# Humans in developed economies spend very little time outdoors

Outdoors
10%

Indoors at work or in other
"public" buildings
30%

Indoors at home
60%

## Healthy Commerical Building Elements

### Harvard 9 Foundations

1. Ventilation
2. Air Quality
3. Thermal Health
4. Moisture
5. Dust and Pests
6. Safety & Security
7. Water Quality
8. Noise
9. Lighting & Views

### WELL Building

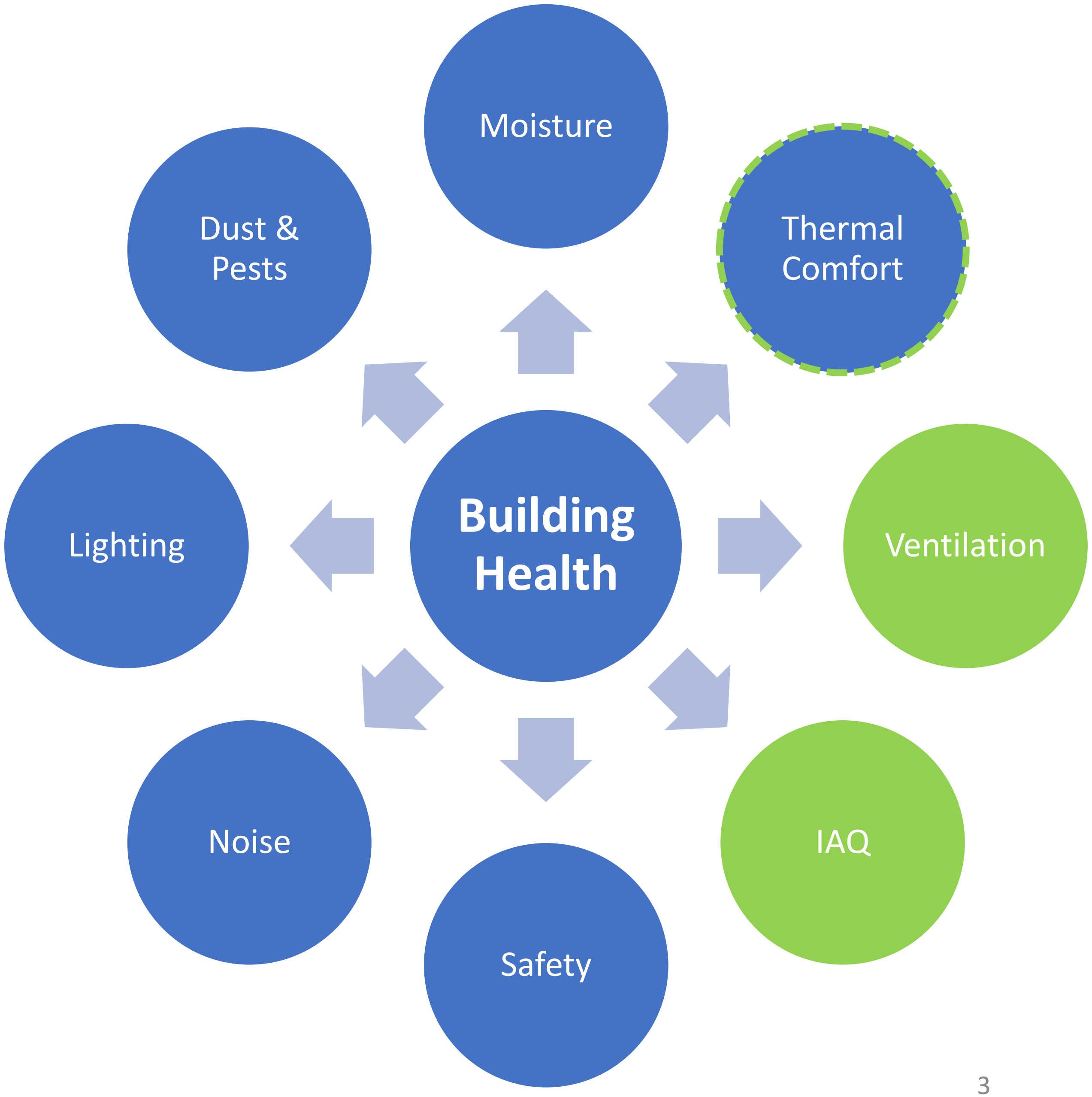
1. Air
2. Water
3. Nourishment
4. Light
5. Fitness
6. Comfort
7. Mind
8. Innovation

### Fitwel for Workplace

1. Location
2. Building Access
3. Outdoor Spaces
4. Entrances/Ground Floor
5. Stairwells
6. Indoor Environment
7. Workspaces
8. Shared Spaces
9. Water Supply
10. Cafeterias & Prepared Food Retail
11. Vending Machines/Snack Bars
12. Emergency Procedures

