ENG-445
Building Energetics
Fall 2024

Green building standards and guidelines

December 5th, 2024

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Mürren, Alpine village
2’522 m

Imagine a place…

Green-certified buildings:

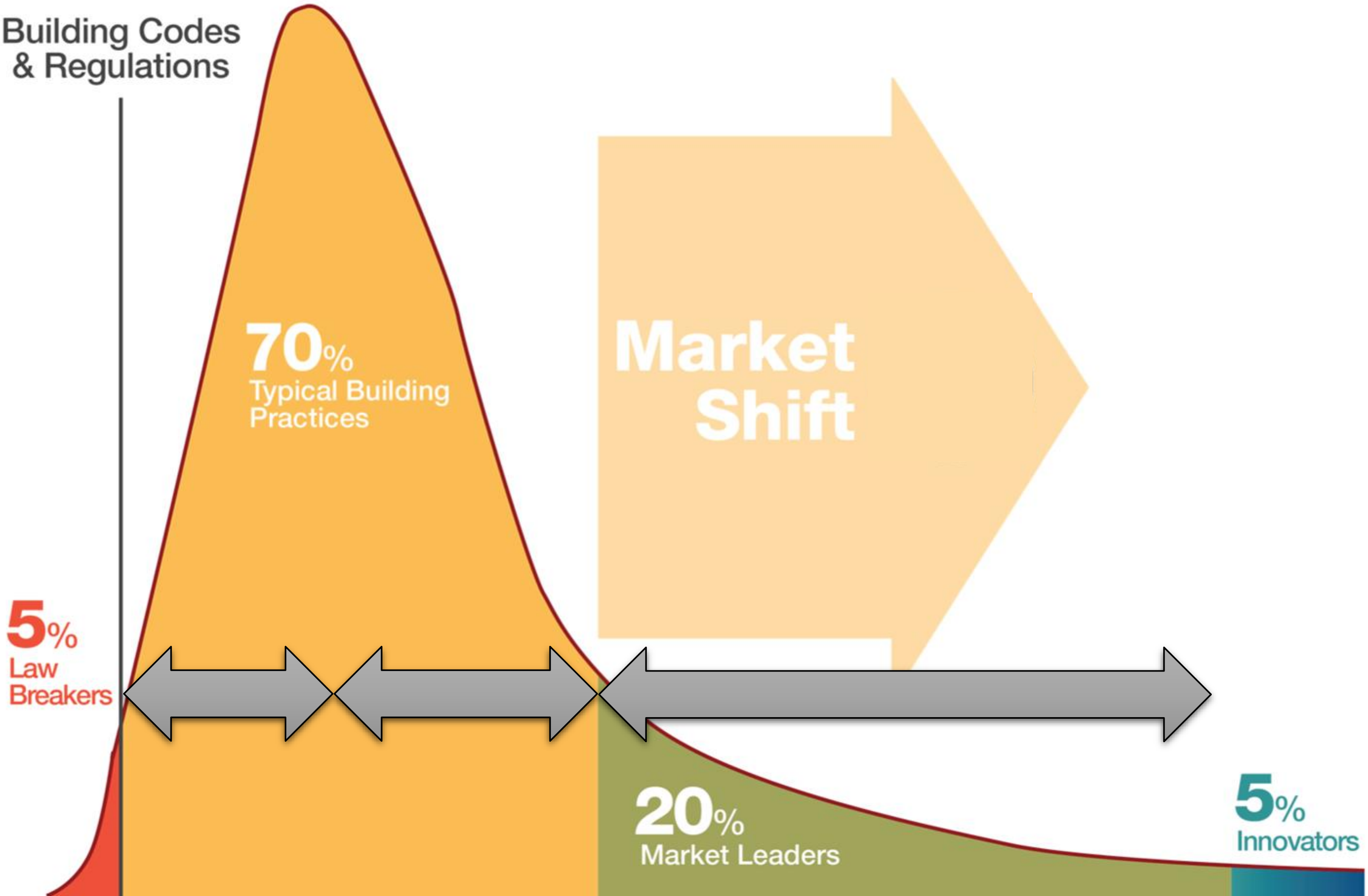
- What do we know about them?
- What are the key challenges?
- What is the envisioned future?

What we know

Key challenges

The envisioned future

Overview of building practices



Designing for sustainability

- Whether designing a new building or retrofitting an old building, there are a number of building codes, standards, and guidelines that help design for energy efficiency and sustainability
- **Codes** generally provide **minimum criteria**
  - Your building usually can't be worse than this
  - City codes, state codes, national codes, etc.
- **Standards** sometimes go **above** and beyond code
  - Or can become **cited in code**
- **Green building standards and guidelines**
  - Many green building standards and guidelines exist with varying levels of building energy efficiency and IEQ criteria

Codes (& Standards) vs. Green ratings

Codes (& Standards)

- Rules define the minimum (i.e., the worst building you can legally build)
- Provide some trade-offs between building elements and systems
- Limits the trade-offs to prevent loopholes for bad design

