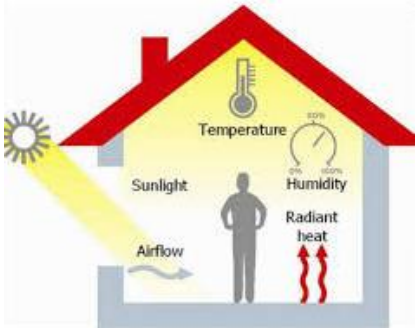
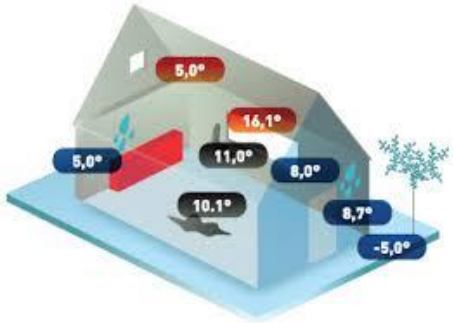
# CIVIL 212
# Indoor Climate
Fall 2024




# Introduction to the topic/field

12 September, 2024

Human-Oriented Built Environment Lab
Website: hobel.epfl.ch
Twitter: @licinadusan

**Asst. Prof. Dusan Licina, Ph.D.**
School of Architecture, Civil and Environmental Engineering
École polytechnique fédérale de Lausanne
dusan.licina@epfl.ch

# Today's objectives…

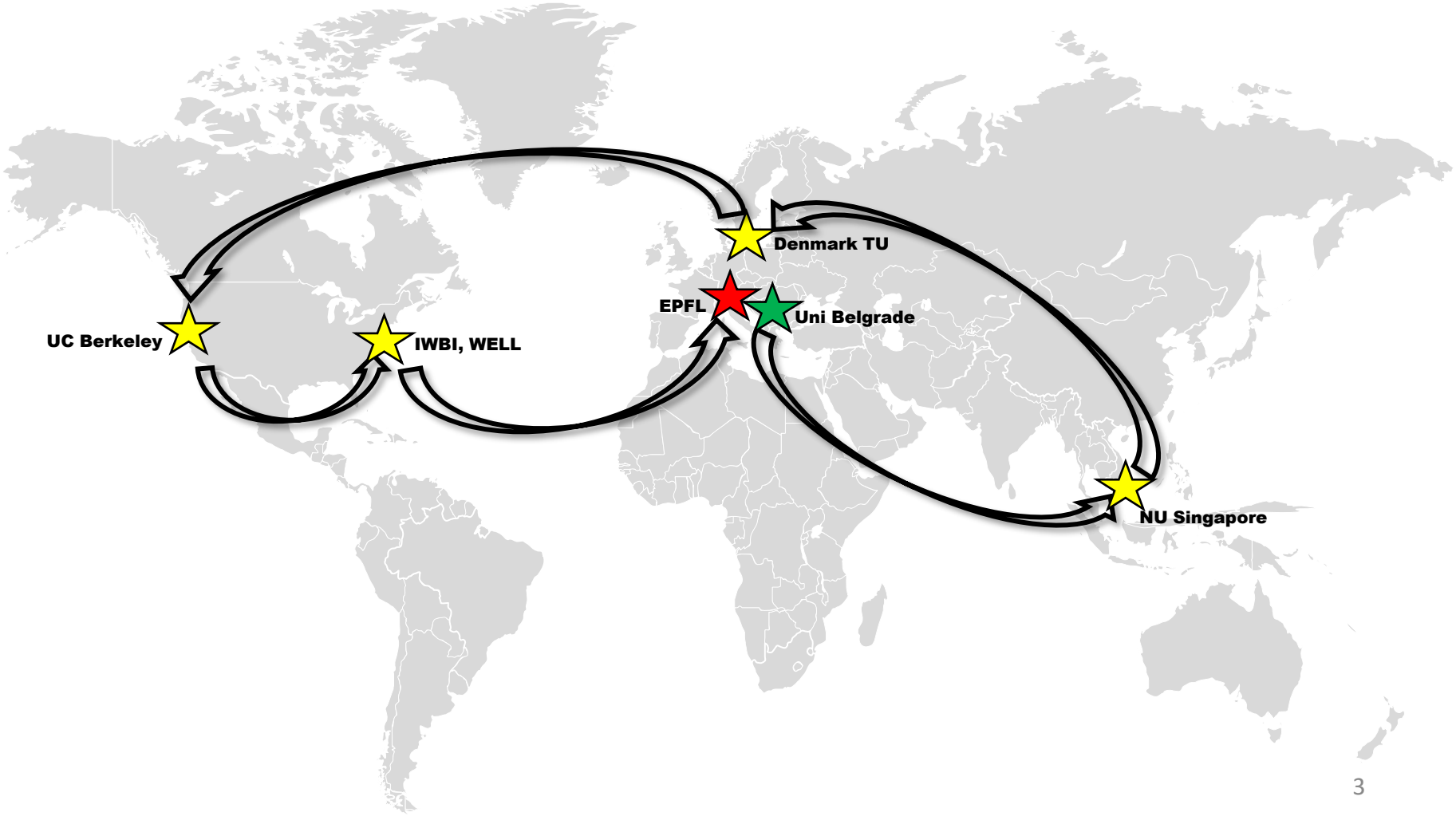
- Introduce myself & the lab
- Introduce the course
- Introduce yourselves
- Discuss the course syllabus
  - Course information, outline, schedule, ground rules
  - Why are we all here?

35 minutes

- Introduce the topic & indoor climate field
  - Why do we study indoor climate?