# What makes a building healthy?

# IAQ and ventilation are the building elements with the biggest known impacts on human health



# How does energy efficiency help occupant health in commercial buildings?

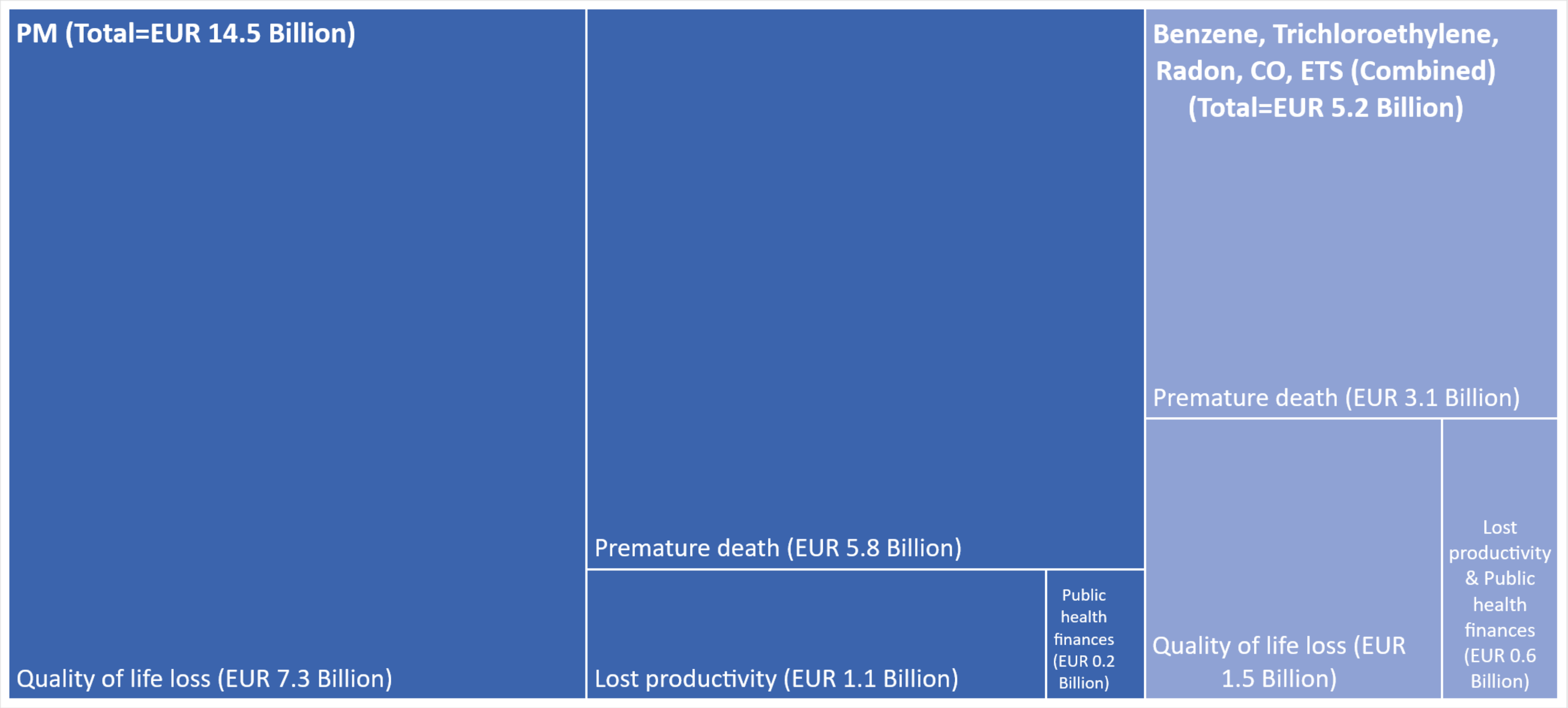
Relationships explored in the paper

| Commercial Building Health Element | Indoor Exposure | Illustrative EE Interventions | Response (Multiple Benefits) |
|---|---|---|---|
| IAQ | PM infiltrating from outdoors | Air sealing | ΔDALYS and ΔHealth costs |
| Ventilation | Air pollutants originating outdoors | All EE that reduces combustion of fossil fuels | ΔDALYS and ΔHealth costs |
| Thermal comfort | Temperature and humidity levels | HVAC and building envelope improvements | ΔWork or cognitive performance |

# Indoor Air Quality

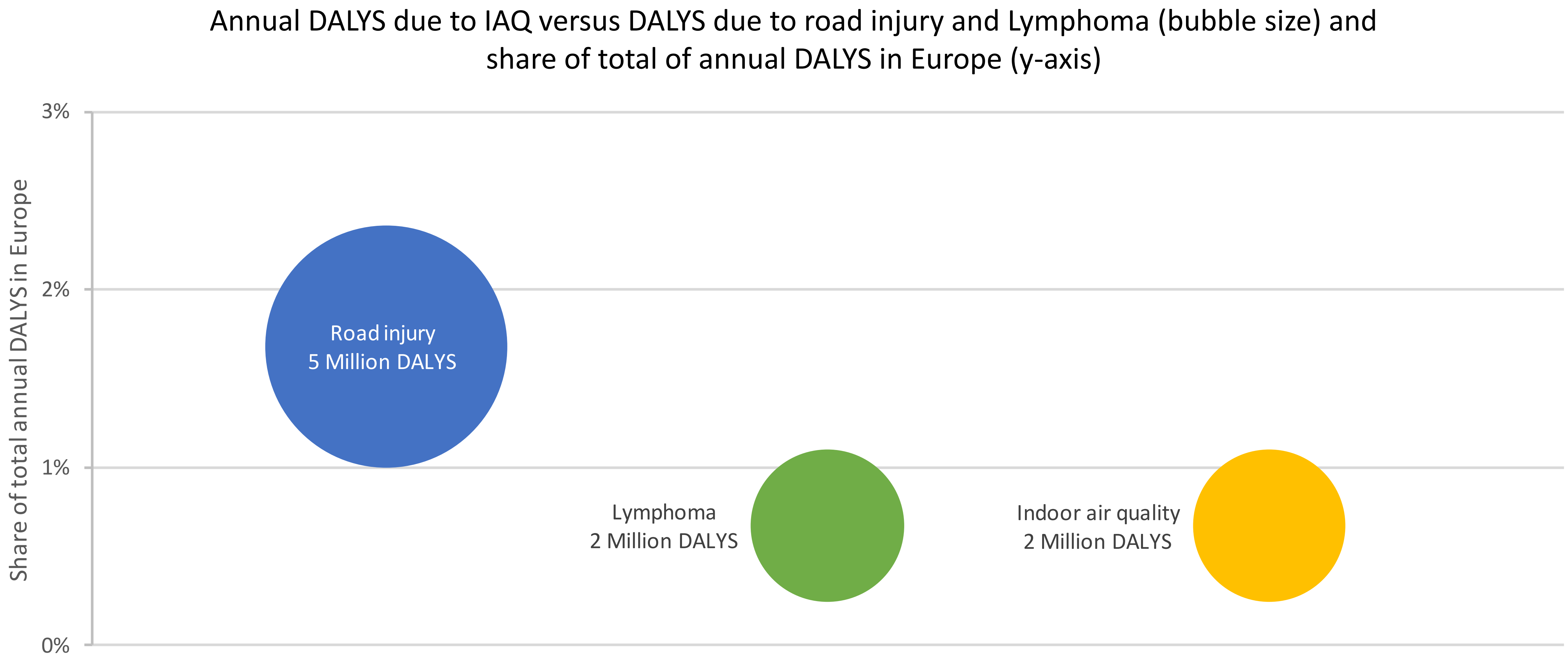
# IAQ costs France EUR 20 Billion per Year

Annual socio-economic costs due to PM and five other indoor air pollutants in France




Source: Boulanger et al, 2017. Additional social costs (estimated in total across all target pollutants) include other public health costs and research costs (total = EUR -187 Million per year), as well as public pension costs avoided, which constituted benefits totaling EUR 289 Million per year. Private costs due to IAQ were not estimated.

# The total burden of disease in the EU-26 due to IAQ is EUR 200 Billion per year, or 2 million years of healthy life lost annually (DALYS)




Source: Jantunen et al., 2011; WHO, 2018

# Exposure to air pollution indoors can cause or worsen a range of diseases

**Jantunen et al.** 2011

- Diseases in humans associated with indoor air pollution include asthma, lung cancer, cardiovascular diseases (CVD), chronic obstructive lung disease (COPD), respiratory infections/symptoms, and acute toxication

**Rudel and Perovich; Wargocki*** 2009; 2018*

- **Older buildings can contain legacy pollutants** such as asbestos that can be exposed during building maintenance or retrofits
- **Newer buildings materials also contain pollutants**, including endocrine disrupting compounds such as polycarbonated biphenlys (PCBs), which can be found in electrical equipment, caulk, paint, and surface coatings

*Direct communication with subject matter expert

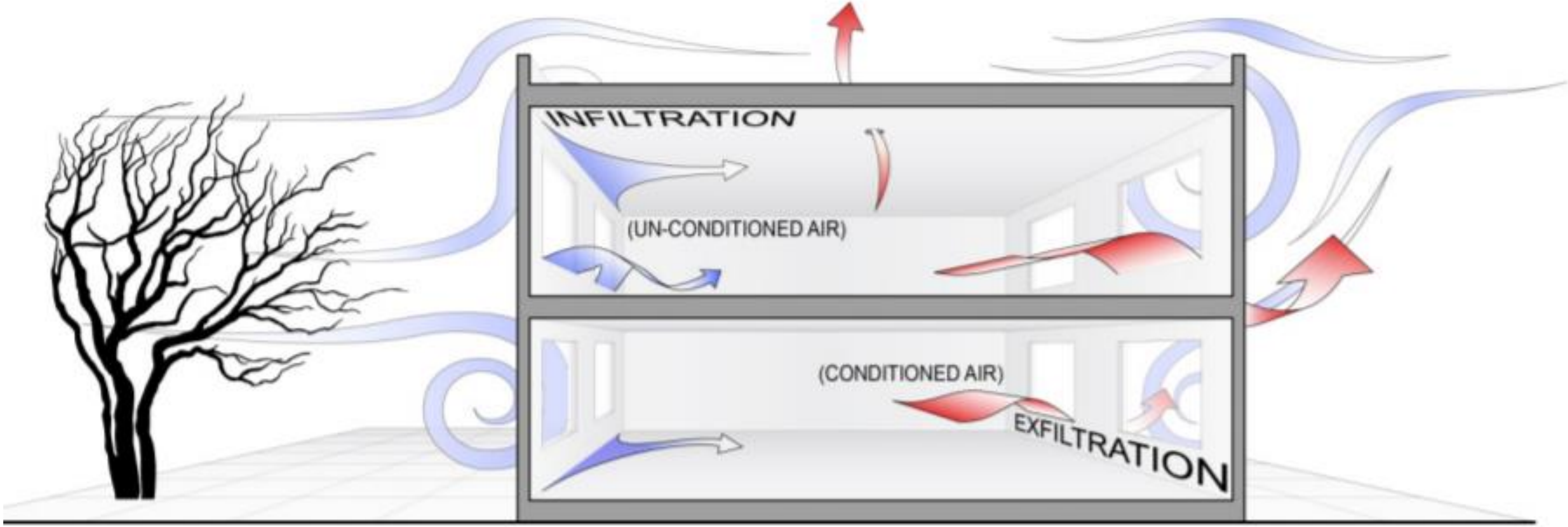
**Jantunen et al.; Shi et al.; Kanchongkittiphon et al.** 2011; 2015; 2015

