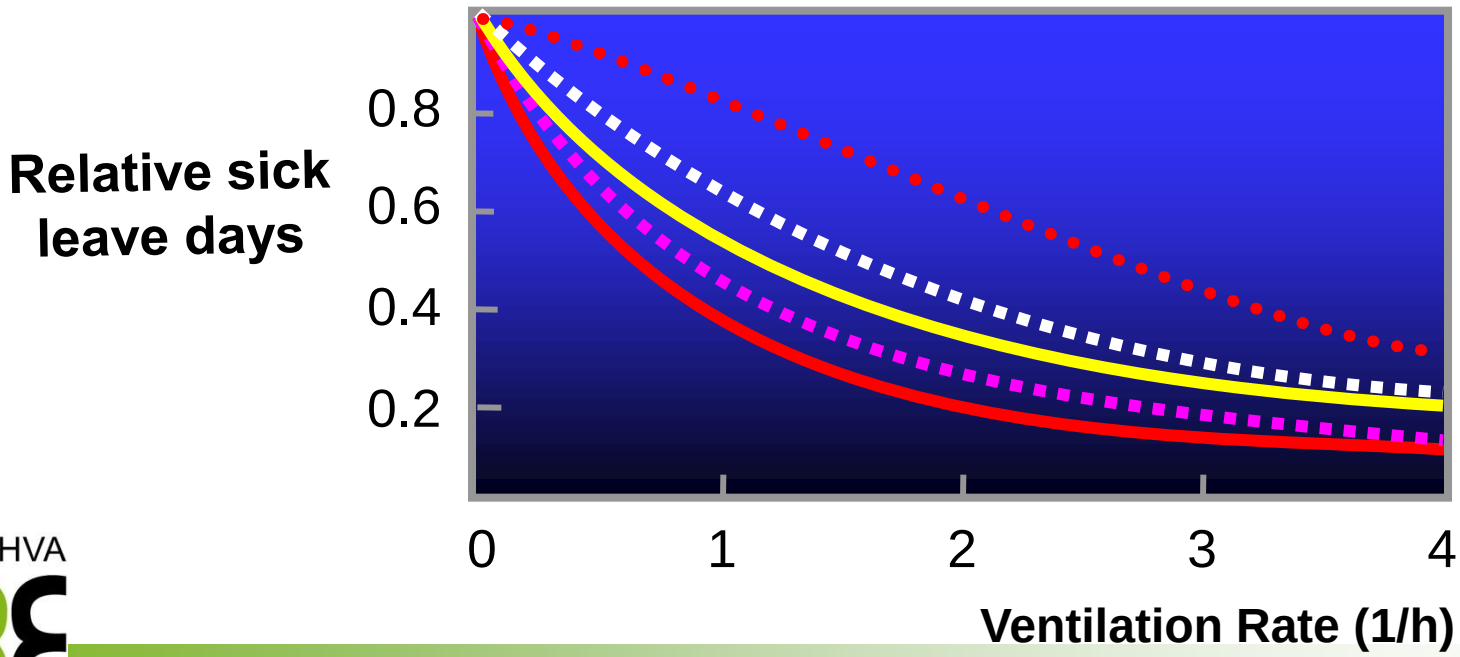
Drinka (1996), illness in nursing home

Brundage (1988), illness in barracks, all years

Particle concentration model

Brundage (1988), illness in barracks, 1983 data

Milton (2000), sick leave in offices



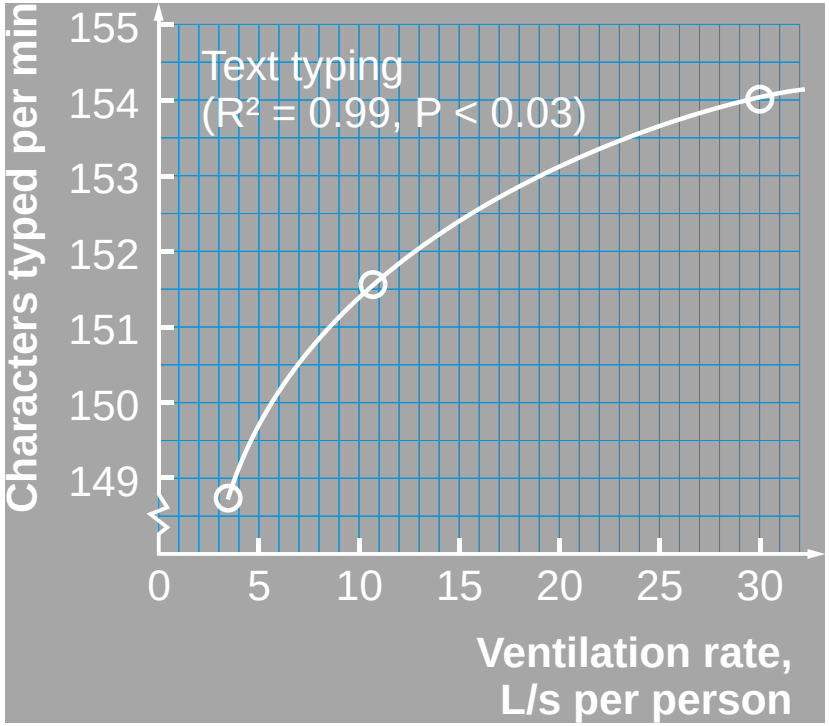
Ventilation rates and performance

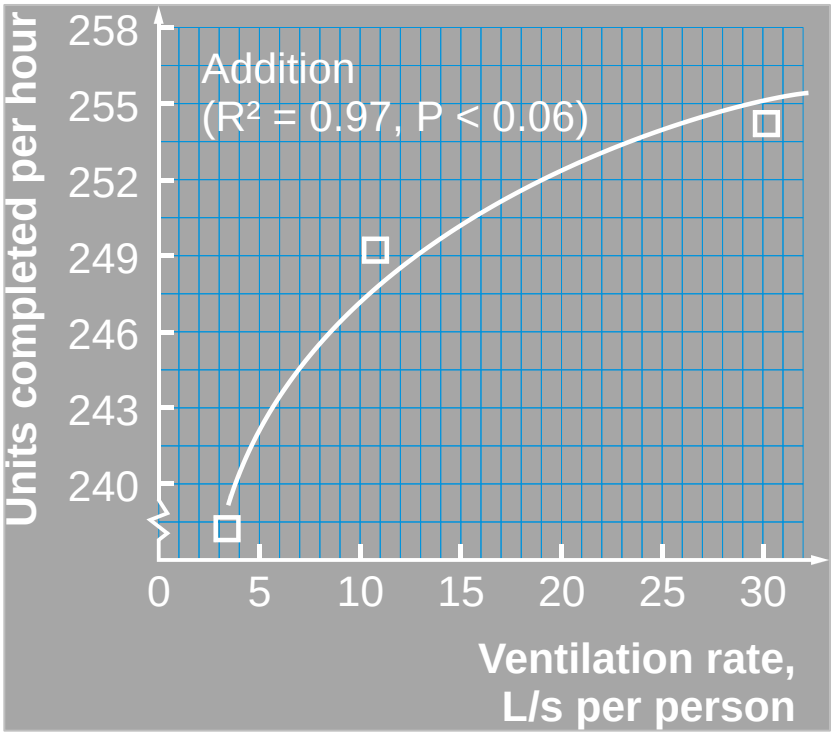
Meta analysis of studies on ventilation rate and performance