55 minutes

# My indoor climate trajectory…



# HOBEL – Research areas of interest

INDOOR AIR QUALITY

THERMAL COMFORT

ENERGY USE

HUMAN EXPOSURE

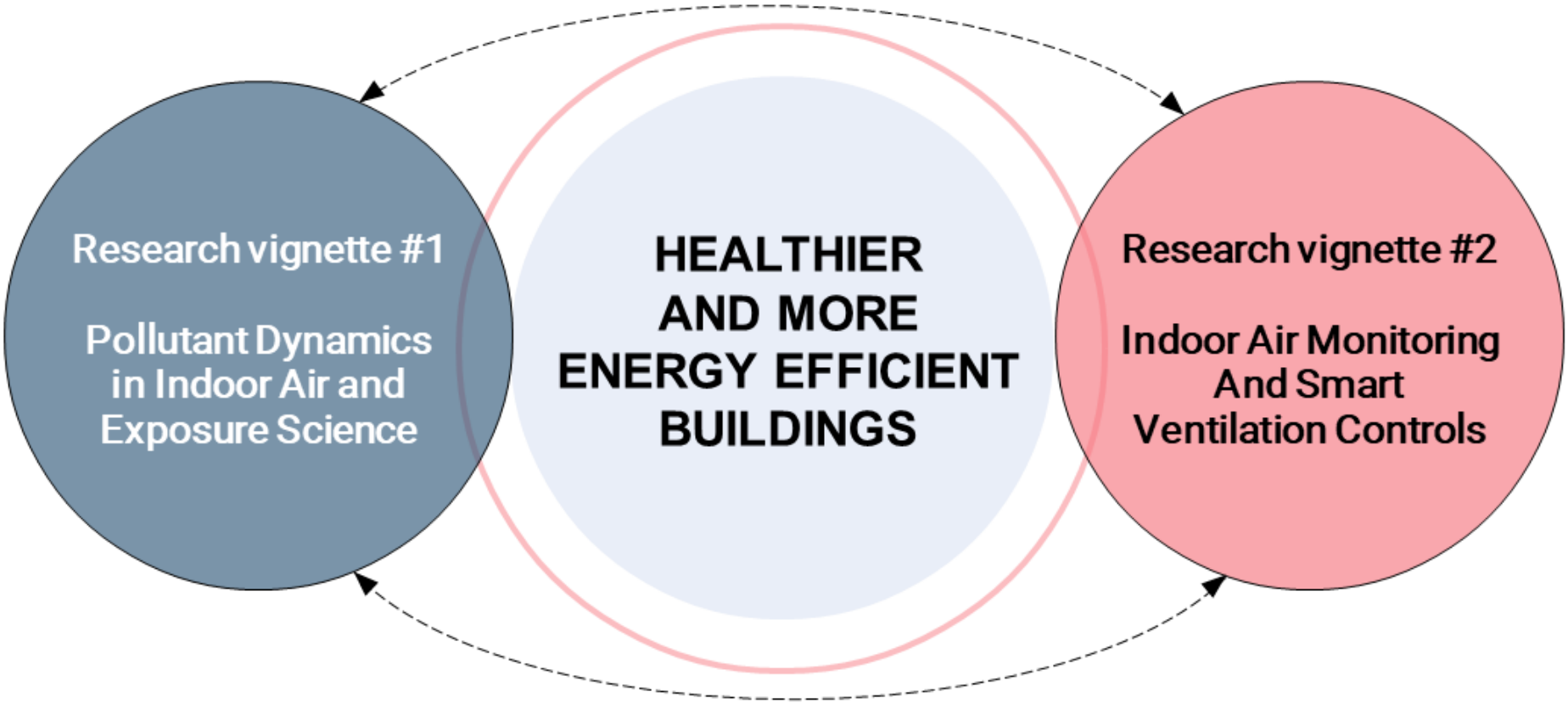
HUMAN BEHAVIOR

BUILDING VENTILATION

HOBEL

HUMAN-ORIENTED BUILT ENVIRONMENT LAB

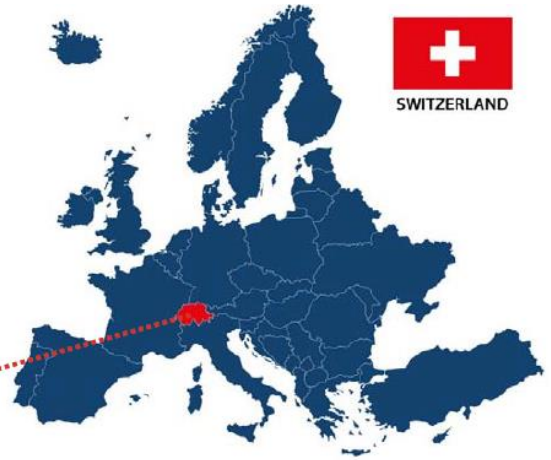
# HOBEL – Specific research areas



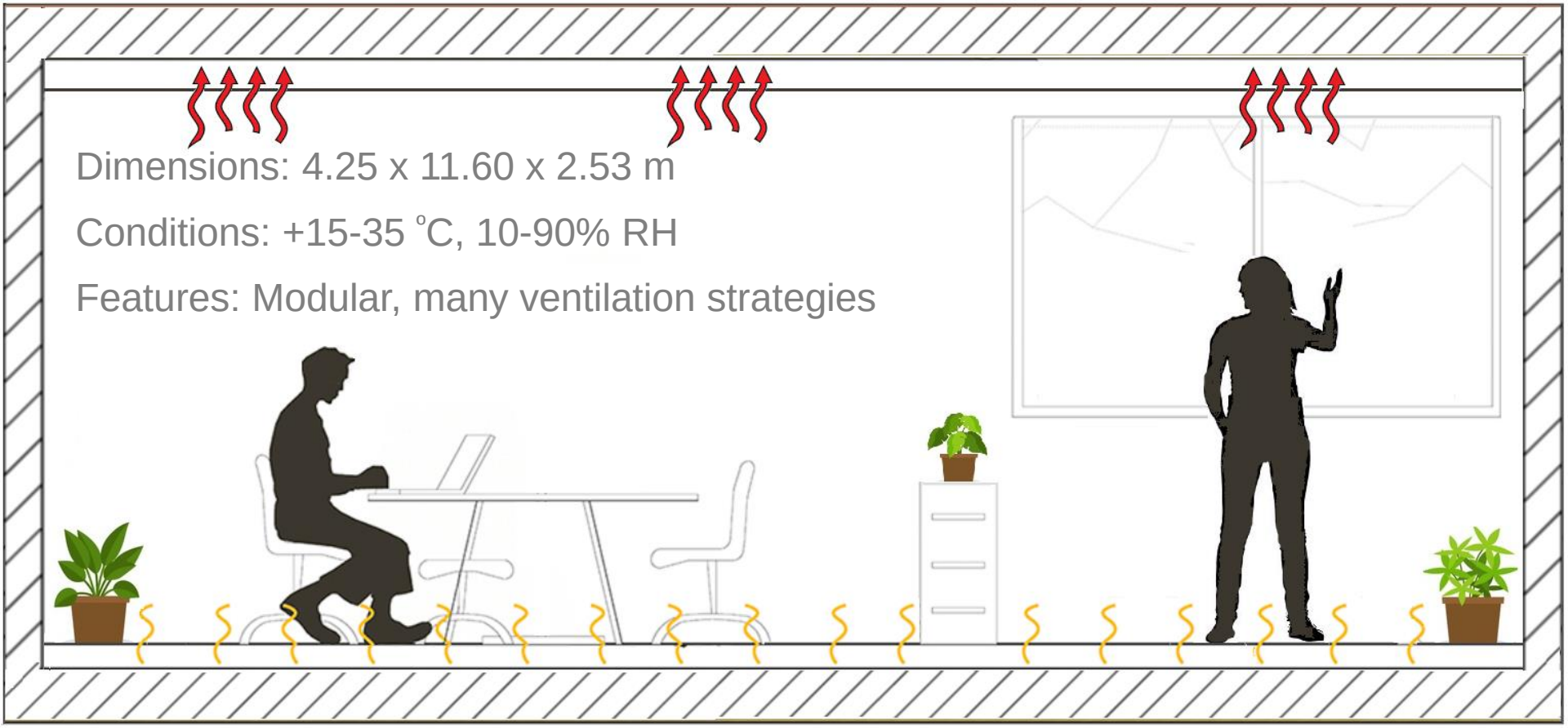
# HOBEL – Team

# HOBEL – Where are we?

Capital of the State of Fribourg




# Unique experimental facility…



# Course information

**Civil 212: Fundamentals of Indoor Climate**

## Classroom and Meeting Time

- Thursdays, 17h15 – 19h00 (sorry about it but the section had no other available time slots)
- Room: INJ218

## Office hours for consultations

- Thursdays, 16h00 to 17h00 (before the class)
- Office GC A1 354 or online (by appointment only - please email me to schedule an appointment)

## Prerequisites

- None, but good familiarity with building physics courses is beneficial.

# Course objectives (in my own words)

To understand important concepts of indoor environmental quality parameters which concern indoor climate: Thermal comfort and indoor air quality. By the end of the course, you are expected to be able to:

- Have a fundamental understanding of indoor climate theory and contemporary issues encountered in the building design and operation cycles.
- Talk about determinants and assessment methods for human thermal comfort and indoor air quality, and to understand their impact on humans.
- Assess thermal comfort and indoor air quality control mechanisms and determine their effectiveness.
- Read and critically analyze articles in the technical literature on thermal comfort, indoor air quality and HVAC.
- Prepare oral presentation for the class.

# Course resources

Purchasing textbook(s) is **not compulsory** for this course

- I will rely on a mixture of notes from various textbooks, technical papers and publications

The reference textbooks from which I will draw information, for your consideration:

- C-A Roulet. Santé et qualité de l'environnement intérieur dans les bâtiments
- Allen, J., Macomber, J. (2020). Healthy Buildings: How Indoor Spaces Drive Performance and Productivity. Harvard University Press
- Parsons K. Human Thermal Comfort. CRC Press (2019)
- Spengler, J., McCarthy, J., and Samet, J. Indoor air quality handbook, McGraw-Hill Professional (2001).
- Awbi, H. B, Ventilation of buildings, E&FN SPON, (2003).
- Peer-reviewed papers and websites

Understanding the presentation slides uploaded to Moodle will be sufficient for achieving the learning outcomes and passing the exam

# Course schedule

| Week | Date | Topics covered | Notes |
|---|---|---|---|
| 1 | 12/09 | Introduction to topic/field:<br>• Course introduction<br>• Why do we care about indoor climate? | |
| 2 | 19/09 | Brush up lecture:<br>• Heat transfer in buildings<br>• Psychometrics: Definitions and charts<br>**Course assignment overview*** | |
| 3 | 26/09 | Human thermal comfort:<br>• Thermal comfort fundamentals<br>• Human body heat balance<br>• Factors affecting thermal comfort<br>• Local thermal discomfort<br>• Quiz time | |
| 4 | 03/10 | Human thermal comfort assessment:<br>• Actual thermal comfort<br>• Models (PMV + Adaptive)<br>• Standards requirements<br>• Exercise<br>• Quiz time | Course assignment topic selection due |
| 5 | 10/10 | Introduction to HVAC & psychrometric processes<br>• Psychrometric processes in HVAC systems<br>• Examples and exercises<br>Project work and consultations (optional, 10 min) | |
| 6 | 17/10 | Written mid-term exam based on theory<br>(Material from the weeks 1-5) | Venue: PO 01 |
| 7 | 24/10 | Fall break (no course) | |

| Week | Date | Topics covered | Notes |
|---|---|---|---|
| 8 | 31/10 | Review of the mid-term exam (10 min)<br>Indoor air quality<br>• Fundamental principles<br>• Sources of indoor air pollution<br>  • Gaseous pollutants<br>  • Particulate matter<br>Quiz time | |
| 9 | 07/11 | Indoor air quality<br>• Air quality assessment in buildings<br>• Quiz time<br>Project work and consultations | |
| 10 | 14/10 | Introduction to Ventilation:<br>• IAQ control overview and definitions<br>• Driving forces of ventilation<br>• Air exchange rates<br>• Ventilation requirements<br>  • Prescriptive method<br>Analytical method | |
| 11 | 21/11 | IAQ controls:<br>• Room air distribution<br>• Ventilation strategies<br>  • Mechanical ventilation<br>  • Natural ventilation<br>• Filtration & air cleaning<br>Remaining schedule overview and course summary | |
| 12 | 28/11 | **Project work and consultations** | |
| 13 | 05/12 | Written exam based on theory<br>(Material from the weeks 8-11 only) | Venue: PO 01 |
| 14 | 12/12 | Course project presentations in class | Final presentations |
| 15 | 19/12 | Course project presentations in class | Final presentations |
| | 20/12 | Course project final submission of presentations | by 23:59h |

# About you…

- Who are you?
  - Are you already familiar with the indoor climate subject?

- Any relevant work and/or research experiences?