- **Things inside a building**, including fixed heating and combustion equipment and appliances, electrical appliances, furniture, upholstery, printer cartridges, cleaning products, personal care products, paint, and insect and rodenticides **can emit a wide range of air pollutants**, including volatile organic compounds (VOCs), carbon monoxide, carbon dioxide ($CO_2$), and particulate matter (PM)

**Cyrys** 2004

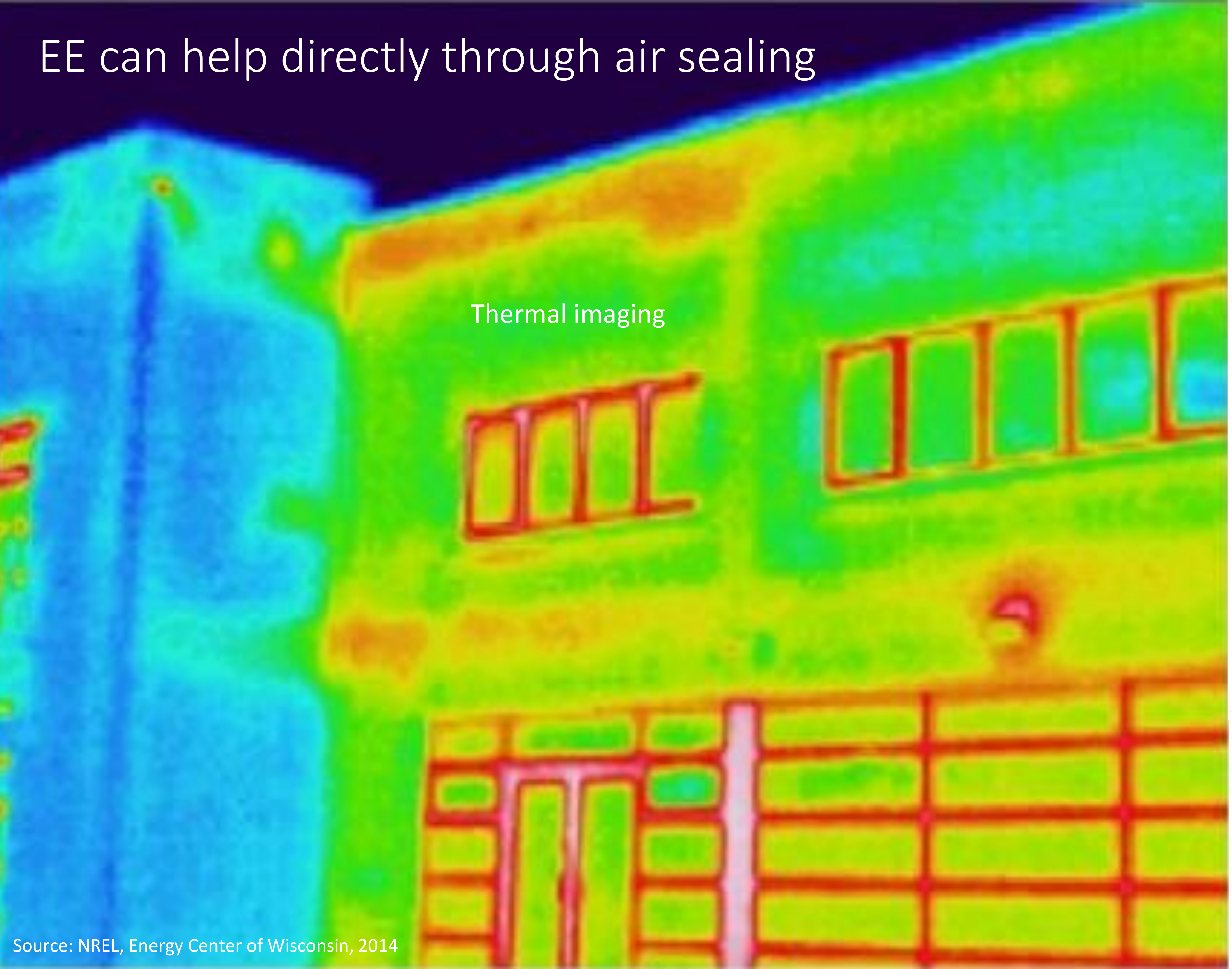
- Air pollutant levels transferred indoors impact humans if the pollutants can penetrate the building envelope