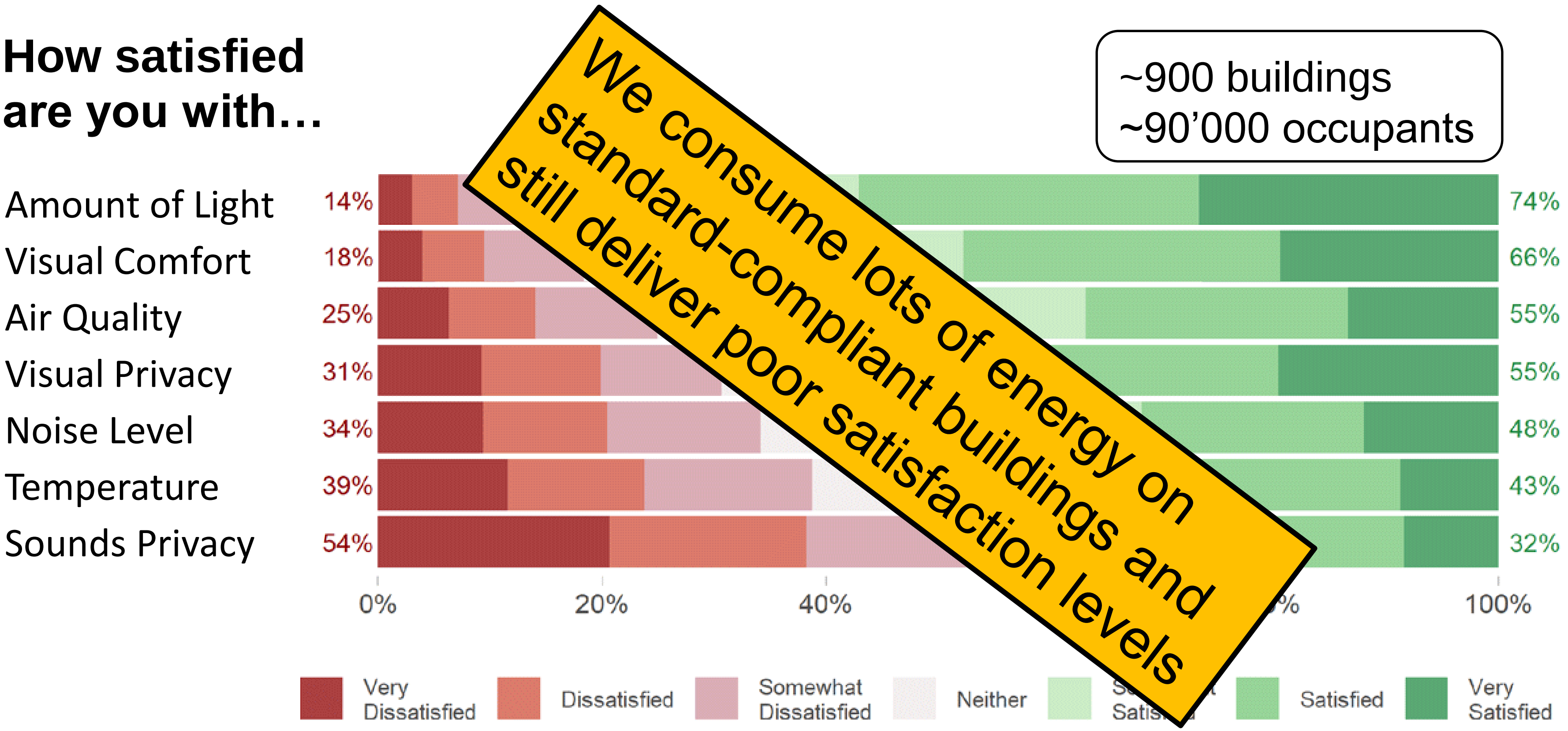
Green rating systems

- Based on incentives
- Rules encourage more (i.e., how much better your building is than the standard practice)
- Base case should reflect common practice, not necessarily code minimum
- Tradeoffs should be provided for all innovative measures that are installed