# Course deliverables

**Grading:**

- Exam(s)
  - One midterm exam (1st half of the course)
  - Second exam (2nd half of the course)

- Course Project
  - Oral presentation on a selected topic
  - Details summarized in the course syllabus (Moodle)

# Course grading

| | |
|---|---|
| • 2 Exams | 60 pts |
| • Course project | 40 pts |
| • Total | 100 pts |

**Grading scale:**

| | |
|---|---|
| • 5.50 - 6.00 | ≥ 90% |
| • 5.00 - 5.49 | 80-89.9% |
| • 4.50 - 4.99 | 70-79.9% |
| • 4.00 - 4.49 | 60-69.9% |
| • 0.00 - 3.99 | < 59.9% |

# A note on course project

- Ultimately, your course project will be to prepare one topic related to the course content
  - The purpose is to become deeply familiar with one topic and to share it with you peers
  - That will be done in groups

- There will be an important deliverable:
  - oral presentation through PPT slides that will be accompanied by feedback session by peers and the teacher, where the students will discuss the topics and lessons learnt

- More information in the course syllabus and throughout the semester

# Other relevant details…

- I will post lecture notes and updated syllabus on Moodle
  - I will do so usually 1-3 days before class
  - Note that pre-lecture notes aren't 100% the same as post-lecture notes (I hide some slides or information during the lecture for the discussion purpose)
- I will generally communicate with the class via email
  - Don't let me go into your spam folder
  - Do you have a different email address that you prefer?
    - If so, email me at dusan.licina@epfl.ch
- During the semester, please make sure to:
  - ask when you have a question or when you want to share a comment / experience
  - participate in discussions whenever given an opportunity
  - participate in all pooling sessions and quizzes

# Any questions so far?

# What do you think when you hear “climate”?

# What do I think when I hear “climate”

# In-class exercise

Try to make a rough diary about the time that you spend in different indoor and outdoor environments during the last 7 days. Then, share your findings within a class…

*Follow this guide:*

- *Separate % of time between indoor and outdoor*
- *Separate % of time spent indoors: between residential, transport, and work environments (campus buildings in your case)*

# The climate we're exposed to: It's indoors!


**The Corsi code:**

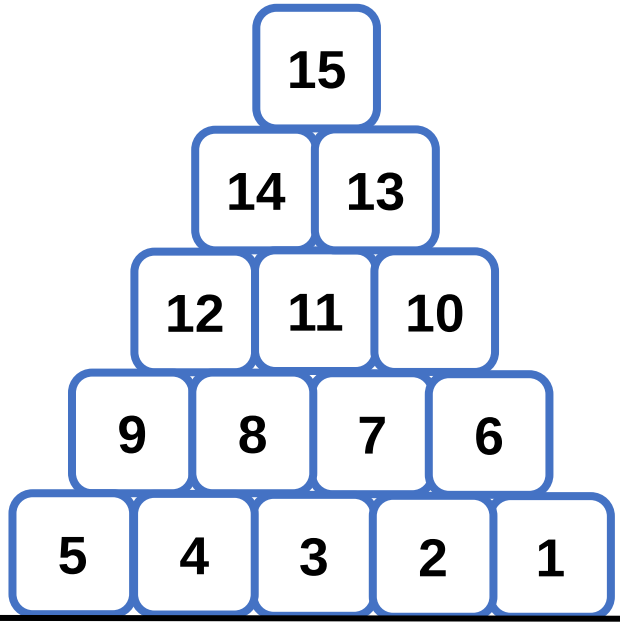
| | |
|---|---|
| **79** | **Average life expectancy** |
| **70** | **Indoors** |
| **50** | **At home** |
| **26** | **In bed** |
| **5** | **In transit** |
| **4** | **Outside** |

*Prof. Richard Corsi, UT Austin, USA*

- We spend most of our time **indoors.**
  - -Around 90% of the time, on average

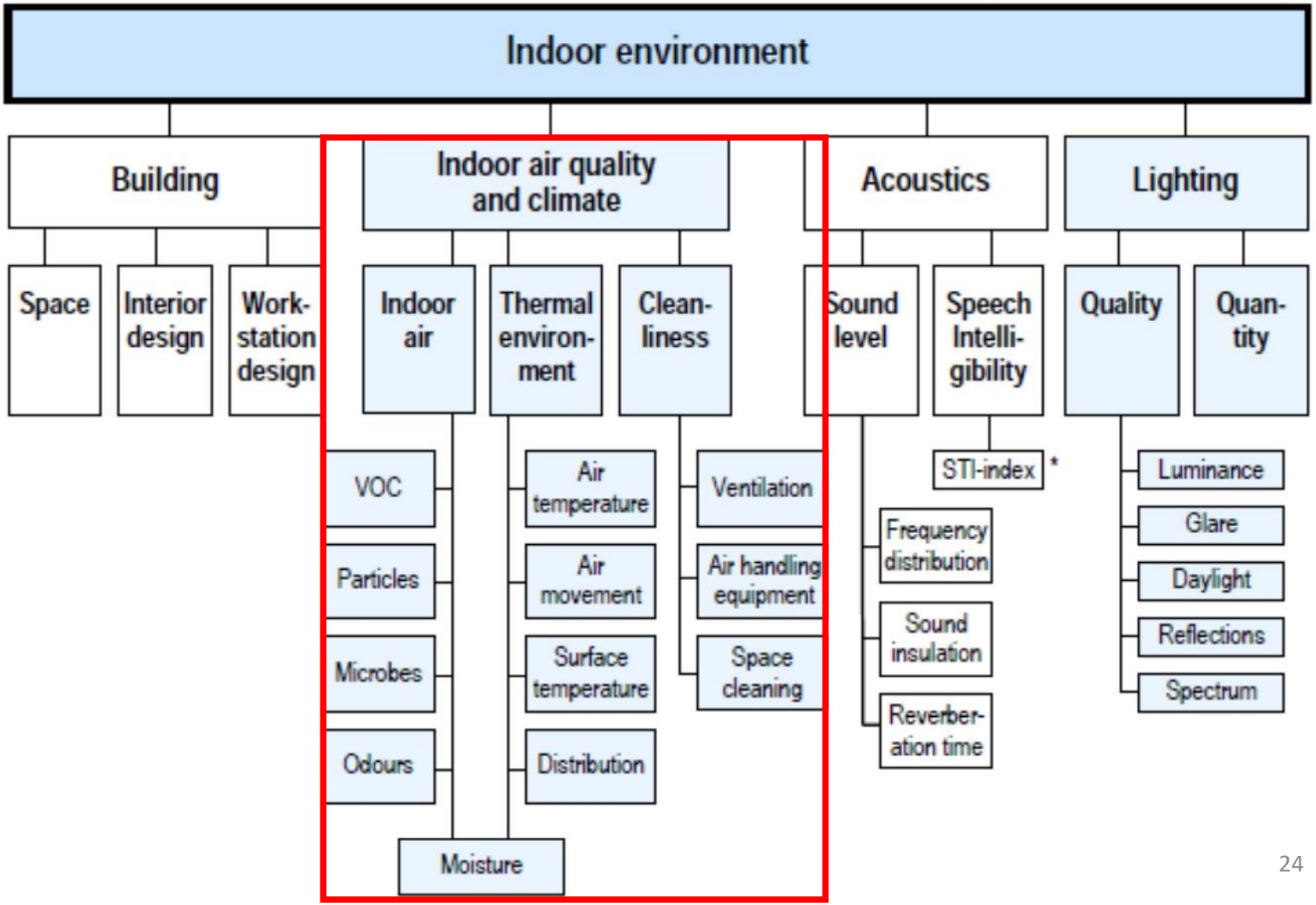
*(Source: Klepeis et al., 2001 J Exp Anal Environ Epidem)*

# Any questions so far?


See you in 15 mins…

# Indoor environment and human comfort



# Indoor environmental quality (IEQ)

- IEQ includes:
  - Indoor air quality
  - Thermal comfort
  - Acoustical quality
  - Lighting quality


# IEQ, Stress mechanisms, and Human Health

**ACOUSTIC QUALITY**

**AIR QUALITY**

**LIGHTING QUALITY**

**THERMAL QUALITY**

**STRESS MECHANISMS**

- Anti-stress
- Circadian rhythm
- Endocrine disruption
- Oxidative stress
- Inflammation, irritation
- Ceil changes/death

**DISEASE / DISORDER**

- Depression
- Obesity
- Diabetes
- Chronic resp. diseases
- Cardiovascular diseases
- Cancers

# Indoor climate and the role of buildings

- Any building has primarily a protective role to occupants
- Occupied buildings should meet indoor climate requirements
- Indoor climate depends on various aspects which should be considered as a whole
- What happens if we don’t know building physics and indoor climate?

# What happens when you don’t understand indoor climate?

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# What happens when you don’t understand indoor climate?

*(Source: https://wet2drysolution.com/)*

# What happens when you don’t understand indoor climate?

ESPN NFL NBA MLB Soccer MMA NCAAF •••

NBA Home Scores Schedule Standings Stats Teams Draft Playoff Basketball Battle

## Warm weather causes water on floor

Chris Forsberg
ESPN Staff Writer

Jan 26, 2010

BOSTON -- Monday's game took Boston Celtics coach Doc Rivers back to his playing days for all the wrong reasons.

Unseasonably warm temperatures caused condensation to form on the floor of the TD Garden during Boston's 95-89 win over the Los Angeles Clippers Monday, leading to a brief delay as workers mopped the court to keep it dry late in the first quarter.

Source: (https://www.espn.com/nba/news/story?id=4858097)

# What happens when you don’t understand indoor climate?

When you don’t understand indoor climate (or more broadly building science), and you are in charge of engineering, design, construction, or maintenance of a building...

… you negatively influence building energy use, energy costs, greenhouse gas and other pollutant emissions, thermal comfort, indoor air quality, productivity and health

# Indoor climate implications

- Health and well-being
- Cognitive performance
- Energy and ecological impacts
- Cost

IBN: Institute for Forestry in the Netherlands. *behnisch architekten* .

# Influence of indoor climate: Health and well-being

## Comfort and health

- Headaches
- Eye strain/damage
- Dry throat and runny nose
- Skin irritation
- Infections
- Fatigue
- Seasonal Affective Disorder
- Asthma & breathing disorders
- Stress & depression
- Other serious disorders, including cardio-vascular, etc.

## Organizational outcomes

- Productivity loss
- Absenteeism
- Presenteeism (working while sick)
- Staff turnover/retention
- Revenue
- Medical costs
- Medical complaints
- Physical complaints
- Task efficiency & deadlines met, etc.