# Infiltration can force outdoor air pollution indoors

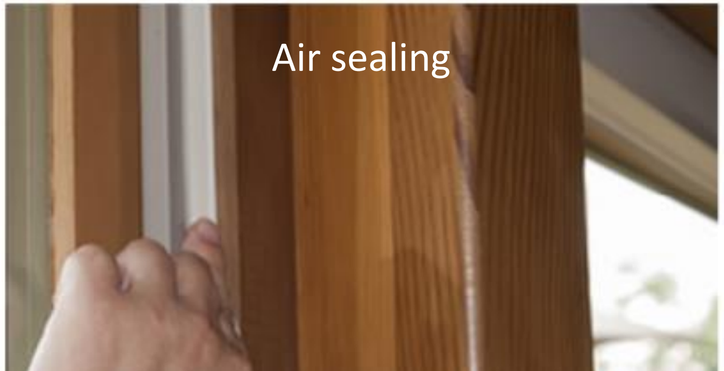



Source: NREL, Energy Center of Wisconsin, 2014

# EE can help directly through air sealing





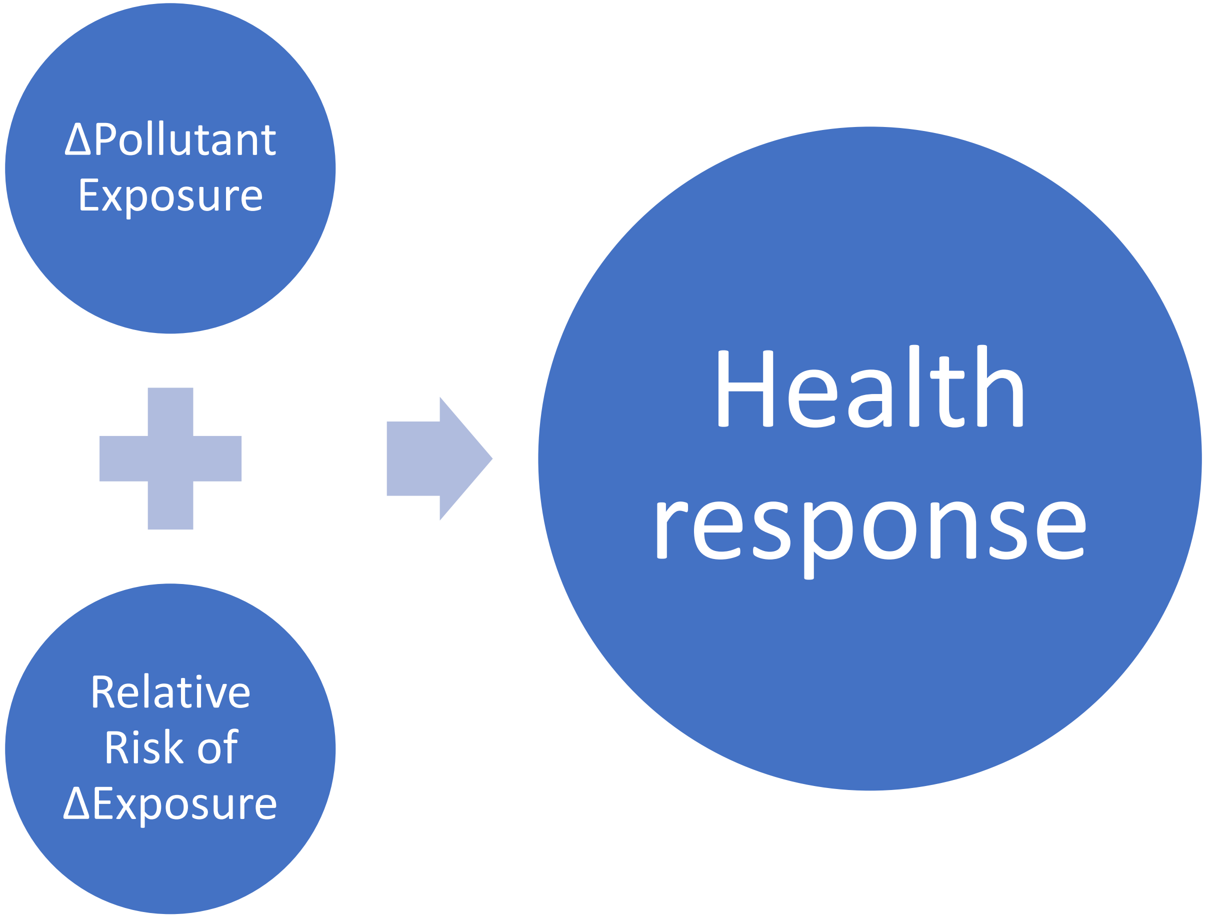



Source: NREL, Energy Center of Wisconsin, 2014

# Multiple benefits of air sealing

- Reduces infiltration of outside air
- Lowers heating bills due to less heat loss (exfiltration)
- Greater comfort due to fewer drafts
- Reduced mould and rot due to decreased moisture trapped in cavities
- Better performing ventilation systems
- Smaller heating and cooling equipment capacities required
- Lower exposure to air pollutants outdoors and therefore indoors

An exposure-response approach provides a useful framework for quantifying the health benefits of energy efficiency

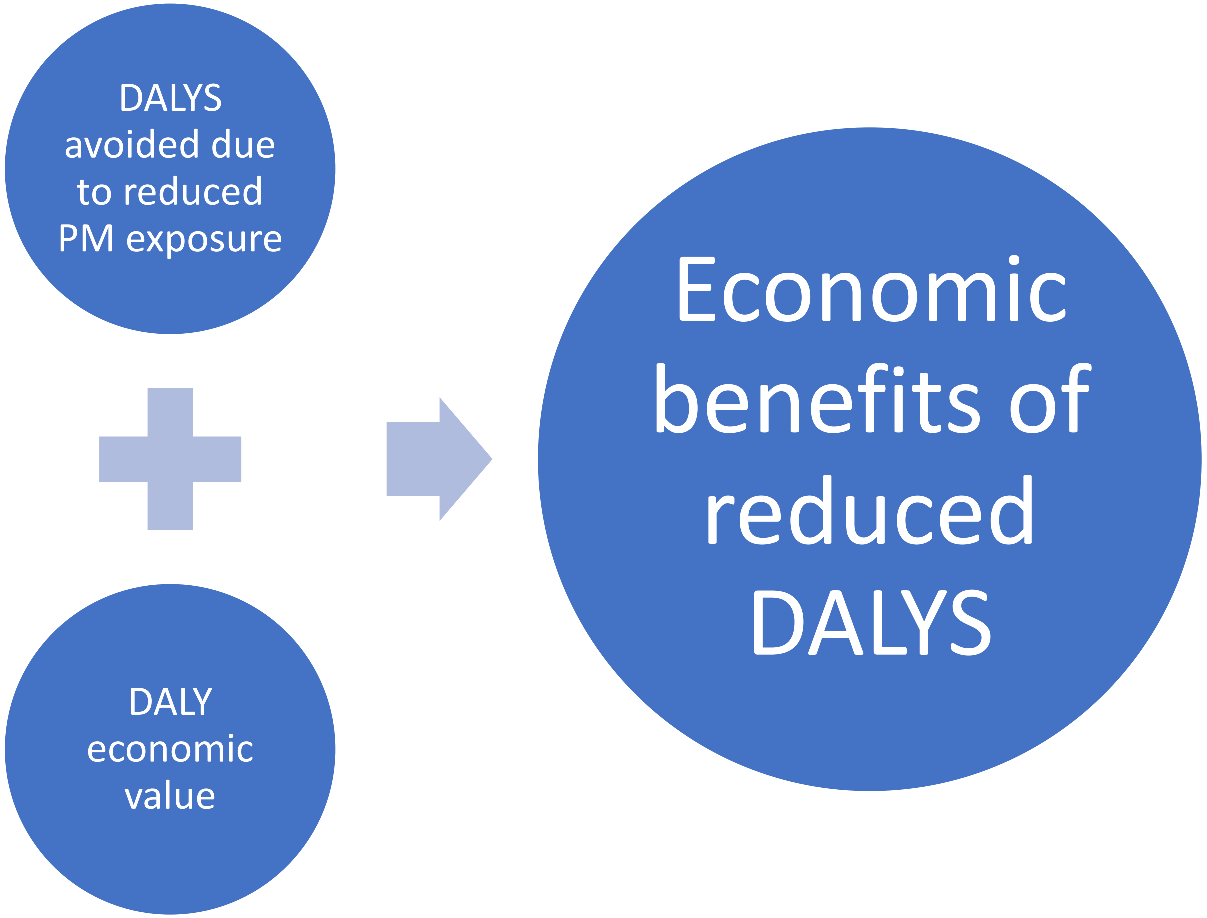


# How feasible is it to quantify these indicators?

Indicators for monetising the health benefits of reduced indoor PM exposure due to commercial building air sealing

| Indicator | Definition |
|---|---|
| **Exposure** | |
| Indoor PM concentration | Mass of pollutant per volume of air, e.g., micrograms of $PM_{2.5}$ per cubic meter ($\mu g\ m^3$). |
| Infiltration (air leakage) | The unintentional introduction of outside air into a building. Measured in air exchanges per hour (e.g., ACH at 50 Pascals) |
| Time spent in building | Hours occupying building as a fraction of total annual hours, varying by time of day and season (depending on level of analysis). |
| **Response** | |
| Relative risk of increase in concentration of PM | Increases in risk of disease, disability or death relative to an increase in indoor PM concentration. |
| Disability adjusted life years (DALY) | The sum of years of life lost as a result of premature death and the years of life spent living with a disease. DALY calculations are based on: 1) an attributable fraction of exposure or disease associated with the examined risk factor and 2) the national estimates available for the target exposure or disease. |
| **Economic** | |
| Economic value of DALY | Calculated based on an assumed value for a statistical life year (e.g., EURO 100 000) and a disability weight, which reflects the severity of a disease on a scale from 0 (perfect health) to 1 (equivalent to death). |