- **six studies in office environment**
- **two studies in laboratory**
- **one in school**
- **some with multiple ventilation rates**

Example of results from a laboratory study

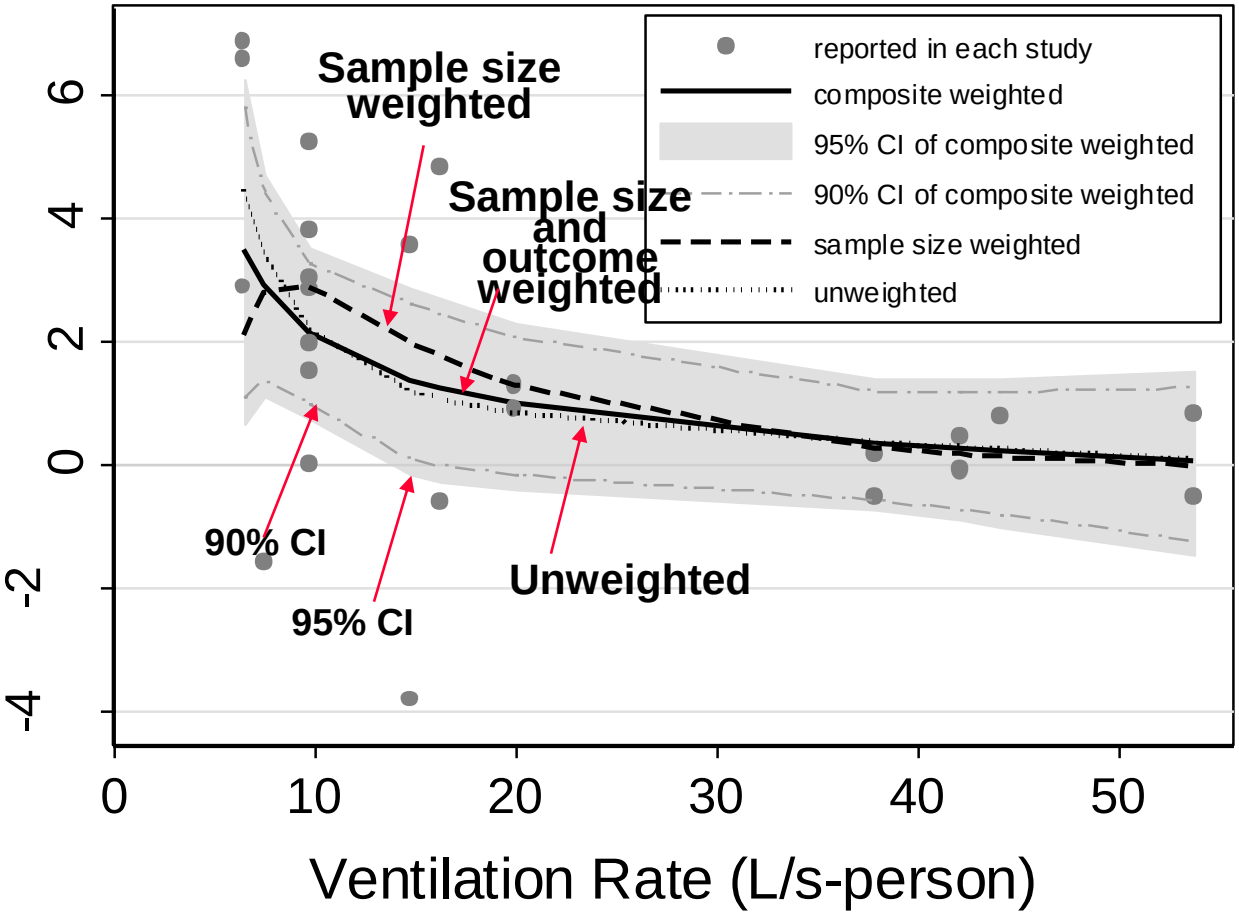
(Wargocki et al. 2000)