# Air quality and health: Global Burden of Disease

## Leading global health risk factors (2016)

*(Source: GBD 2016 Risk Factors Collaborators, Lancet 390: 1345-1422, 2017)*

| Males | Females |
|---|---|
| 1. Smoking | 1. High blood pressure |
| 2. High blood pressure | 2. High body-mass index |
| 3. Low birthweight & short gestation | 3. High fasting plasma glucose |
| 7. Ambient particulate matter | 6. Ambient particulate matter |
| 10. Household air pollution | 8. Household air pollution |
| 16. Unsafe water | 13. Unsafe water |
| 21. Unsafe sanitation | 16. Unsafe sanitation |
| 23. No access to handwashing | 20. No access to handwashing |
| 30. Second-hand smoke | 21. Second-hand smoke |

# Residential air quality and health

- Residential indoor air pollution is estimated to result in **5-14%** of the annual non-communicable, non-psychiatric **disease burden** in the U.S.
  - Excludes SHS and radon *(Source: Logue et al., Environ. Health Perspect. 2012, 120, 216-222)*

- Cumulative lifetime **cancer risks** of **1-10** excess cases **per 10'000** people

*(Sources: Wallace et al., Environ. Health Perspect. 1991, 95, 7-13; Sax et al., Environ. Health Perspect. 2006, 114, 1558-1566; Hun et al., Environ. Health Perspect. 2009, 117, 1925-1931)*

Household air pollution – 3rd most important cause of ill health for the world's population

*(Source: Lim et al. 2012, Lancet)*

Biomass fuels in households are responsible annually for ~0.7 to 2.1 million premature deaths in low-income countries, from a mix of lower-respiratory infections, chronic obstructive pulmonary disease, and lung cancer.

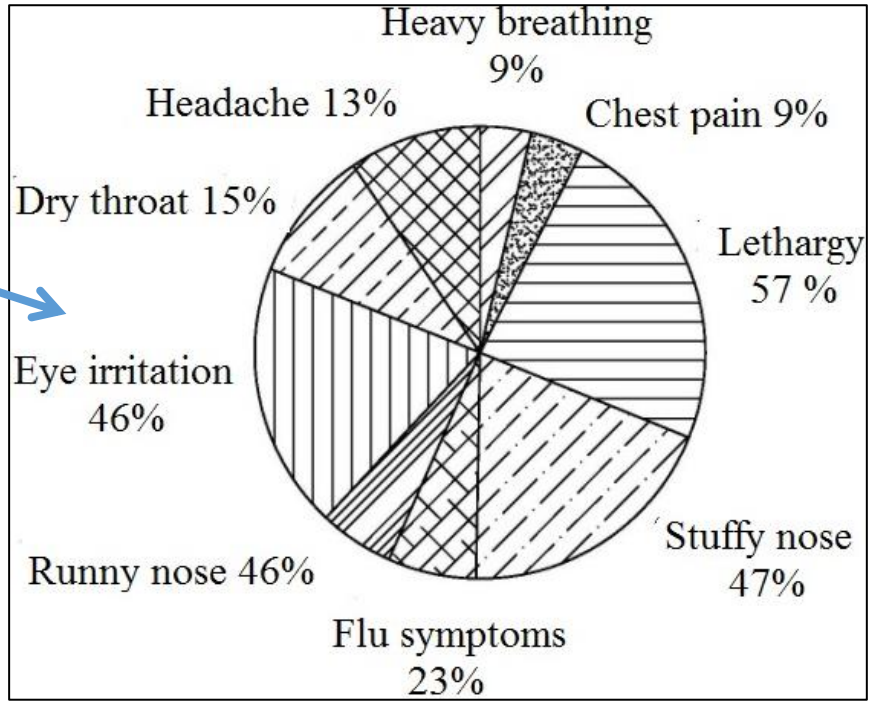
# Sick building Symptoms and Building-Related Illnesses

Sick Building Syndrome (SBS) symptoms

Building-Related Illnesses

Exposure to indoor air climate

- SBS symptoms - Building occupants experience acute health and comfort effects that are linked to the time spent indoors
- BRI - Health problems accompanied by physical signs that persist




*(Source: US EPA, 1991)*

# Influence of indoor climate: Performance

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv


10 Questions

## Ten questions concerning thermal and indoor air quality effects on the performance of office work and schoolwork

Pawel Wargocki*, David P. Wyon

*DTU-ICIEE, Technical University of Denmark, Denmark*

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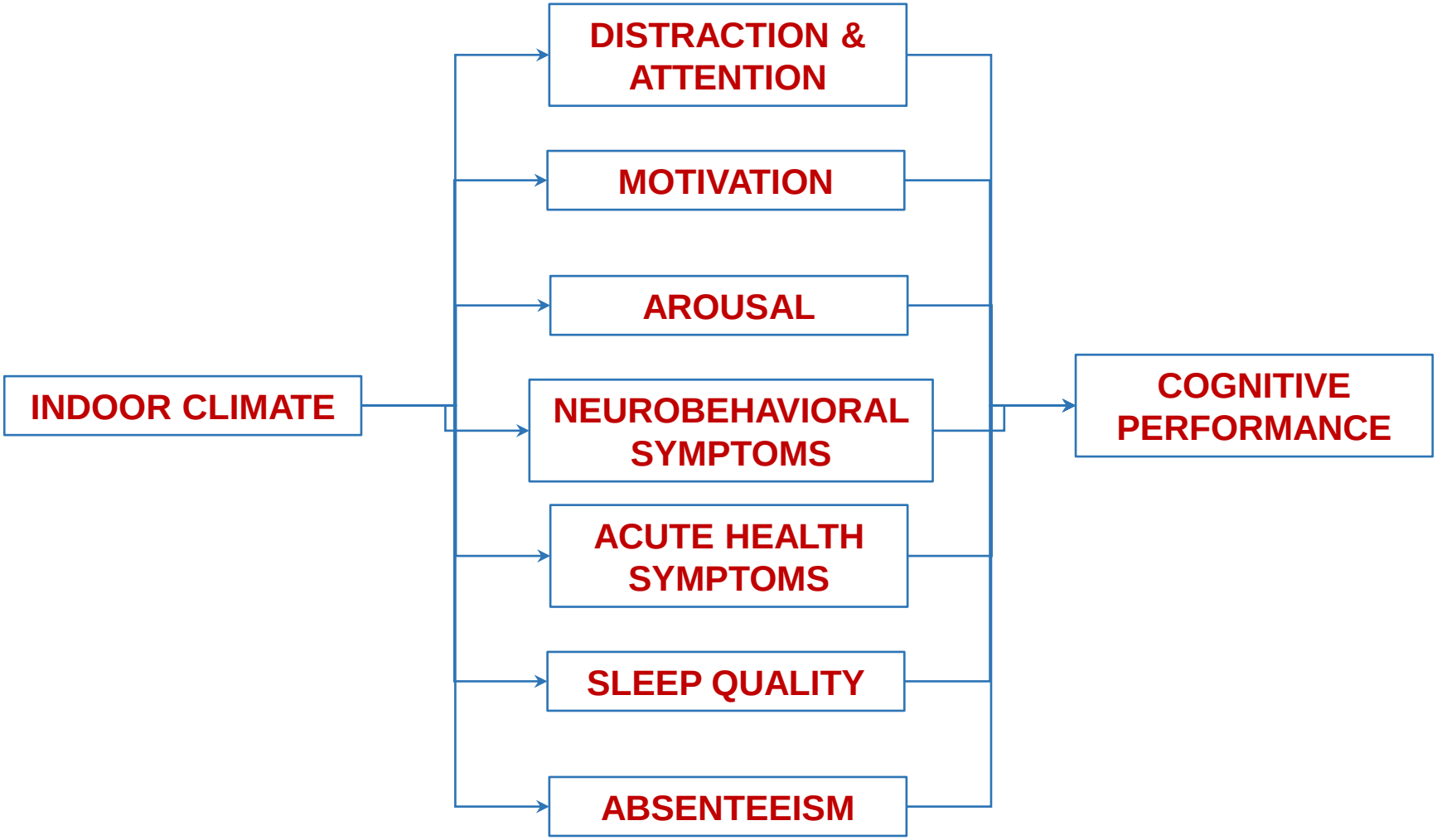
ABSTRACT

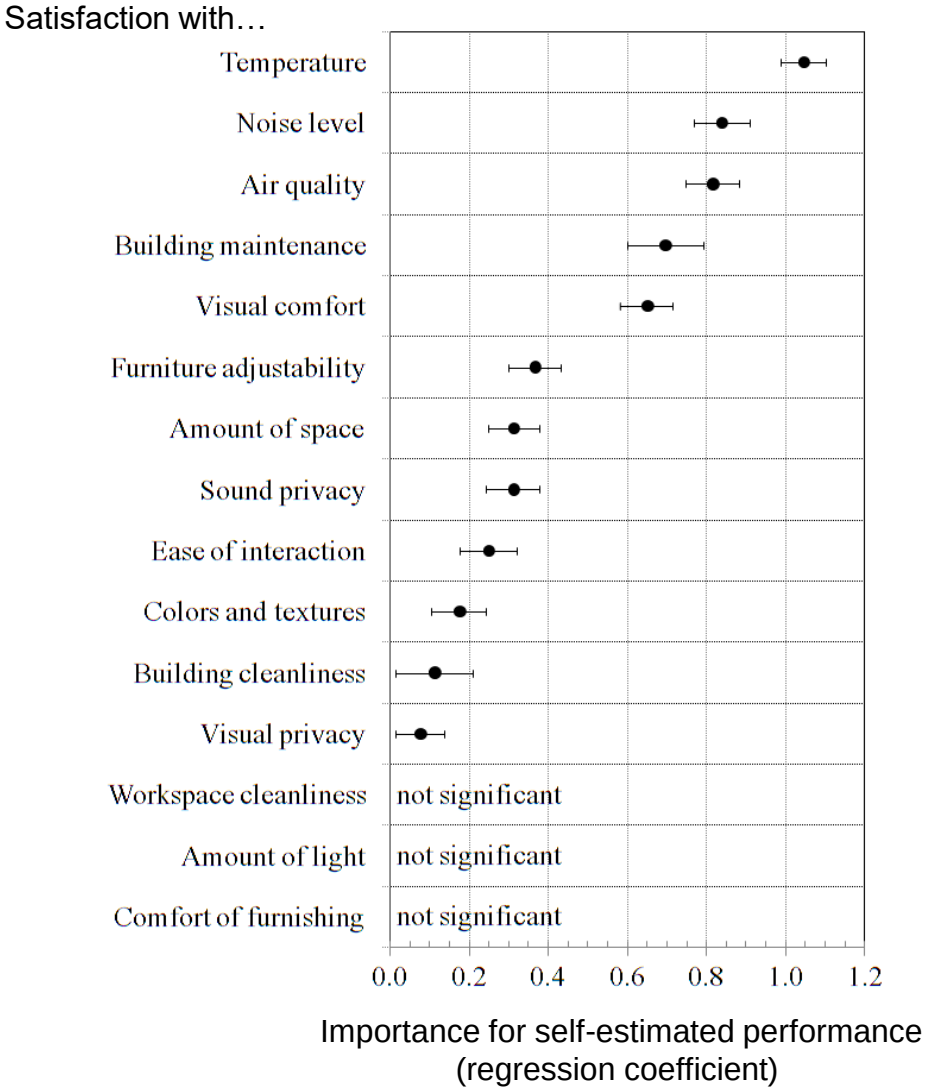
Energy conservation in buildings as a way to reduce the emission of greenhouse gases is forcing an urgent re-examination of how closely thermal and air quality conditions should be controlled in buildings. Allowing conditions to drift outside the optimum range would conserve very large amounts of energy and would in most cases have only marginal effects on health or subjective comfort. The question that then arises is whether occupant performance would be negatively affected and if so, by how much. This information is required for cost-benefit analyses. The answers in this paper are based on laboratory and field experiments that have been carried out since the massive increase in energy costs that took place in the 1970s. Although only a few of the mechanisms by which indoor environmental effects occur have been identified, it is already clear that any economies achieved by energy conservation will be greatly exceeded by the costs incurred due to decreased performance. Reducing emissions by allowing indoor environmental conditions to deteriorate would thus be so expensive that it would justify greatly increased investment in more efficient use of energy in buildings in which conditions are not allowed to deteriorate. Labour costs in buildings exceed energy costs by two orders of magnitude, and as even the thermal and air quality conditions that the majority of building occupants currently accept can be shown to reduce performance by 5–10% for adults and by 15–30% for children, we cannot afford to allow them to deteriorate still further.