# Monetising the health benefits of reduced indoor PM exposure due to commercial building air sealing



# PM data pre- and post- air sealing is likely required

For exposure-response functions and economic indicators, desktop analysis of data the literature is probably sufficient

Approaches to quantifying indicators for estimating the economic benefits of reduced indoor PM exposure due to commercial building air sealing

| Indicator / Approach | Level of analysis: National or Subnational (Province or City) | Individual building | Programmes or projects targeting few building types | Programmes or projects targeting many building types | Analysis Timeframe (Months) |
|---|---|---|---|---|---|
| **Indoor PM concentration** | | | | | |
| Collected data (direct measurement of indoor PM levels) | ○ | ● | ○ | ● | 36 |
| Simulation of indoor PM levels | ○ | ● | ○ | ● | 6-9 |
| Desktop analysis of secondary data (literature or government data) | ● | ○ | ● | ○ | 1-6 |
| **Infiltration** | | | | | |
| Collected data (air tightness testing) | ○ | ● | ○ | ● | 36 |
| Simulation (estimated during building energy modelling) | ● | ○ | ● | ○ | 6-9 |
| **Time spent in building** | | | | | |
| Collected data (human activity pattern surveys) | ○ | ● | ○ | ● | 6-12 |
| Desktop analysis of secondary data (literature, government or industry data) | ● | ○ | ● | ○ | 1-6 |
| **Exposure-response coefficient** | | | | | |
| Desktop analysis of secondary data (literature or government data) | ● | ● | ● | ● | 1-6 |
| **Economic value of DALY** | | | | | |
| Desktop analysis of secondary data (literature or government data) | ● | ● | ● | ● | 1-6 |

● Most applicable or required ○ Applicable

# Ventilation

MacNaughton et al. 2015

- Most standards for building ventilation are based on acceptable minimum ventilation rates, yet 30 years of research shows there are human health benefits to increasing ventilation rates above these minimum levels

Seppanen and Fisk 2006

- Lower ventilation rates in buildings are associated with higher transmission rates of some communicable diseases

Loftness et al. 2003

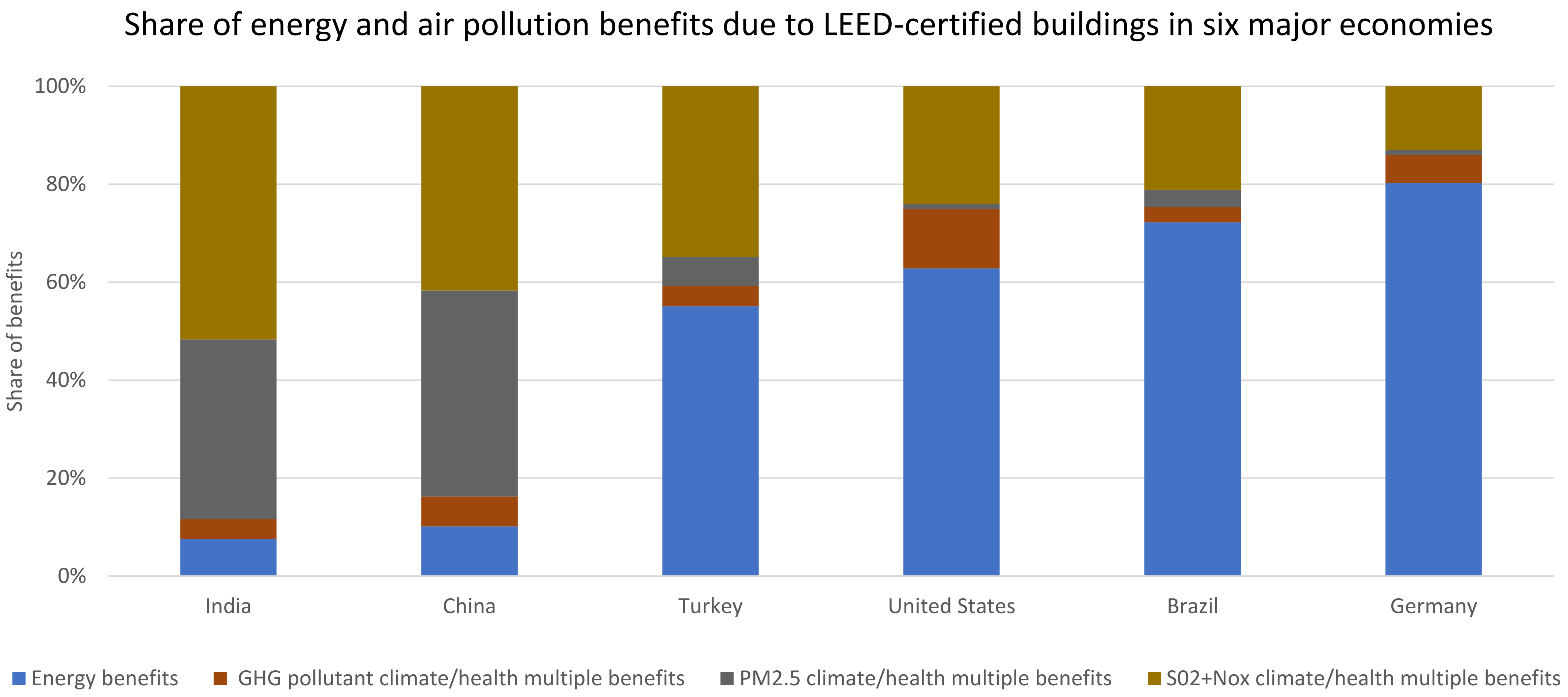
- Estimated 11% work performance gains from increased ventilation

Higher ventilation rates reduce indoor air pollution and increase work performance

# There are synergies between efficiency and ventilation rates, but caution must be exercised

- Increasing ventilation in commercial buildings with mechanical ventilation systems requires increasing energy use
  - Installing an **energy recovery ventilator (ERV)** could offset up to 60% of energy cost increases and up to 30% of additional environmental costs (MacNaughton et al 2015)
  - Using an **economizer system** to double ventilation rates from 10 to 20 L/s-person saves €23 per person per year in energy costs and reduces sick leave by one day per person per year, resulting in annual economic benefits of €160 per person (Seppanen and Fisk, 2006)
- Opinions vary on whether **demand controlled ventilation systems** help or hurt building health
- **Passive ventilation** saves a lot of energy
  - Applicable in areas with low levels of outdoor air pollution