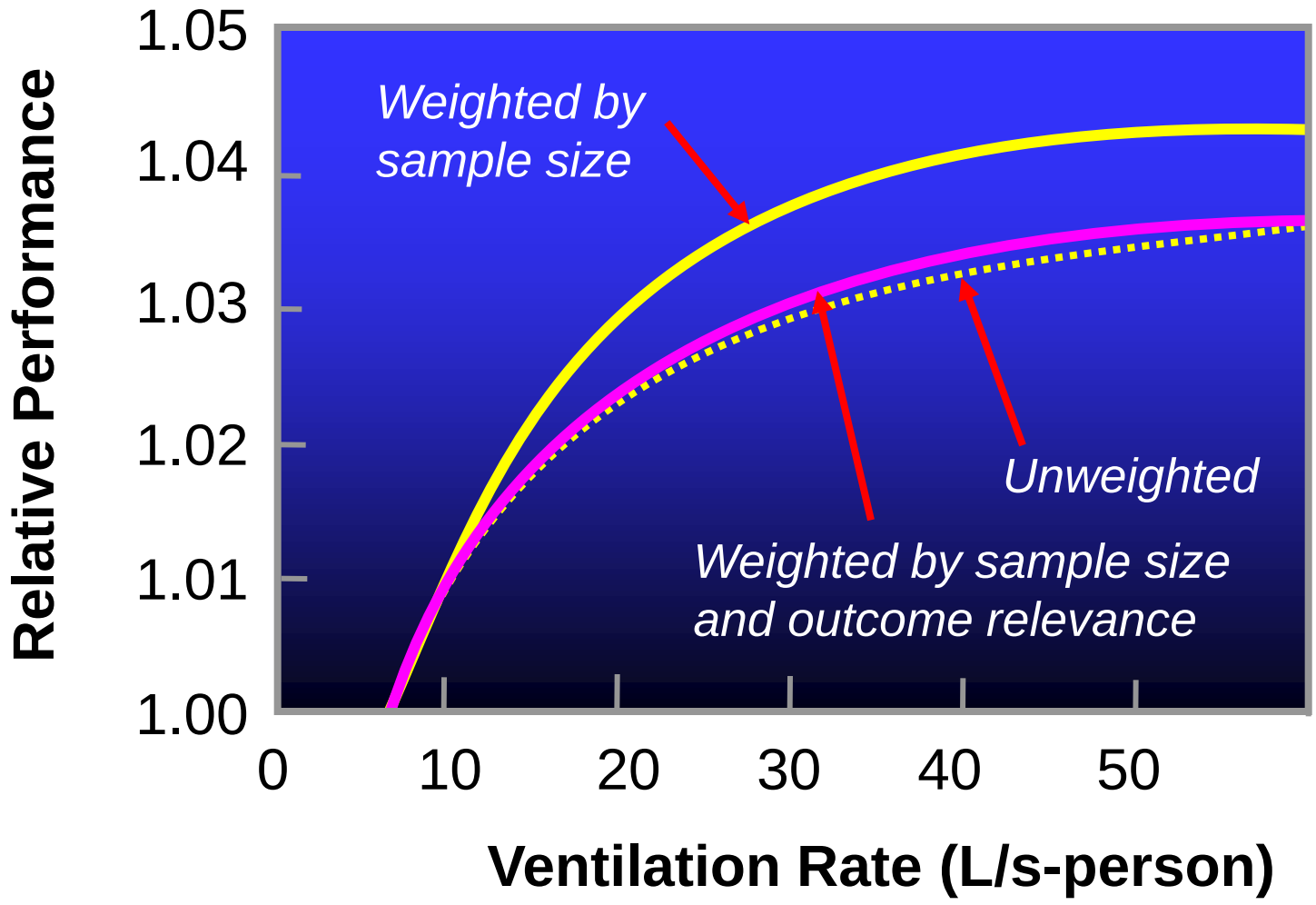


Increase of ventilation rates 3, 10, 30 L/s per person improved performance of office tasks in simulated office environment

Increase of performance (%) per in increase in ventilation rate of 10 L/s-person

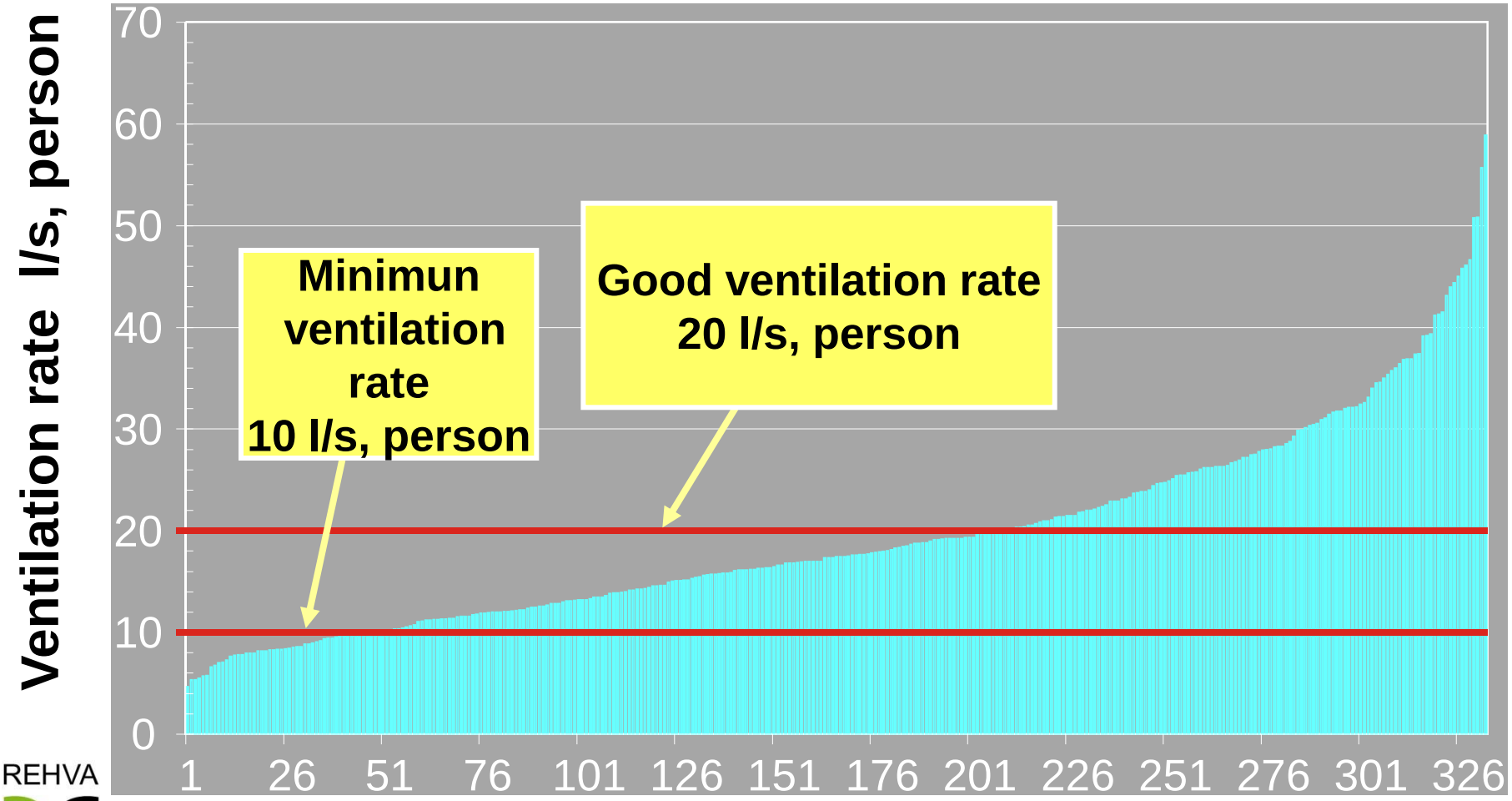


Relative performance vs. ventilation rate in L/s-person in relation to 6.5 L/s-person