Occupant satisfaction in buildings

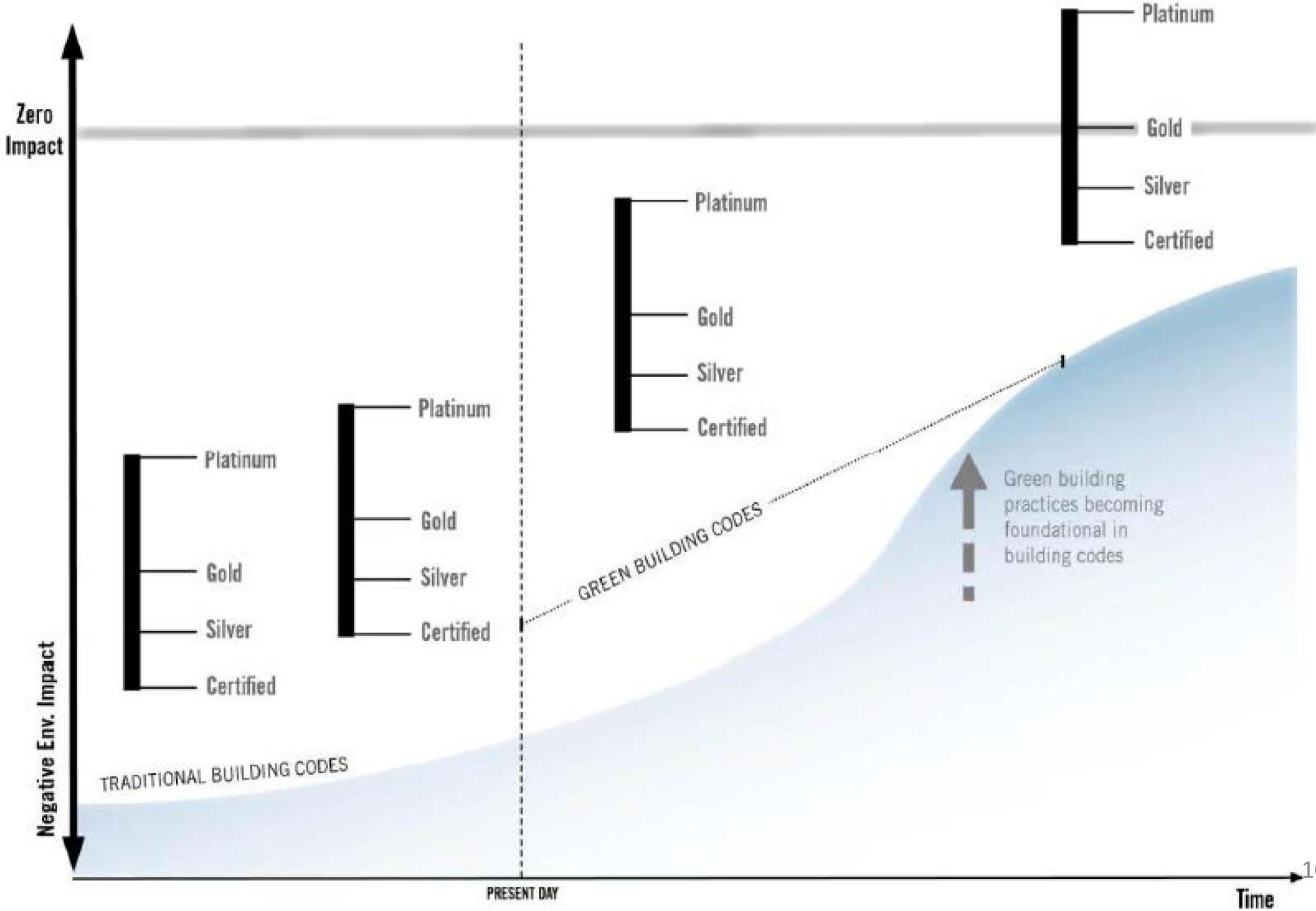
How satisfied are you with…

~900 buildings
~90’000 occupants

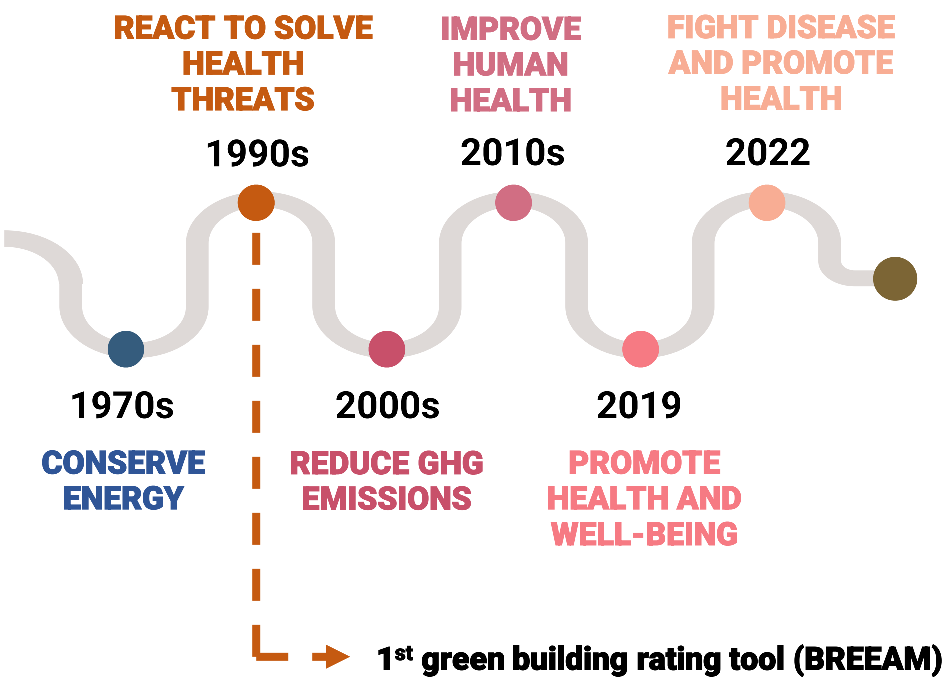


(Adapted from: Graham et al 2021, Buildings and Cities 2:166-184)

Can green ratings drive improvements in code?