# Influence of indoor climate: Performance




*(Source: Wargocki and Wyon (2017))*

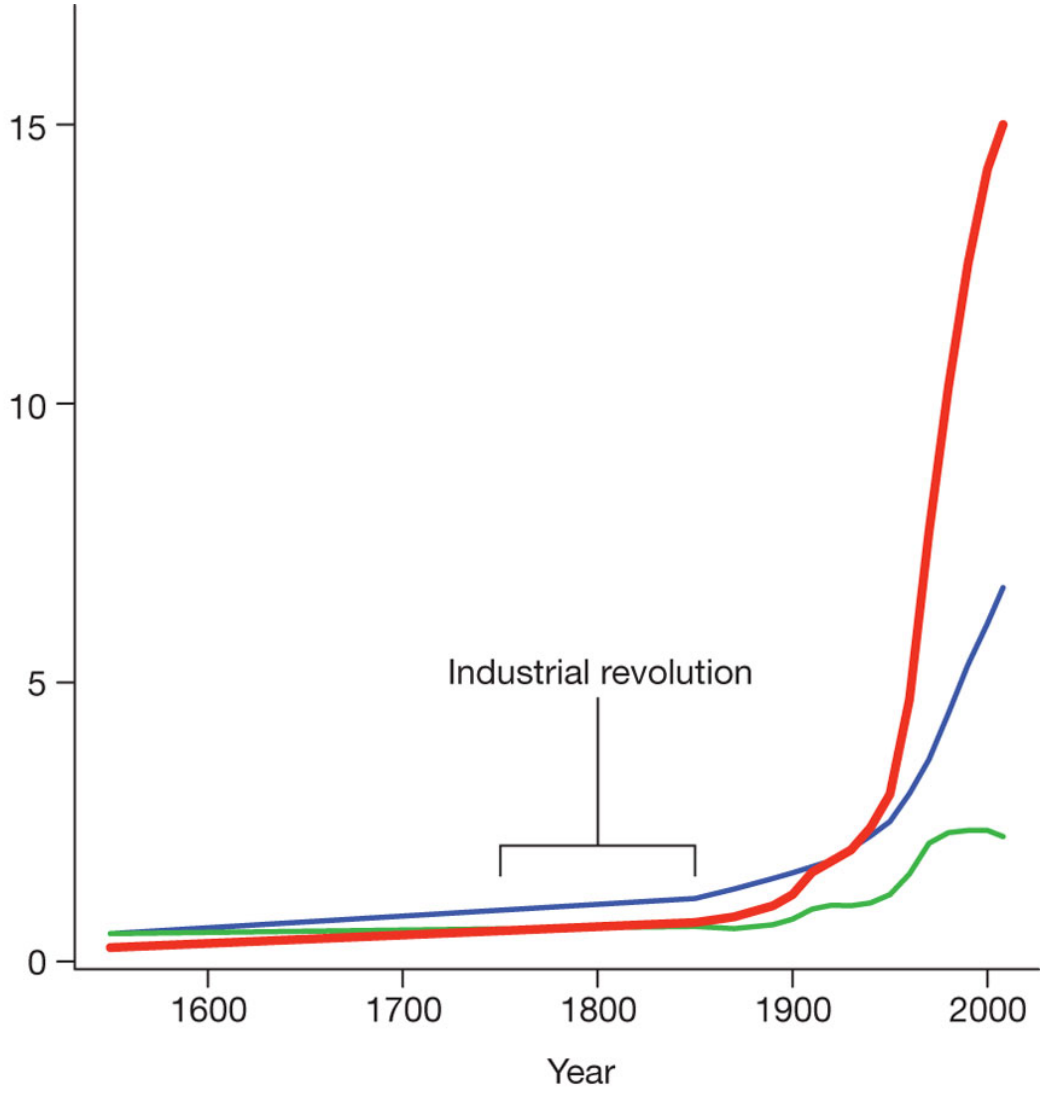
# Influence of indoor climate: Performance




- Satisfaction with temperature, noise level and air quality = satisfaction with IEQ
- For example, ~15% increase in satisfaction with temperature would increase self-estimated job performance by ~1%
- Question to think about – how important is 1%?

*(Source: Wargocki et al. 2012)*

# Energy use – how much indoor climate matters?



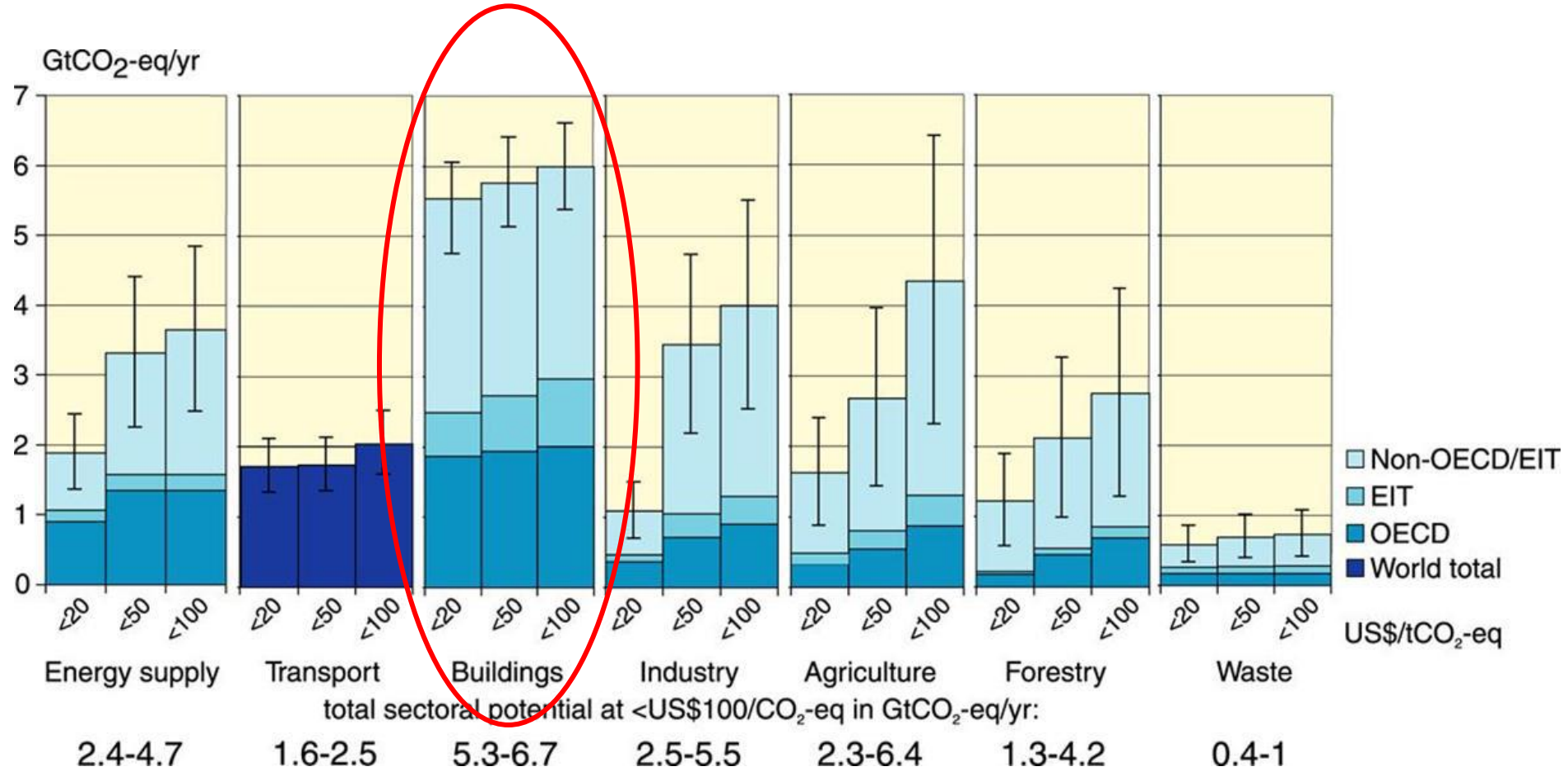

Total energy consumption (TW)