With balancing of air ventilation rates to better IAQ and energy efficiency

An office building in Helsinki



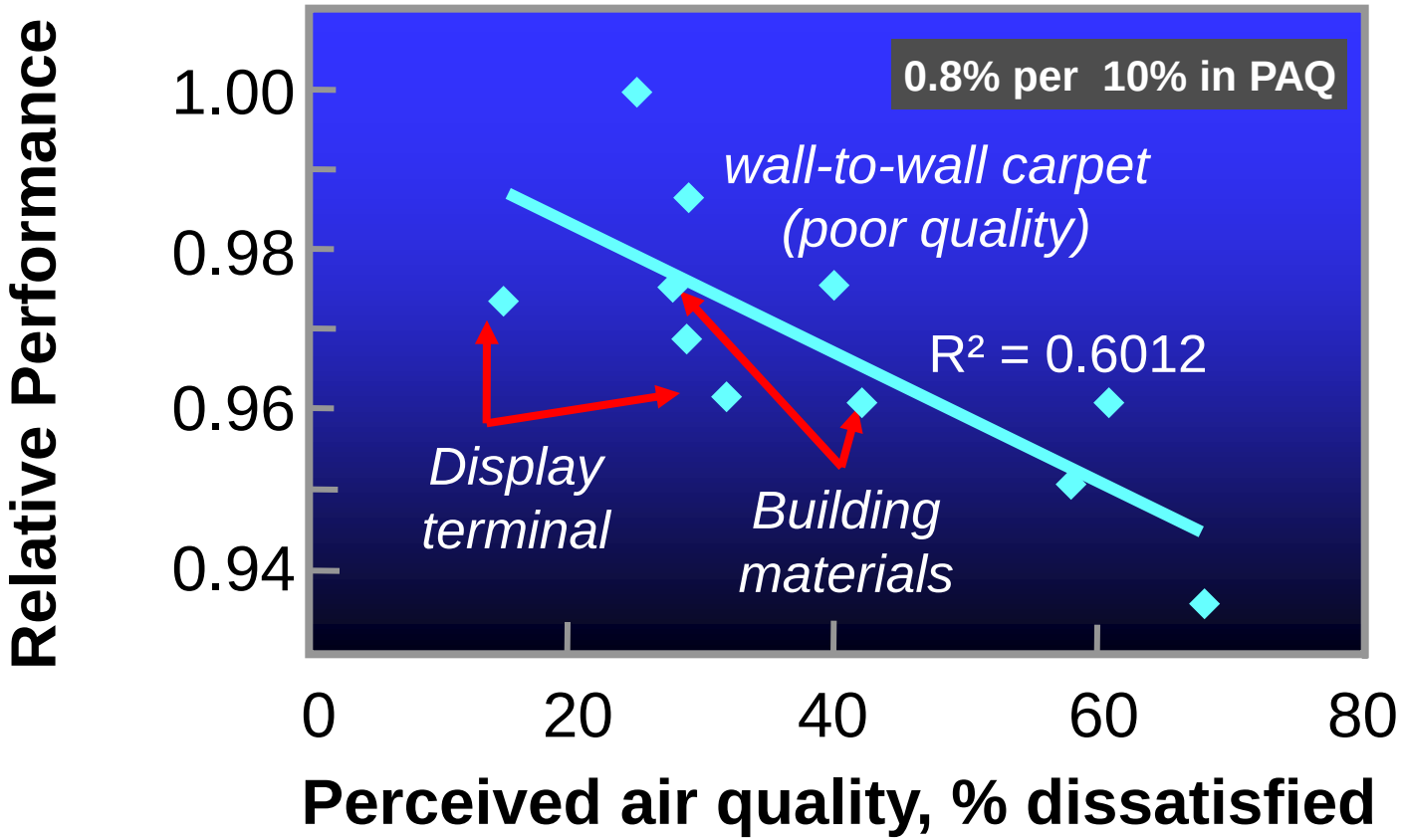
(Tuomainen ym. 2003)

Performance and perceived air quality (PAQ)

- **Perceived air quality has been used close to hundred years as a criteria of air quality and ventilation rates – also in many standards**
- **PAQ is affected by pollutants, adaptation, ventilation and other environmental parameters (ºC, RH)**
- **PAQ is used also as an indicator of air quality for performance**

Performance in text-typing vs. perceived air quality in percentage of dissatisfied (PD%)-

IAQ can be improved either by removal sources or by incresing ventialtion reates



Temperature and performance

Effects of Temperature

- **High temperature**
  - causes discomfort
  - increases heart attacks and mortality
- **Low temperature**
  - causes discomfort
  - decreases the dexterity of fingers
- **High temperature in the winter**
  - increases SBS-symptoms
  - deteriorated perceived indoor air quality
  - increases the complaint on dry air

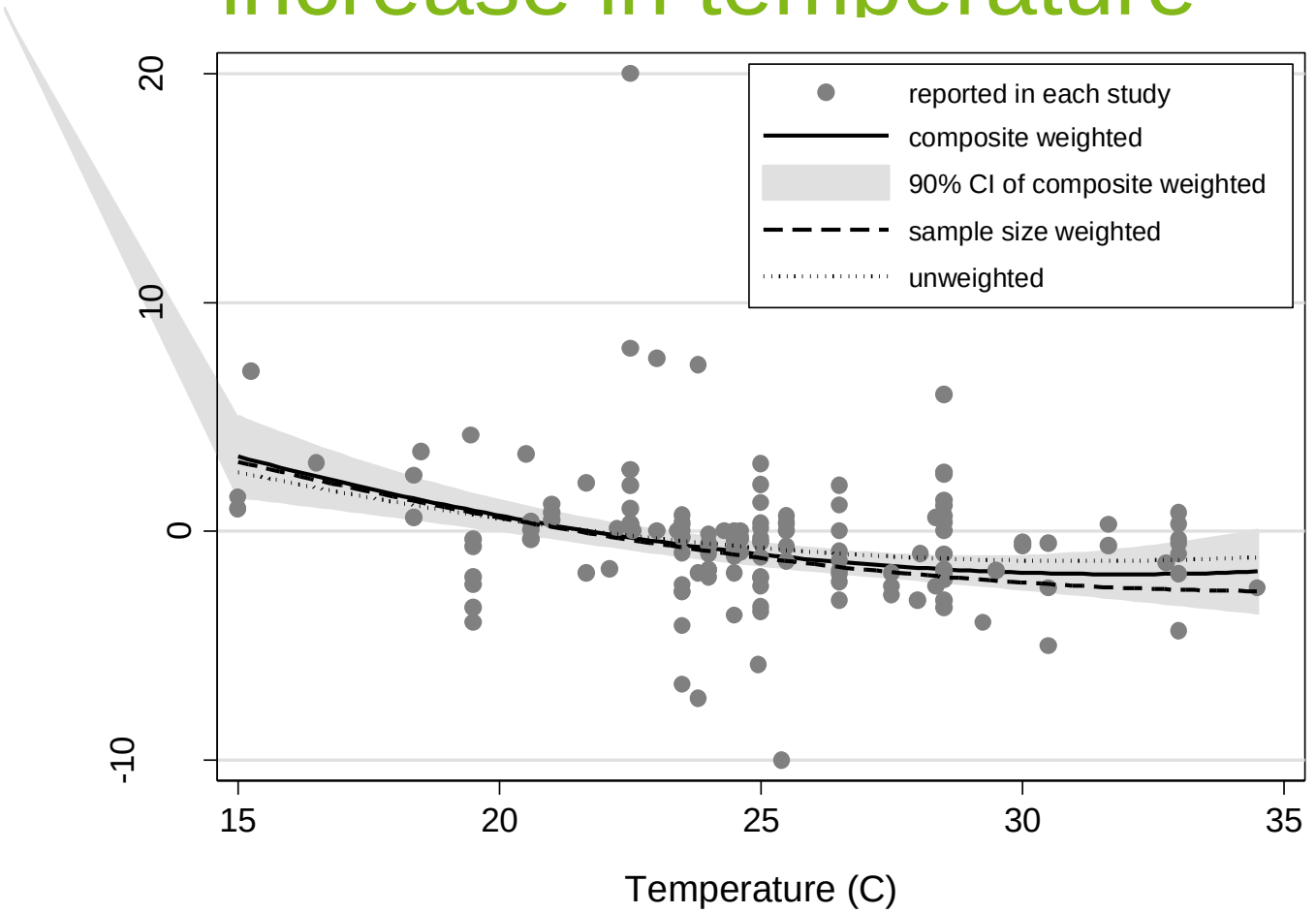
What about performance?