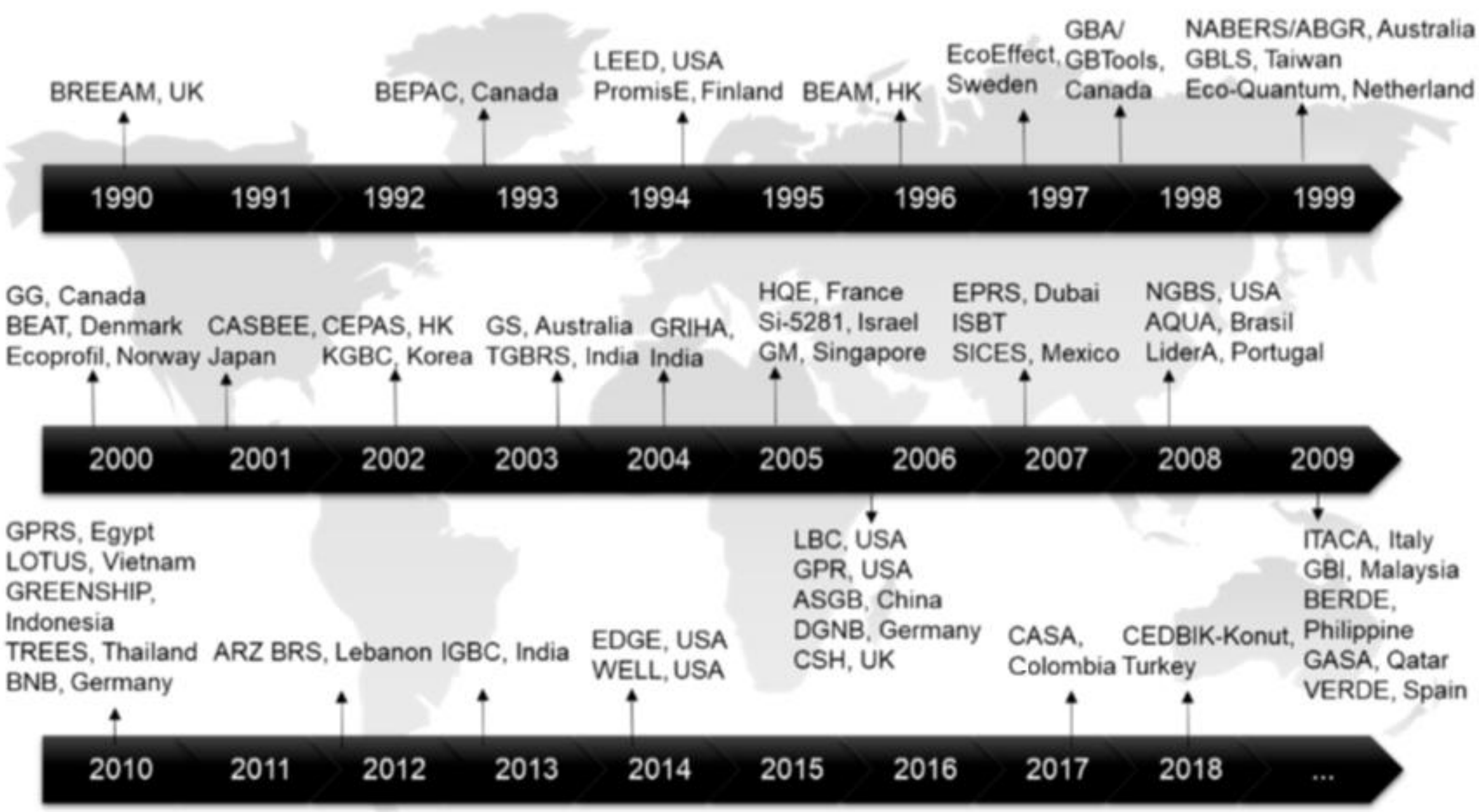


Evolution of priorities



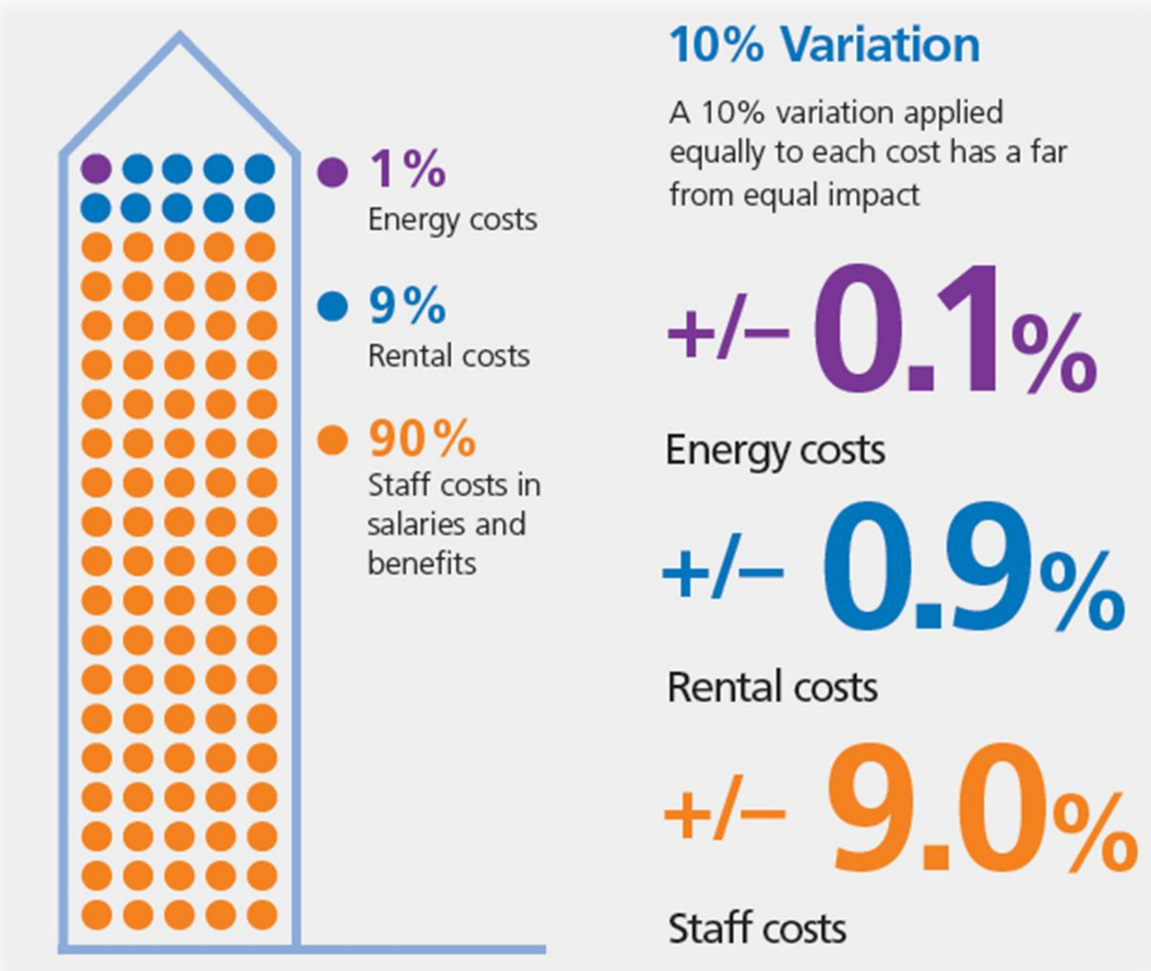
(Image sources: www.npr.org; www.health.clevelandclinic.org; www.benchmarkdigitalesg.com)