Population (billions)

Energy per capita (kW)

*(Source: Ehrlich et al. 2012, Nature)*

# Where should we focus our efforts?

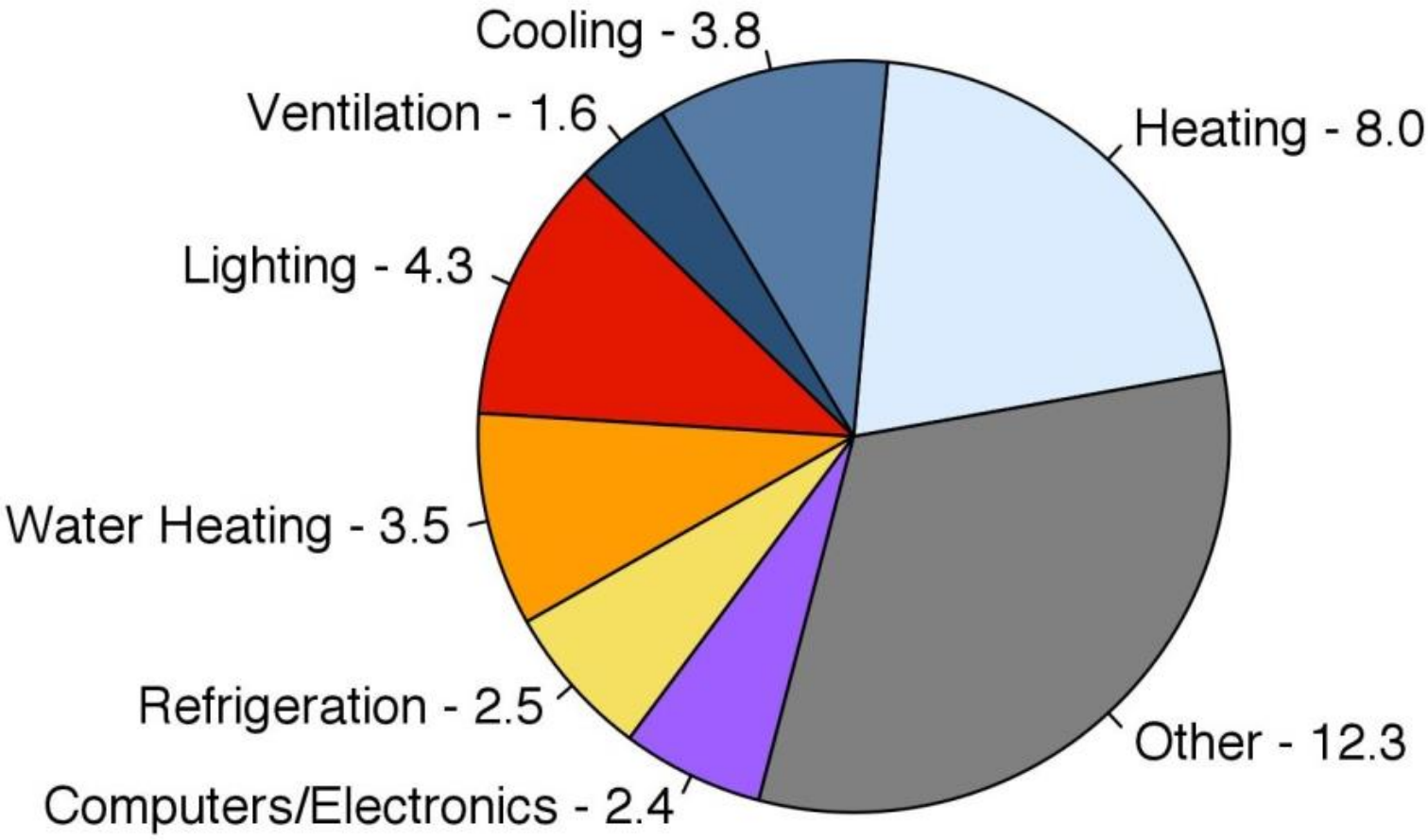





*(Source: Climate Change 2007: Mitigation of Climate Change. Summary for Policymakers)*

# Influence of indoor climate: Energy

2014 Residential and commercial building primary energy use (%)

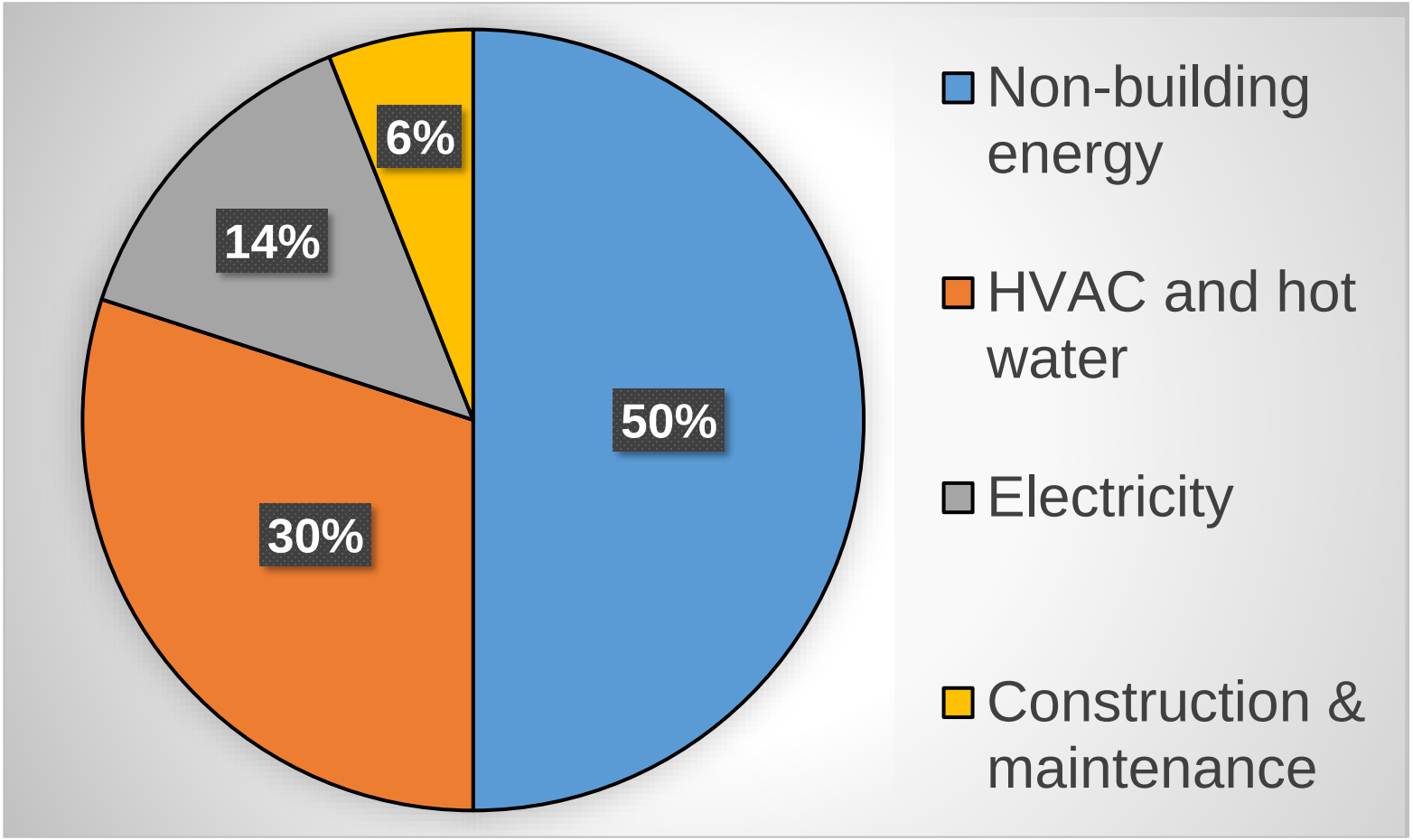





*(Sources: 2013, 2014 EIA Annual Energy Outlook; 2010 Manufacturing Energy Consumption Survey)*

# Influence of indoor climate: Energy

Energy consumption in Switzerland




*(Source: Swiss Federal Office of Energy)*

# Where do we stand with energy in Switzerland?



- The energy policy of Switzerland aims at reducing the emissions of $CO_2$ by 20% by 2020 and by 70-85% on the horizon 2050 compared to emissions in 1990
  - Read about Energy Strategy 2050 here:

    https://www.bfe.admin.ch/bfe/en/home/policy/energy-strategy-2050.html#tab__content_bfe_en_home_politik_energiestrategie-2050_jcr_content_par_tabs
- The energy efficiency and the use of renewable energies are both strategic options that are being implemented in general especially for the housing stock

# How to save energy?

(Image source: Pyongyang at night: AP Photo/Damir Sagolj, Reuters)