Meta analysis of studies on temperature and performance in office work

(Seppänen, Fisk, Lei 2005)

- **24 studies with objectively measured performance and temperature – 148 data points**
- **All included studies were controlled for**
  - work environment (ventilation, humidity, work load etc.)
  - clothing
  - personal factors

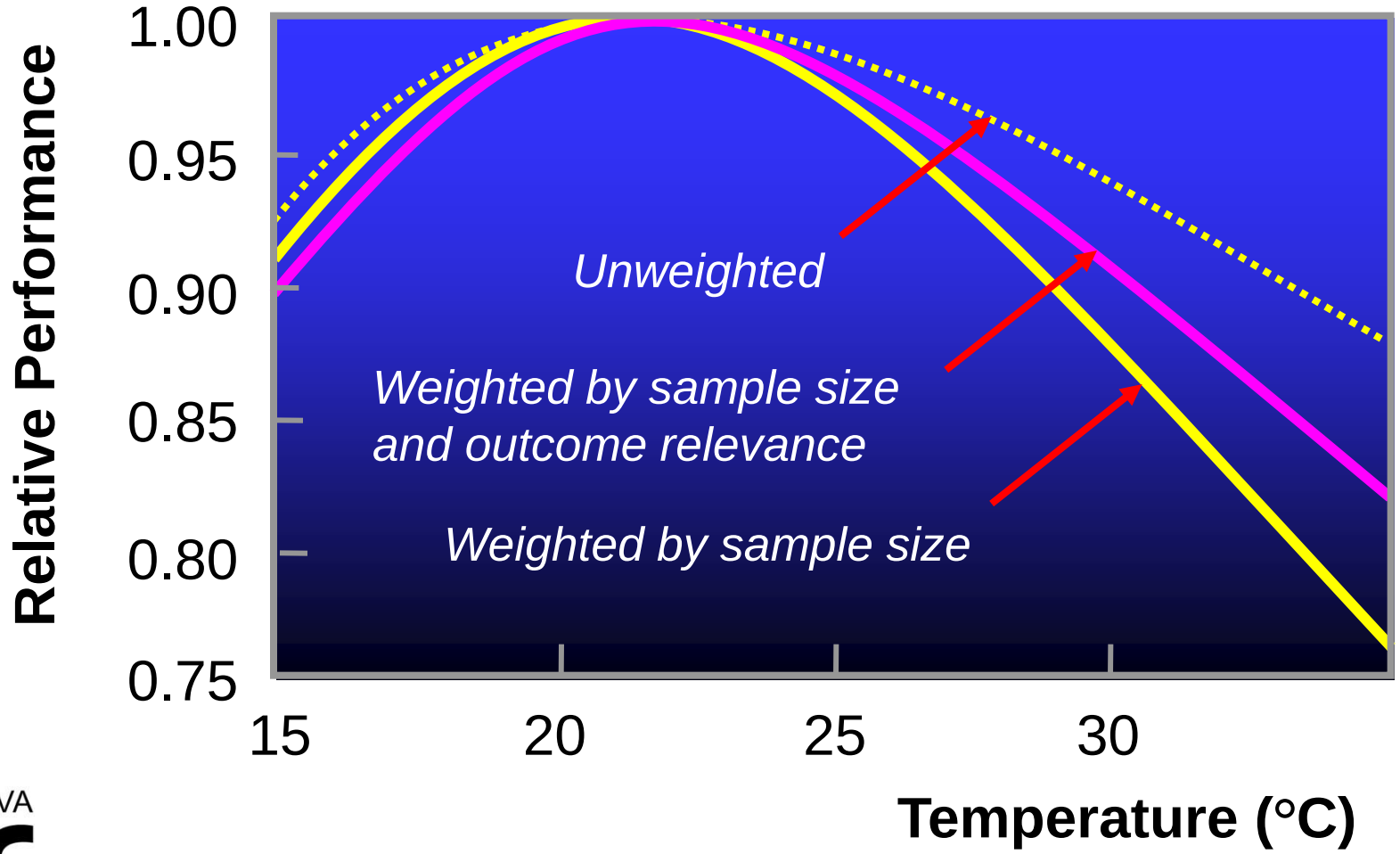
Change in performance in % per 1 oC increase in temperature