New principles reflected in dozen of languages



(Source: Zhang et al. 2019 Sustainability)

Typical business operating costs



Small gains in staff health and well-being can deliver significant financial savings

(Source: World Green Building Council, 2014)

LEED Green Building Rating System

Administered by US Green Building Council (USGBC)

<u>Purpose:</u>

To transform the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life.

- Founded in 1993
- LEED green rating system
- Education and accreditation
- Research promotion
- Greenbuild conferences
- Emerging green builders

LEED Green Building Rating System

- Buildings get “certified”
- People get “accredited” or “credentialed”

LEED professional credentials

LEED Green Associate

A foundational professional credential signifying core competency in green building principles. The exam measures general knowledge of green building practices and how to support others working on LEED projects and is ideal for those new to green building

LEED AP with speciality

An advanced professional credential signifying expertise in green building and a LEED rating system. The exams measure knowledge about green building, a specific LEED rating system and the certification process and are ideal for individuals who are actively working on green building and LEED projects

Why was LEED created?

- Reduce “greenwashing” by developing industry standard
- Promote whole-building, integrated design processes
- Recognize leaders
- Stimulate green competition
- Raise consumer awareness
- Transform the marketplace

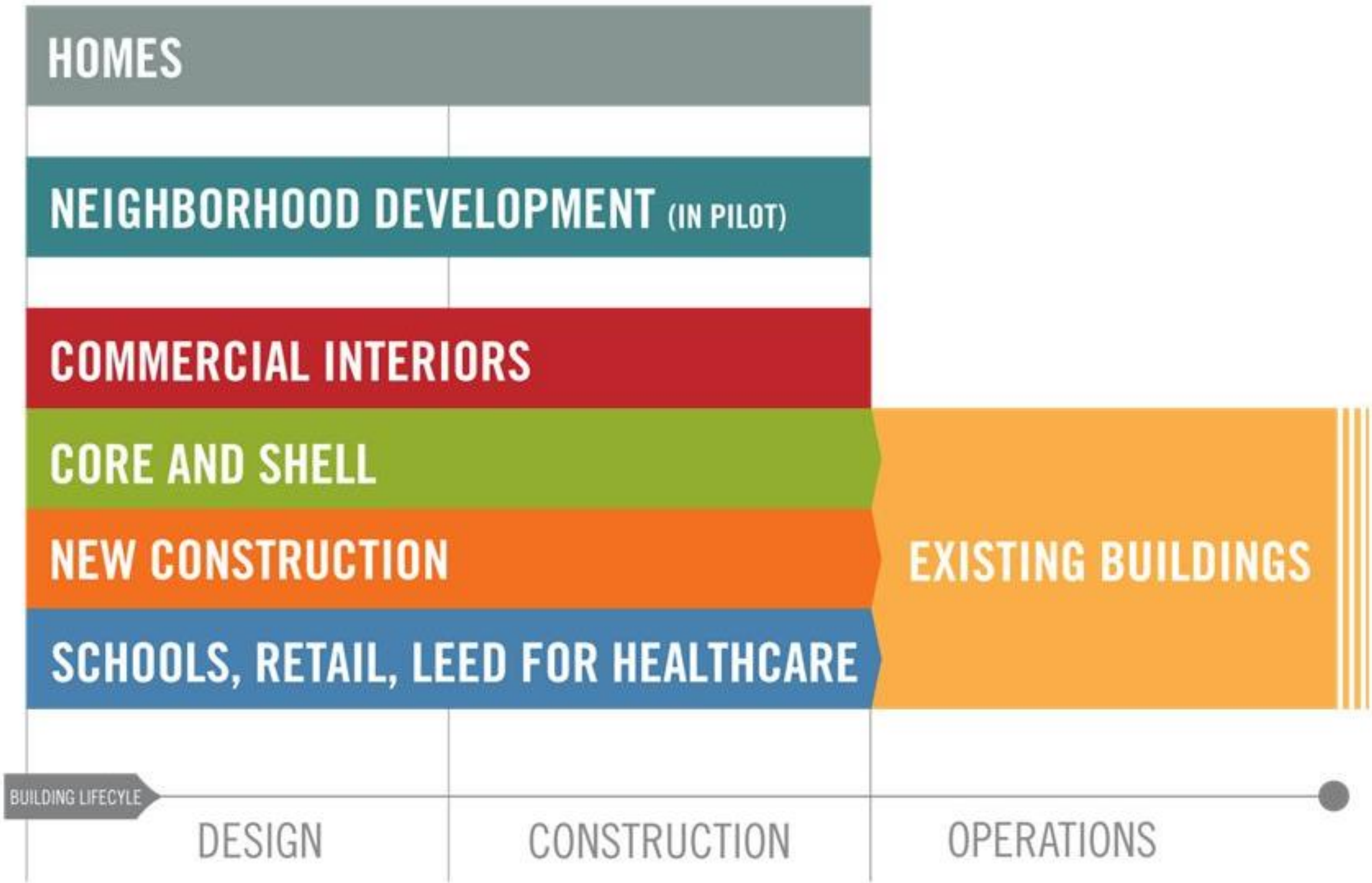
Helen Sommers, Washington

New Balance World Headquarters

Alucobond, München

Business Garden Warsaw

LEED addresses the full building lifecycle



(Source: U.S. Green Building Council)

How does LEED work?

Projects pursuing LEED certification earn points for green building strategies across several categories. Based on the number of points achieved, a project earns one of four LEED rating levels: Certified, Silver, Gold or Platinum

Platinum	**Gold**	**Silver**	**Certified**
80+ points earned	60-79 points earned	50-59 points earned	40-49 points earned

(Source: U.S. Green Building Council)

What are the LEED credit categories?

Each rating system is made up of a combination of credit categories. Within each of the credit categories, there are specific prerequisites projects much satisfy and a variety of credits projects can pursue to earn points. The number of points the project earns determines its level of LEED certification

(Source: healthybuildingscience.com)

LEED: “Energy & Atmosphere” credit allocation

Prerequisite 1	**Fundamental Commissioning and Verification**	Required
Prerequisite 2	**Minimum Energy Performance**	Required
Prerequisite 3	**Building-Level Energy Metering**	Required
Prerequisite 4	**Fundamental Refrigerant Management**	Required
Credit 1	**Optimize Energy Performance**	up to 18 pts
Credit 2	**Enhanced Commissioning**	up to 6 pts
Credit 3	**Advanced Energy Metering**	1 pt
Credit 4	**Renewable Energy**	up to 5 pts
Credit 5	**Enhanced Refrigerant Management**	1 pt
Credit 6	**Grid Harmonization**	up to 2 pts

(Source: LEED v4.1. Note that v5 is being developed)