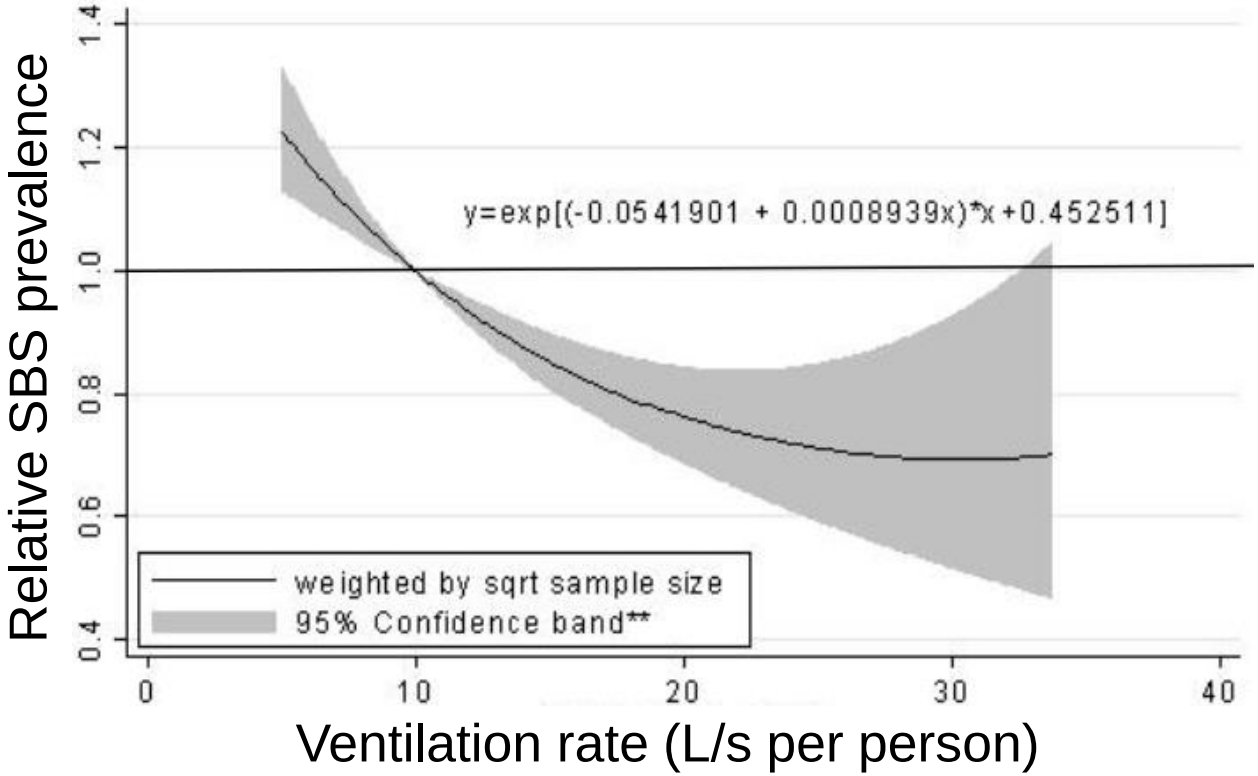
# Energy conservation could decrease IAQ

- Low ventilation rates cause an increased risk of allergies, SBS symptoms, and respiratory infections

*(Source: Sundell at al. 2011)*

- Low ventilation rates in dwellings increased the risk of allergic symptoms among children *(Source: Bornehag et al. 2005)*

*(Source: Fisk et al 2009 Indoor Air)*



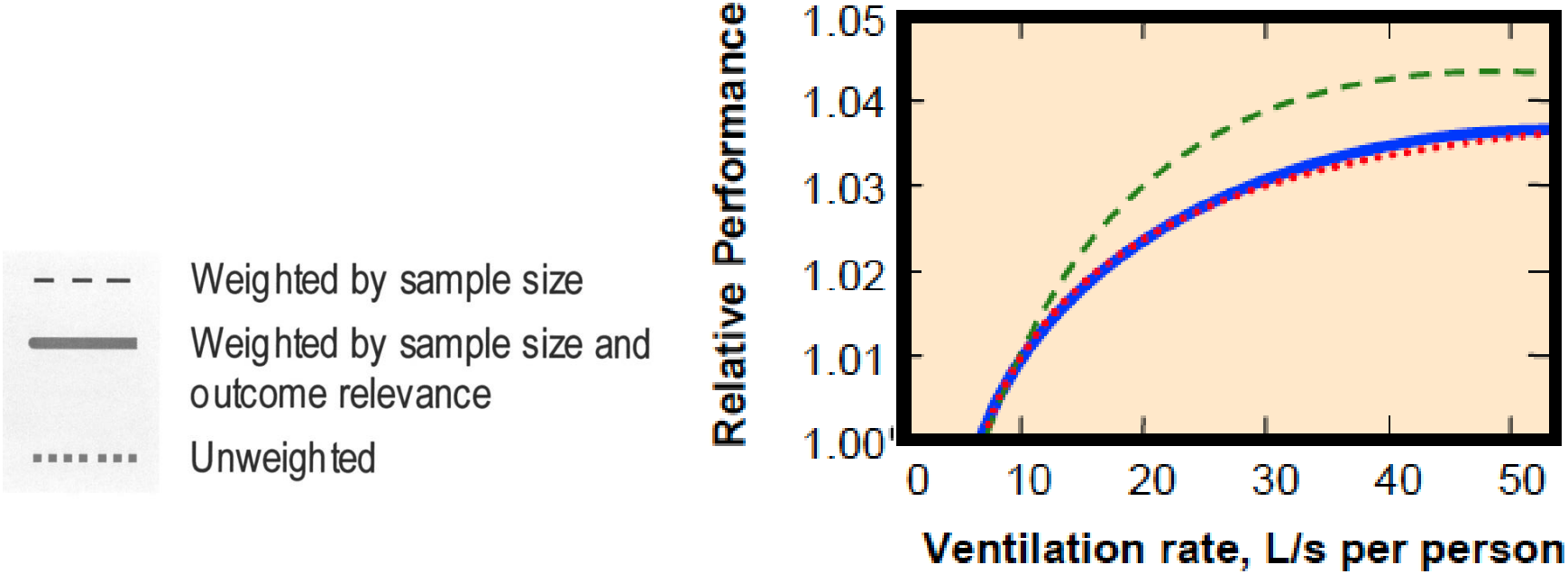
# Energy, IAQ and health

- Improved ventilation in a manufacturing facility led to reduced sick days

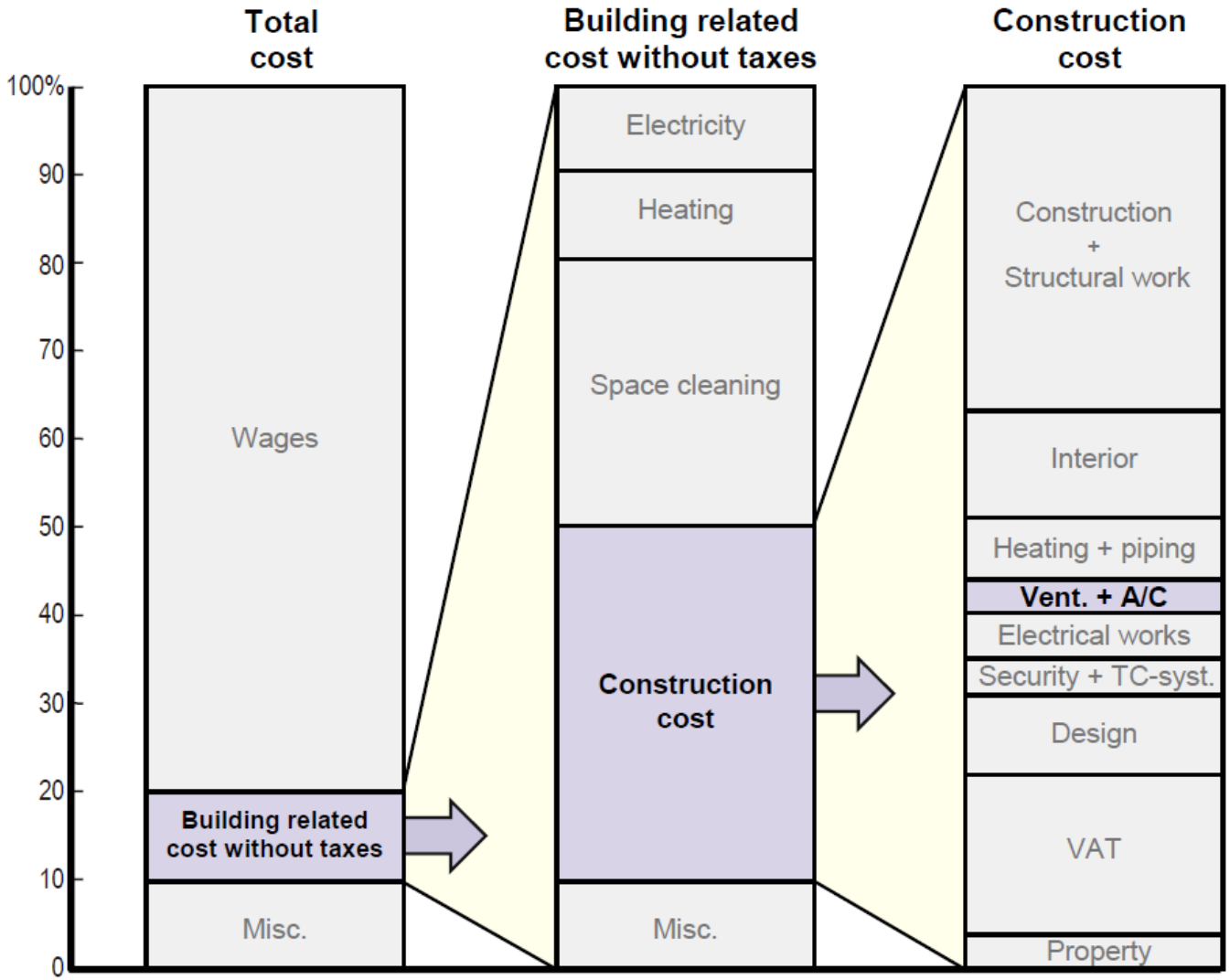
*(Source: Milton et al. (2000) Indoor Air)*