Seppanen et al. 2005

Relative performance vs. temperature compared to the maximum

95% confidence range 20-24 °C



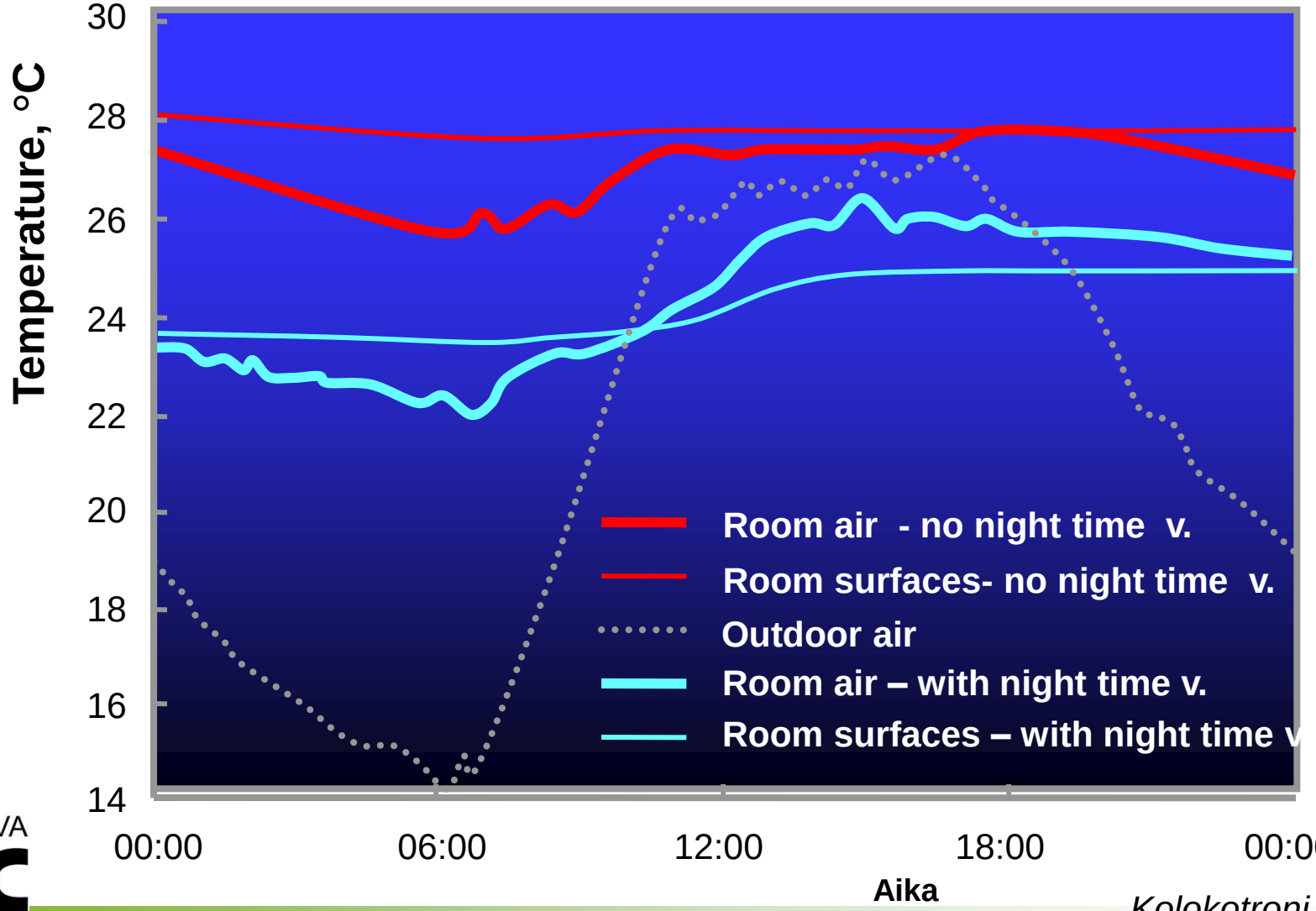
APPLICATION OF THE PROCEDURE IN ENGINEERING ANALYSIS

Example 1
Feasibility of night-time ventilative cooling

Cool night time outdoor air is used to cool down the building during night

Fans use energy but day-time indoor temperature is reduced and work performance improved

Effect of night time ventilative cooling on room temperatures

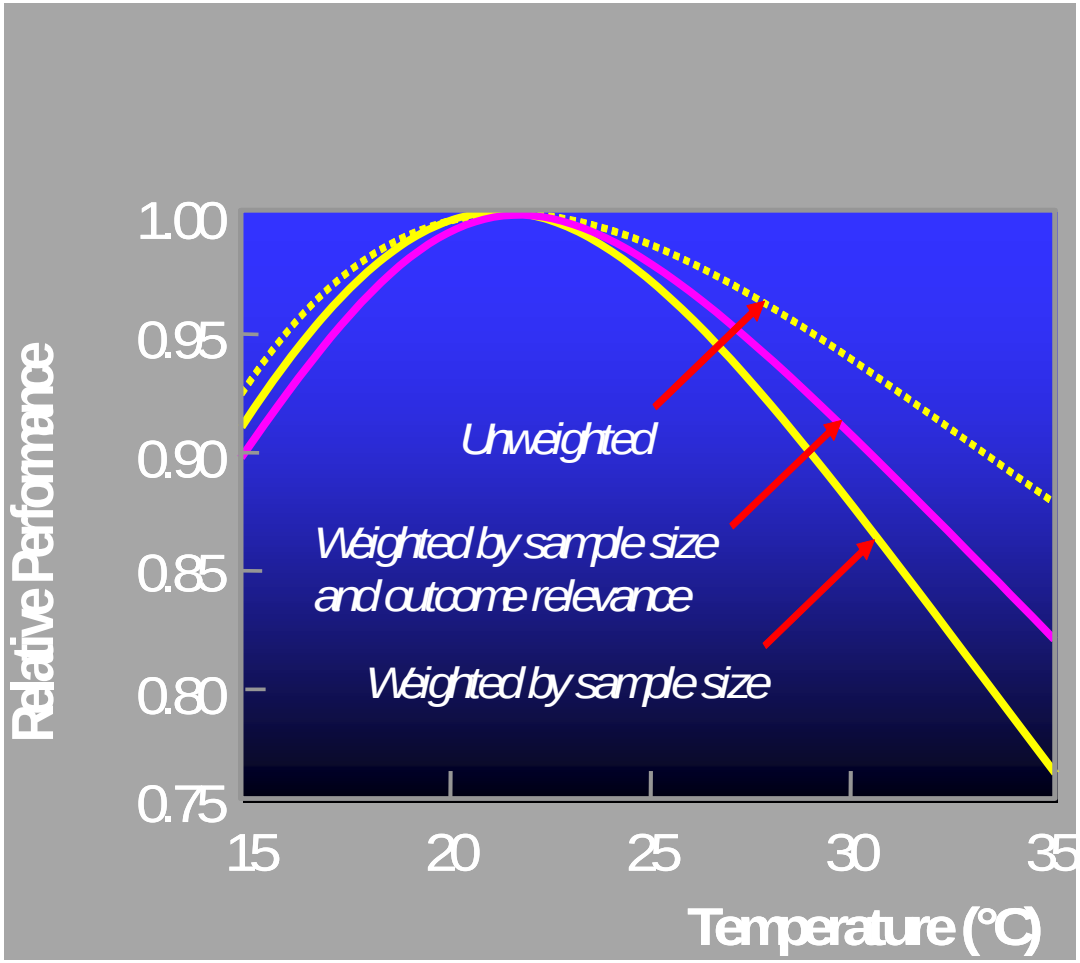


Kolokotroni et al. 2001

Data used in the analysis

Extra operation time of fans 10 h/night

- **Power use 2.5 kW per m^3/s**
- **Cost of electricity 0.5 – 0.20 c/kWh**
- **Value of the work 25 €/h**
- **Effect of temperature on performance at office work**



Effect on temperatures and lost work time

	8-9	9-10	10-11	11-12	13-14	14-15	15-16	16-17	8-17
t out	19	21.5	24.5	26.5	26.8	27.0	27.1	27.3	
				Without night-time cooling					
t op	27.1	27.2	27.6	27.8	27.8	27.9	27.9	27.9	
lost min	2.5	2.9	2.9	3.0	3.0	3.1	3.1	3.1	23.4
				With night-time cooling					
t op	23.5	23.6	24	24.5	25.9	26.1	26.1	26	
lostmin	.2	.3	.4	.6	1.1	1.2	1.2	1.2	6.2
				Less lost work time, min per day					17.2

Cost effectiveness of night- time ventilative cooling

(4 ach, 8 h/night, 2.5 kW/m^3s^{-1}

Cost of electricity	Use of electricity during night (8 h)	Additional cost of electricity	Increase in productivity, € 23.4-6.2 =17.2 min/d, 25 €/h	Benefit to cost ratio
c/kWh	kWh/d	$/d		
5	1.84	0.09	7.15	79
10	1.84	0.18	7.15	40
15	1.84	0.28	7.15	26
20	1.84	0.37	7.15	19

(REHVA Guidebook no 6, 2006)