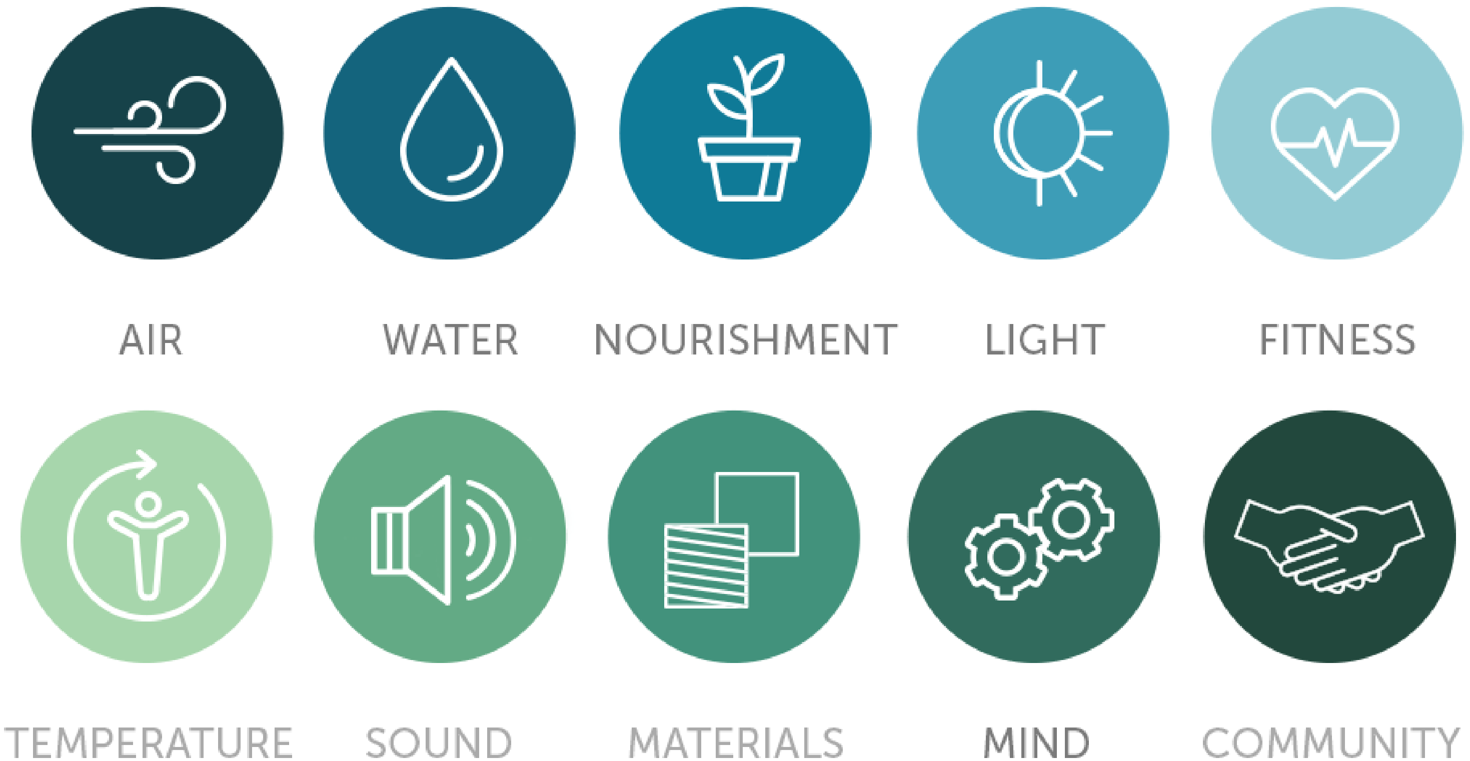
LEED: "IEQ" credit allocation

Prerequisite 1	**Minimum Indoor Air Quality Performance**	Required
Prerequisite 2	**Environmental Tobacco Smoke Control**	Required
Credit 1	**Enhanced Indoor Air Quality Strategies**	up to 2 pts
Credit 2	**Low-Emitting Materials**	up to 3 pts
Credit 3	**Construction Indoor Air Quality Management Plan**	1 pt
Credit 4	**Indoor Air Quality Assessment**	up to 2 pts
Credit 5	**Thermal Comfort**	1 pt
Credit 6	**Interior Lighting**	up to 2 pts