# One clear benefit of EE on ventilation systems is reduced air emissions from electricity generation



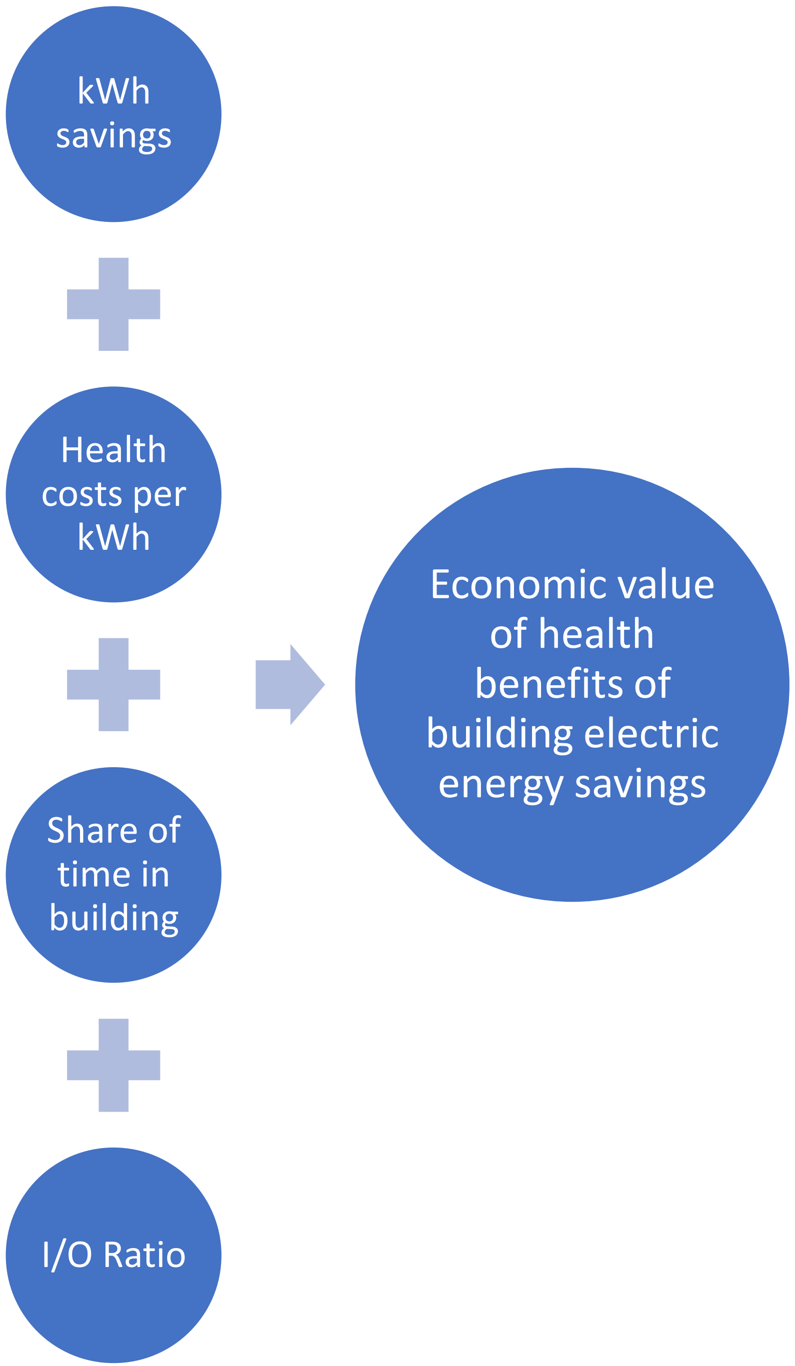

Source: MacNaughton et al, 2018. GHG pollutants include $CO_2$, $CH_4$, and $N_20$.

# How feasible is it to quantify these indicators?

Indicators for monetising health benefits of building electric energy savings

| Indicator | Definition |
|---|---|
| **Exposure** | |
| Time spent in building | Hours occupying building as a fraction of total annual hours, varying by time of day and season (depending on level of analysis). |
| I/O ratio | The ratio of the mass of an air pollutant found indoors to its mass outdoors. |
| **Response** | |
| Economic value of health impacts per kWh | Health costs per kWh of electricity production due to fossil fuel combustion. |
| **Building performance** | |
| Electric energy savings | Annual and/or lifetime kWh reduction in building energy use from implementation of energy efficiency measures. |

Monetising the societal indoor health benefits of reduced air pollutant exposure indoors due to electric energy savings in commercial buildings



# This analysis is most useful for national or sub-national ex-ante studies

In some countries, most or all of the data could be gathered from the literature

Approaches to quantifying indicators required to estimate the economic value of the indoor health benefits of electric energy savings in buildings

| Indicator / Approach | Level of analysis: National or Subnational (Province or City) | Level of analysis: Individual building | Level of analysis: Programmes or projects targeting few building types | Level of analysis: Programmes or projects targeting many building types | Analysis Timeframe (Months) |
|---|---|---|---|---|---|
| **Time spent in building** | | | | | |
| Collected data (human activity pattern surveys) | ○ | ● | ○ | ● | 6-12 |
| Desktop analysis of secondary data (literature, government or industry data) | ● | ○ | ● | ○ | 1-6 |
| **I/O Ratio** | | | | | |
| Collected data (direct measurement of indoor PM levels) | ○ | ● | ○ | ● | 36 |
| Collected data (direct measurement of outdoor PM levels) | ● | ○ | ○ | ○ | 36 |
| Simulation | ○ | ● | ○ | ● | 6-9 |
| Desktop analysis of secondary data (literature or government data) | ● | ○ | ● | ○ | 1-6 |
| **Economic value of health impacts per kWh** | | | | | |
| Original economic analysis of secondary data (literature, government, or industry data) | As required | | | | 6-18 |
| Desktop analysis of secondary data (literature) | ● | ● | ● | ● | 1-6 |
| **Electric energy savings** | | | | | |
| Collected data (metering) | ○ | ● | ○ | ● | 36 |
| Simulation (building energy modelling) | ○ | ● | ○ | ● | 6-9 |
| Desktop engineering calculations | ● | ○ | ● | ○ | 1-6 |

● Most applicable or required ○ Applicable

# Thermal comfort

Seppanen et al. 2005

- Metastudy showing a 9% to 10% reduction in workplace performance at 30°C and 15°C, respectively, compared to a baseline of 22°C

Wargocki and Wyon 2006

- The average speed of eight simulated school work tasks performed by students in Denmark was increased by approximately 2% per 1°C as temperatures decreased from 25°C to 20°C

Lan et al. 2011

- Found a 4% reduction in workplace performance at cooler temperatures, and a 6% reduction at warmer ones

"that condition of mind which expresses satisfaction with the thermal environment"

-British Standard BS EN ISO 7730. 7.

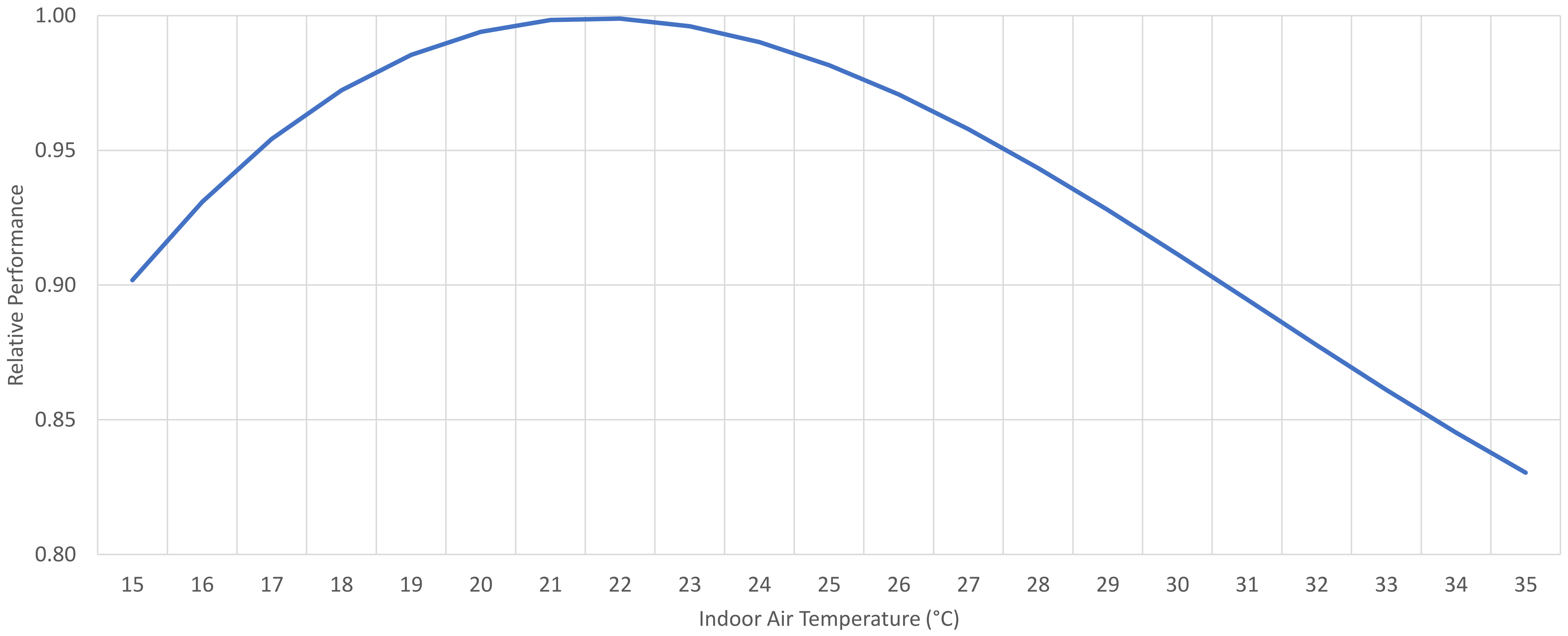
# Building codes only sometimes address thermal comfort