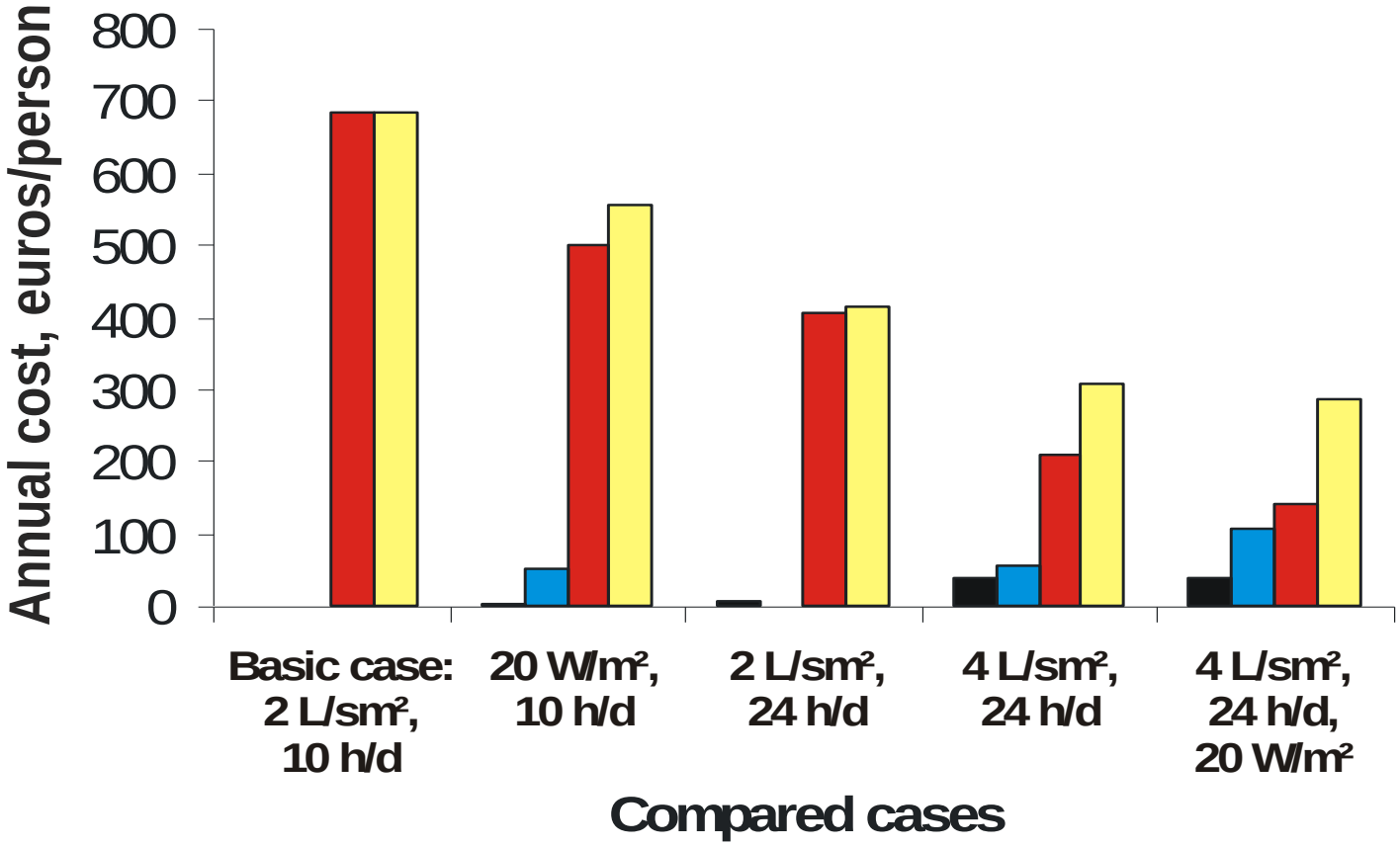
Example 2

Cost effectiveness of air conditioning, extended operation time of ventilation, and increased supplu air flow rate

Simulated case study

- **Building description**
  - concrete construction
  - private office of 15 m^2
  - 2 m^2 window facing south
  - venetian blinds between the glazing
- **Basic case**
  - ventilation 2 L/sm^2
  - no air conditioning
  - operation 10 h per day
- **Improved cases compared with IDA/ICE simulation program**
  - central cooling 20 W/m^2
  - operation time 24 h per day
  - supply air flow rate 4 L/sm^2

Costs and benefits of air conditioning and extended operation time



Example 3

Economizer System Evaluation = use more outdoor air and less return air when feasible

Economizer Systems

Modulate Outdoor Air (OA) Supply

Purpose

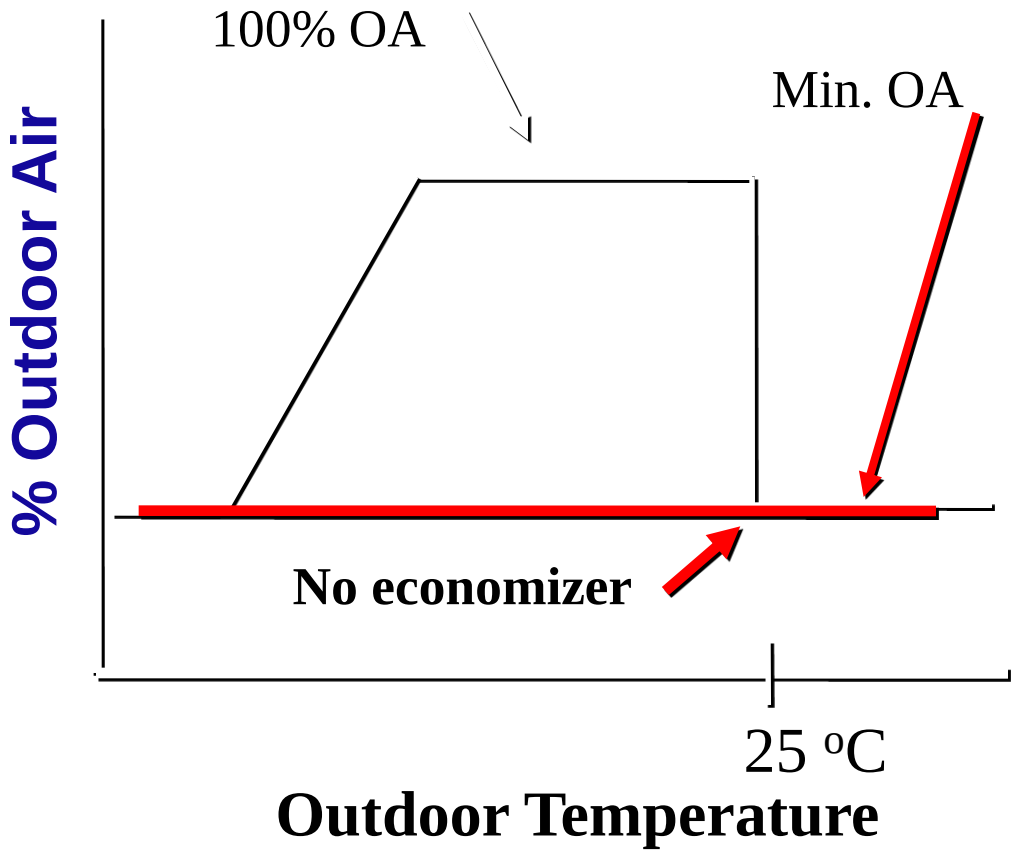
- reduce HVAC energy
- maintain minimum vent. rate