Credit 7	**Quality Views**	1 pt
Credit 8	**Acoustic Performance**	1 pt

(Source: LEED v4.1. Note that v5 is being developed)

A few words about WELL v2…

- Newer green building standards have a new emphasis on features that promote the human experience in buildings
  - WELL is one of the most comprehensive and fastest growing one



(Source: https://v2.wellcertified.com/v/en/overview)

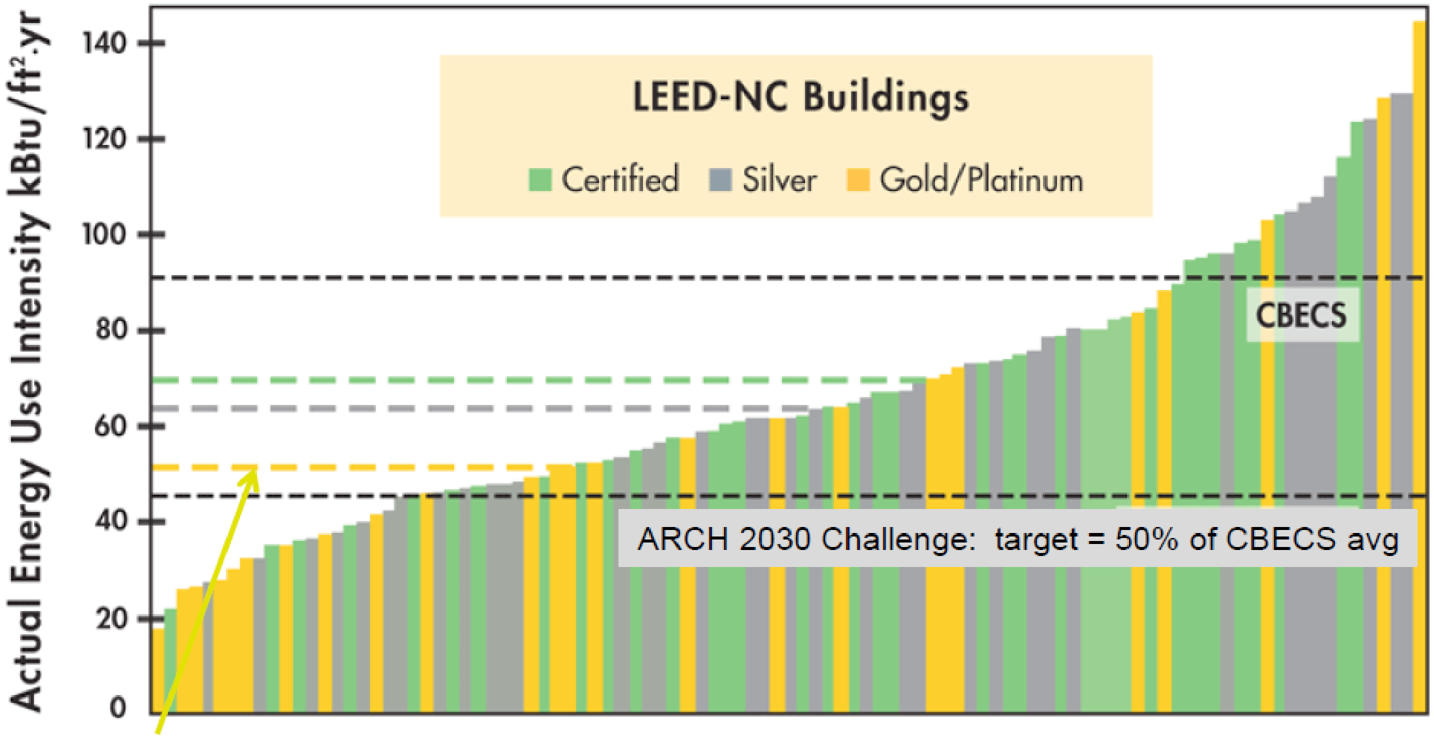
What we know

Key challenges

The envisioned future

Do LEED-certified buildings save energy?