- **Out of eight EU countries surveyed, BPIE found five** (Belgium, Denmark, France, Germany and the United Kingdom) **have limitations on overheating in buildings codes**, where overheating indicators differ by temperature and time (BPIE, 2015)

- **Thermal comfort can also contribute to green building certification**
  - Existing buildings can gain one optional LEED credit for having a permanent monitoring system to ensure ongoing building performance

# Most studies suggest that moderately high temperatures are less tolerated than low

Relationship between office work performance and indoor temperature based on a statistical analysis of reported data




Source: Fisk and Seppanen (2007). Performance increases up to 21°C to 22°C and decreases as temperature rise. Increasing the temperature from 22°C to 30°C decreases performance 9%.

- HVAC system optimization (EMS)
- Night time ventilative cooling
- Efficient windows
- Solar shading
- Insulation
- Air sealing
- Cool roofs

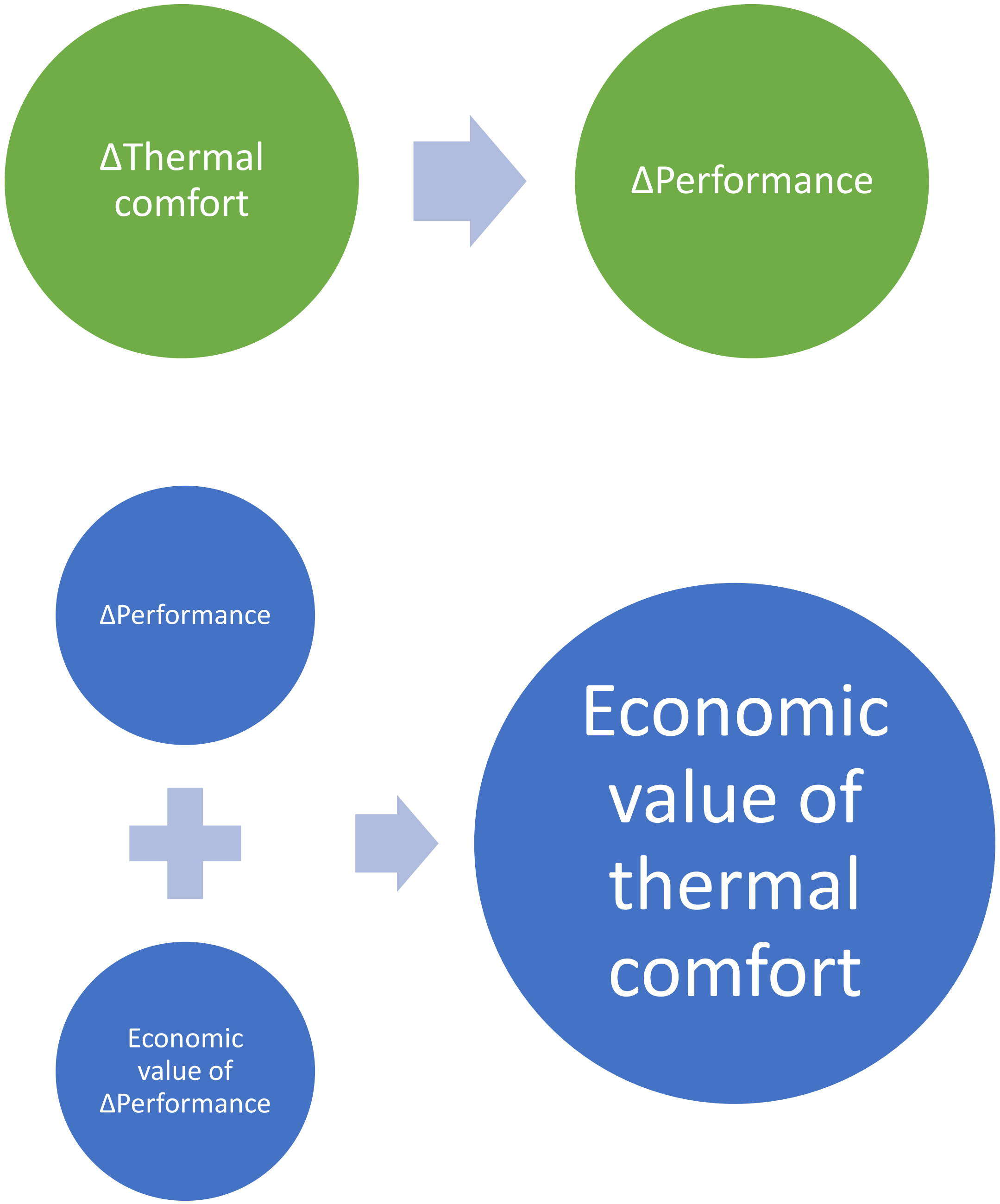
Many energy efficiency measures can improve thermal comfort

# How feasible is it to quantify these indicators?

Indicators for monetising the work performance benefits of thermal comfort

| Indicator | Definition |
|---|---|
| **Exposure** | |
| Indoor air temperature and/or humidity | Seasonal and annual average indoor temperatures and/or humidity measured in occupied building zones before and after energy efficiency project. |
| **Response** | |
| Relative performance | Performance of work or cognitive performance relative to a maximum performance level. |
| **Economic** | |
| Economic value of performance | Change in income due to change in relative performance. |

Monetising the work or cognitive performance benefits of thermal comfort



# Thermal parameters require metering

- Work performance data is readily available in the literature
- Cognitive performance data availability is growing

Approaches to quantifying indicators required to estimate the economic value of thermal comfort due to energy efficiency

| Indicator / Approach | Level of analysis: National or Subnational (Province or City) | Level of analysis: Individual building | Level of analysis: Programmes or projects targeting few building types | Level of analysis: Programmes or projects targeting many building types | Analysis Timeframe (Months) |
|---|---|---|---|---|---|
| **Indoor air temperature and/or humidity** | | | | | |
| Collected data analysis (metering) | ○ | ● | ○ | ● | 36 |
| Simulation (building energy modelling) | ● | ○ | ● | ○ | 6-9 |
| **Relative performance** | | | | | |
| Collected data analysis (work or cognitive performance testing) | ○ | ● | ○ | ● | 36 |
| Desktop analysis of secondary data (literature) | ● | ○ | ● | ○ | 1-6 |
| **Economic value of performance** | | | | | |
| Desktop analysis of secondary data (literature, government or industry data) | ● | ● | ● | ● | 1-6 |