- Increased ventilation leads to slight increase (5%) in productivity

*(Source: Wargocki et al. (2000) Indoor Air)*



# Operating costs disentangled

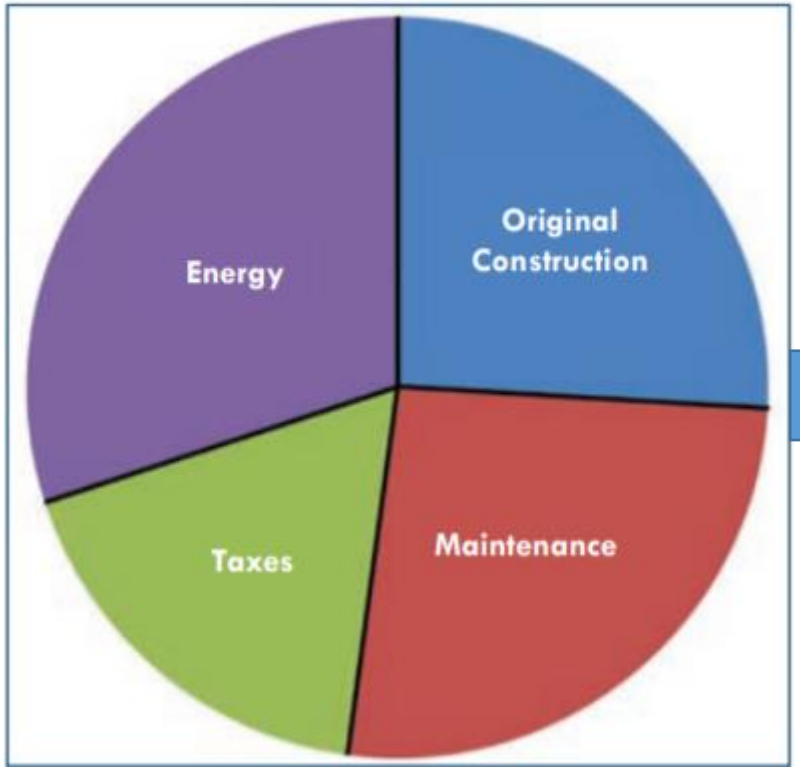



*(Source: S.O. Henssen. 2000. Economics vs. Indoor climate. The economics of indoor climate. RCN, Oslo. Norway)*

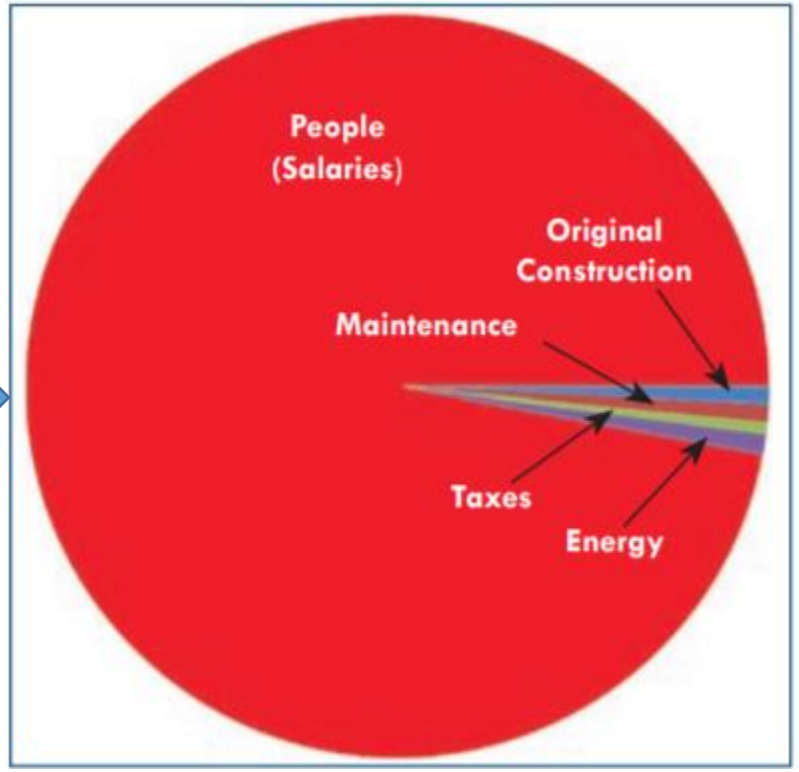
*(Source: Dan Int-Hout, ASHRAE Journal, July 2013)*

# Operating costs disentangled

**Life-cycle building costs breakdown**




**Life-cycle building costs breakdown with people**




- We can argue the numbers here, but not the orders of magnitude
- Reducing energy by 30% is negligible compared to the cost of people
- A net zero energy building (if possible) saves only 1% of salary costs!

# How much $ we could save?

- Health and productivity gains from better indoor environments in the U.S.
  - $6-14 billion from reduced respiratory disease
  - $1-4 billion from reduced allergies and asthma
  - $10-30 billion from reduced sick building syndrome
  - $20-160 billion from direct improvements in worker performance

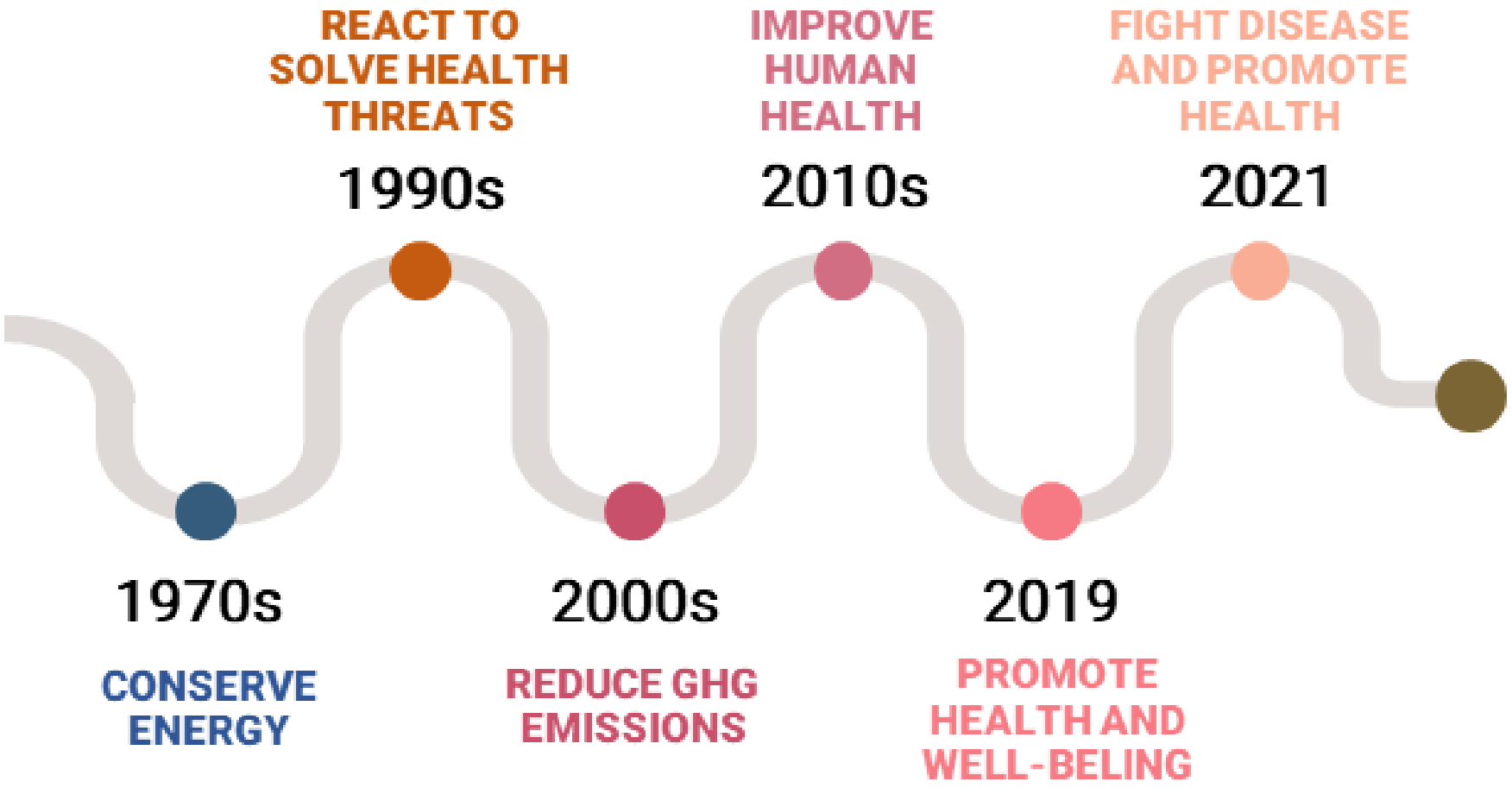
*(Source: Fisk, 2000'; Annual Reviews of Energy and Environment)*

- $37-208 billion annual savings possible

*(Source: Fisk, 2000; ASHRAE Journal)*

- Are building practitioner aware of this?
  - There is an increased awareness, but….
  - Recent COVID-19 pandemic is contributing to this paradigm shift

# Priorities in buildings have been changing…




*(Source: Licina et al 2021, Submitted)*

# Any questions?

# Additional thoughts and the big picture

- Indoor climate isn't really a standalone discipline
  - Involves engineers, architects, public health professionals, analytical chemists, building scientists, architects, contractors, medical professionals, epidemiologists, academics, biologists, psychologists, economists, etc.
  - Many different approaches

- The big picture is that:
  - We are interested in indoor climate because of its impact on:
    - Worker productivity/safety
    - Human comfort
    - Health effects
    - Material degradation
    - Biological growth/disinfection
    - Energy use

# In summary

Buildings are complex systems and are trending toward greater complexity. This is not necessarily a good thing.

Buildings (indoor climate) exert profound influence on their occupants, and vice versa

We have an ample opportunity to reduce energy use and its associated external costs. The challenge is to improve the quality of the indoor climate at the same time.

General notion is that building energy use and good indoor climate are always in conflict. However, if a building is well designed and operation, this will not be the case.

# Bravo for surviving the first class!

Next time:

- Brush up of:
  - Heat transfer in buildings
  - Psychometrics: Definitions and charts
- Course project overview

*"We should design indoor environments that are better than the best environment found in nature"* — *Ole Fanger*