Method

- use outdoor air for cooling when less expensive than mechanical cooling

Usage in the USA

- common in large HVAC
- considered too expensive for small HVAC



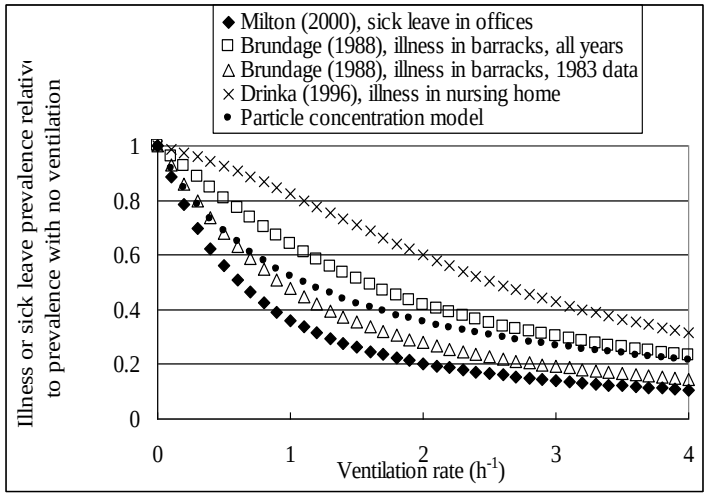
Approach – simulation of a case building

Energy & Ventilation Rate Modeling

- **2000 m² office building in Washington, DC, VAV HVAC, with and w/o economizer**
  - Used DOE 2 energy simulation model
  - Hourly ventilation rates for year
  - Energy use for year

Economic analyses

- **energy cost savings from DOE-2 model**
- **apply absence - vent. rate model**
- **value of absence based on salary & benefits**



Results

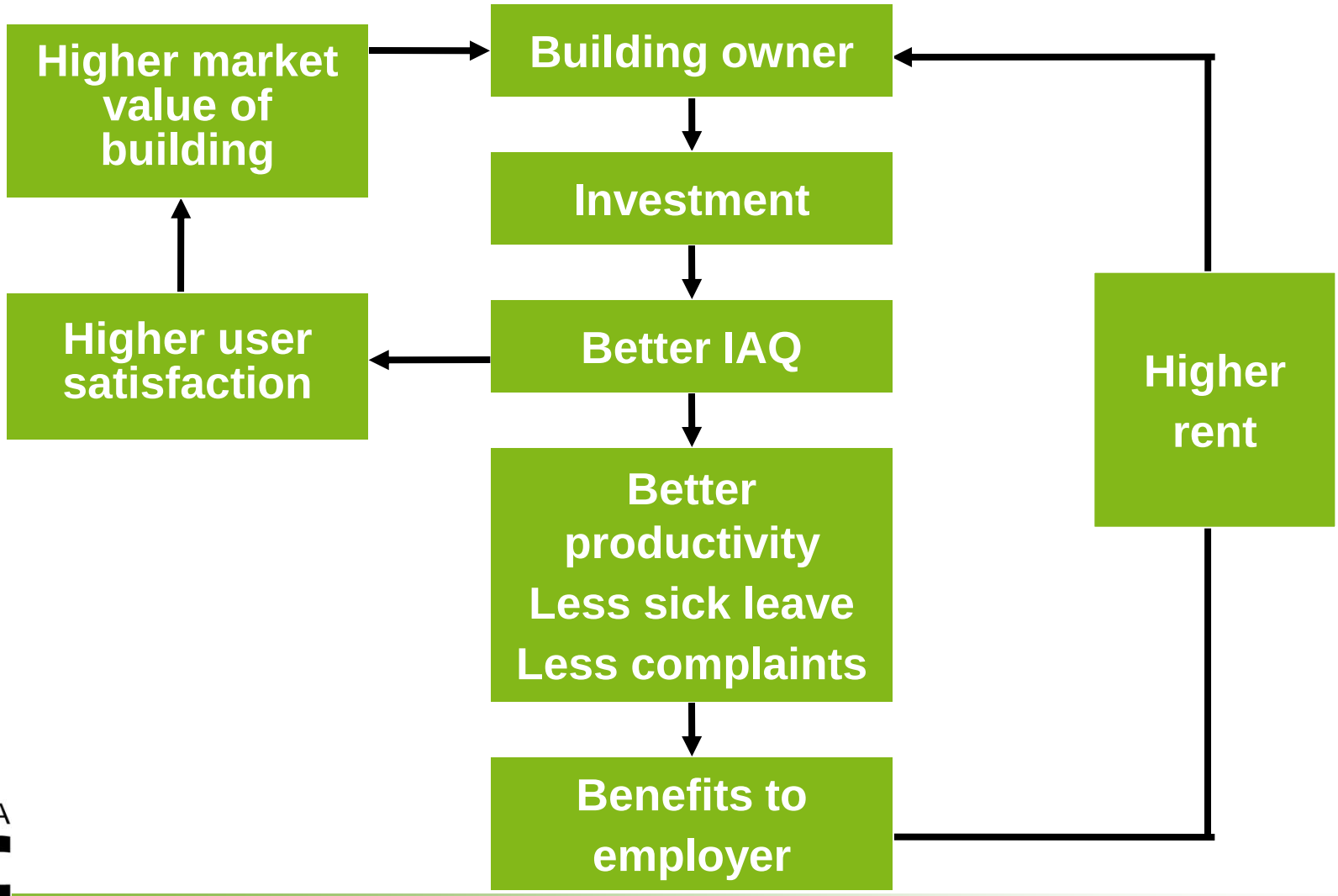
Estimated Annual Benefits of Economizer

Number of Buildings	Savings for Europe		
	Energy Cost Savings	Sickness Savings	
Assumption	per year	Days per year	per year
10	26	09-11	€18-€21
20	31	04-05	€8-€9

Estimated savings from reduced illness-related absence is 3 - 8 times energy cost savings

Economic benefits as driving force

Leased building



Conclusion

- **Value of productivity and health improvements should be included in the life cycle calculations**
- **These costs are significant, and in same oder of magnitude or higher than the energy cost of buildings**
- **Most IAQ improvements are very cost effective when producitivity and health benefits are included**
- **Qualitative data is not adequate between IAQ and human responses – more quantitative data is needed**

Thank you for your attention

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