● Most applicable or required ○ Applicable

Health

Building envelope **air sealing can reduce ventilation**, which can have deleterious effects on human health

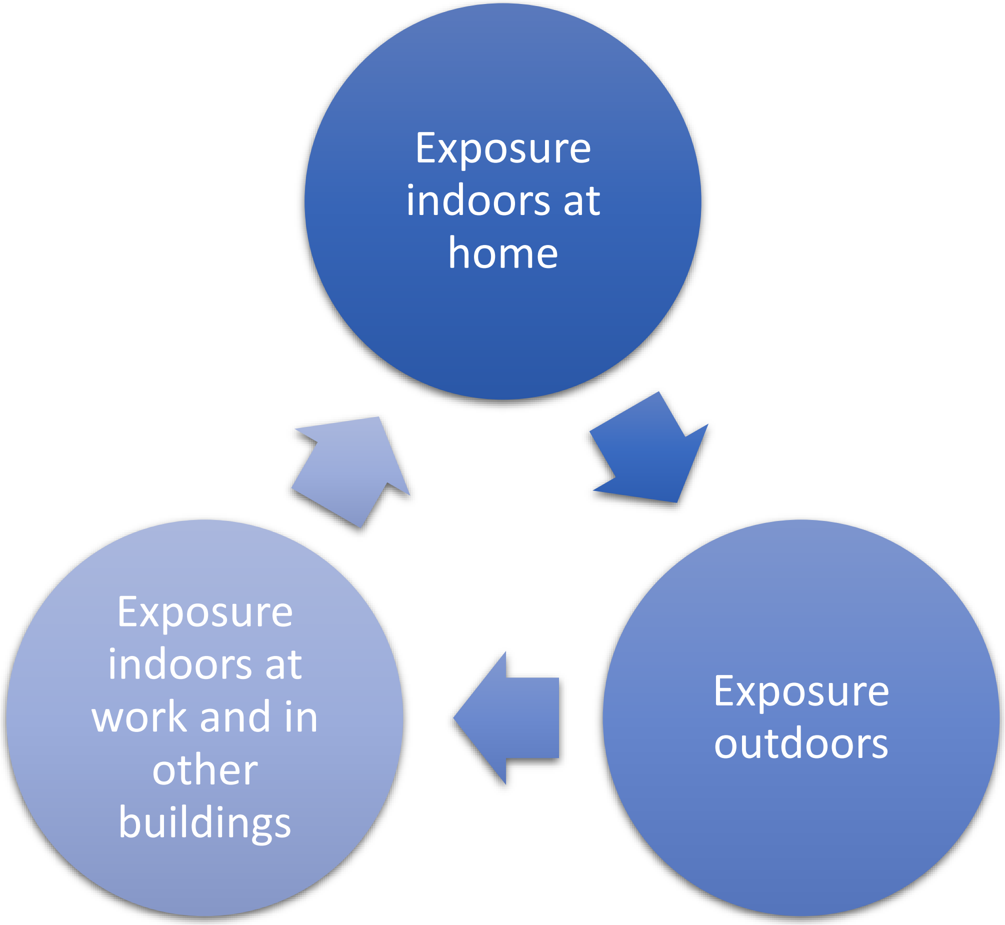
These effects can be mitigated by increasing ventilation rates at **the expense of increased energy use**

Energy use

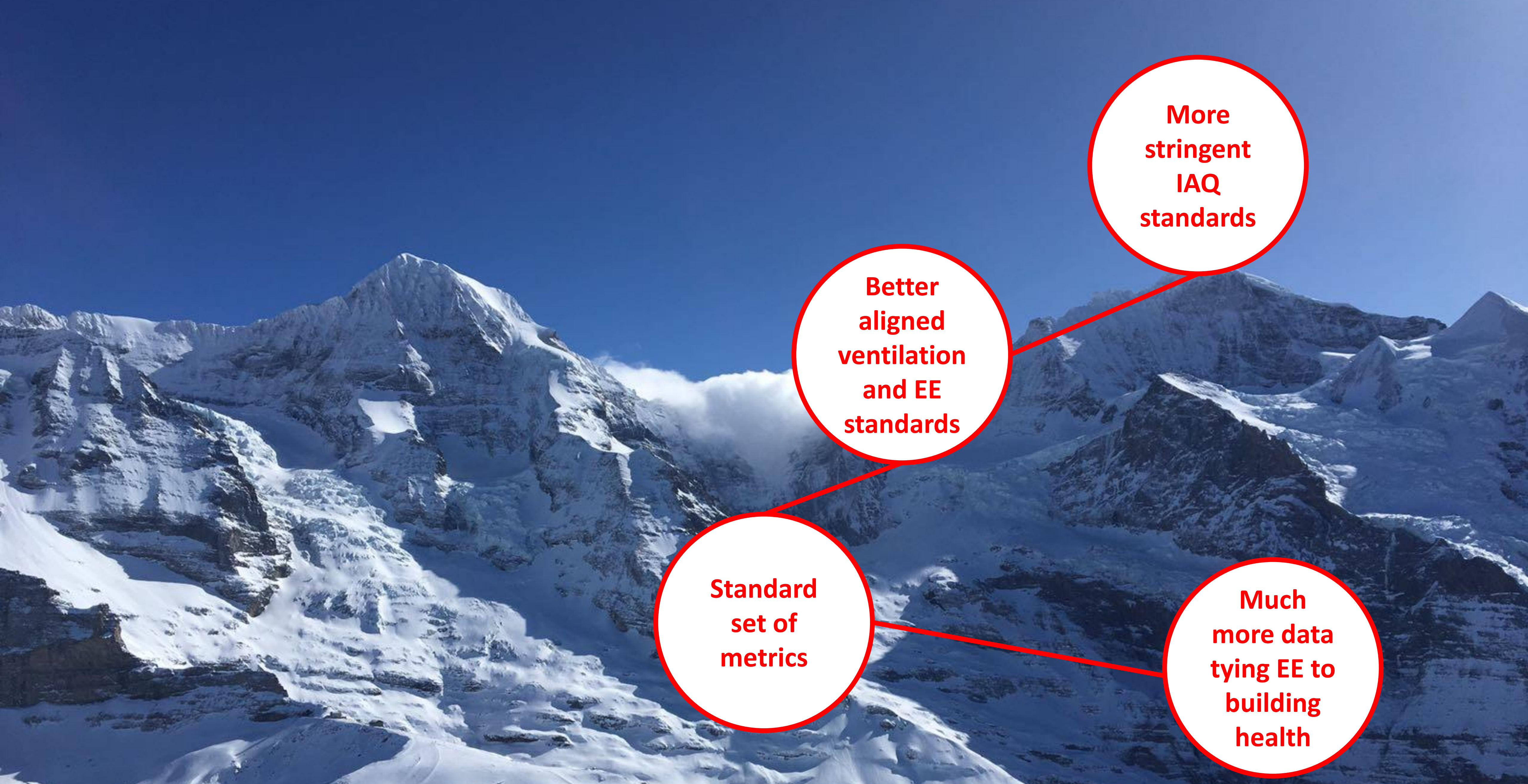
# Relationships and trade-offs

- Increased energy use can result in higher outdoor and indoor air pollutant levels
- If outdoor air pollution levels are sufficiently reduced, energy penalties from mechanical ventilation can be eliminated by switching to passive ventilation methods

# Interactive effects are not well understood



# Recommendations



# How does energy efficiency help occupant health in commercial buildings? Drivers, impacts and trade-offs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Presented during the Evaluating Multiple Benefits Session of the Multiple Benefits of Energy Efficiency Conference
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