- Depends who (and how) you ask...
  - Actual energy use of individual LEED buildings varies widely
  - Higher level of certification doesn't always result in lower energy use

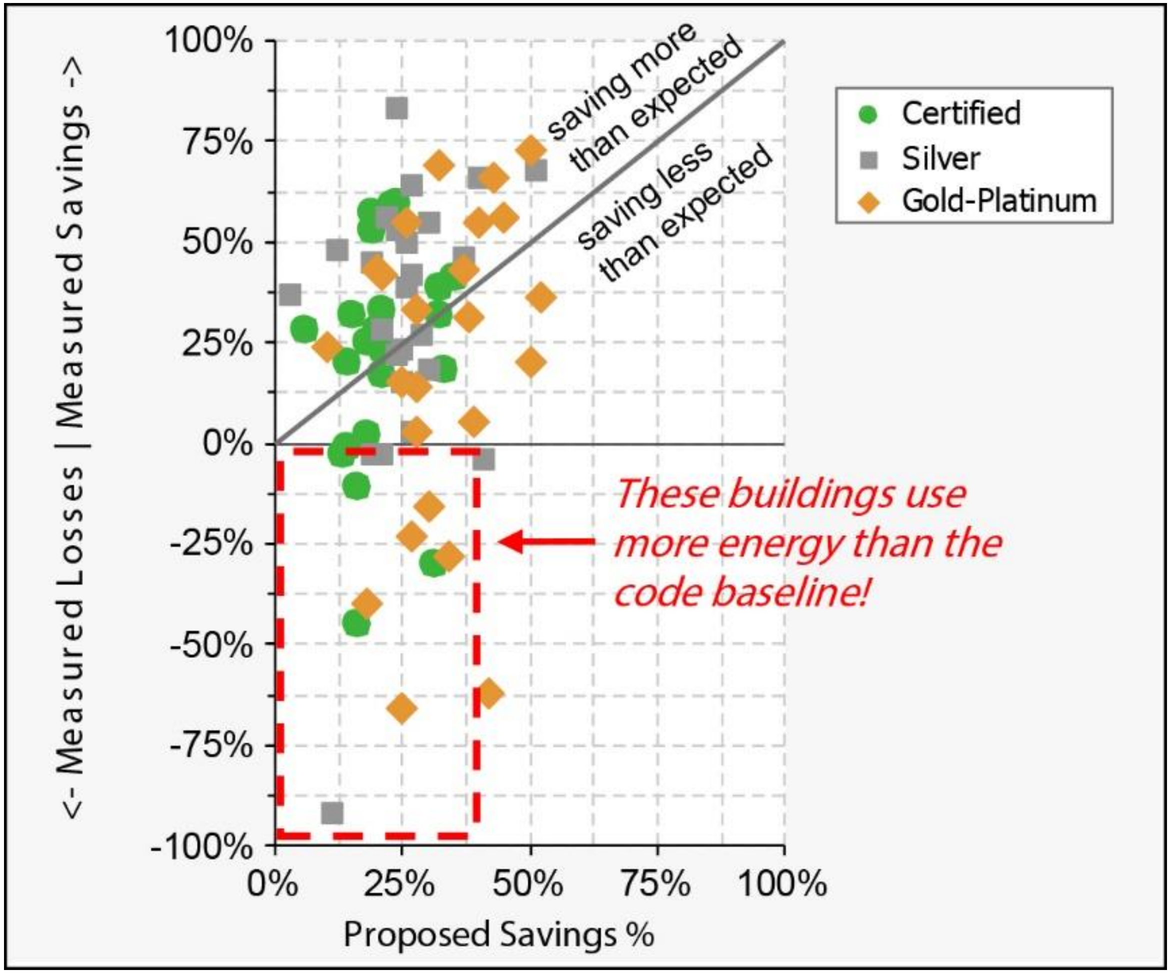


Gold/Platinum bldgs, on average, 45% better than CBECS

(Source: New Buildings Institute)

Predicted vs actual energy use

Most individual buildings use more than predicted, some use less



(Source: New Buildings Institute)

What do the researchers say?

Paper 1

ELSEVIER

Energy and Buildings
Volume 41, Issue 8, August 2009, Pages 897-905

Do LEED-certified buildings save energy? Yes, but...

Guy R. Newsham, Sandra Mancini, Benjamin J. Birt

Paper 2

ELSEVIER

Energy and Buildings
Volume 41, Issue 12, December 2009, Pages 1386-1390

Do LEED-certified buildings save energy? Not really...

John H. Scofield

Controversy:

Same data, 3 different groups analyzing it, 3 different conclusions

"Projects certified by the LEED program average substantial energy performance improvement over non-LEED building stock"

Turner C and Frankel M. 2008. Energy performance of LEED for new construction buildings. New Buildings Institute

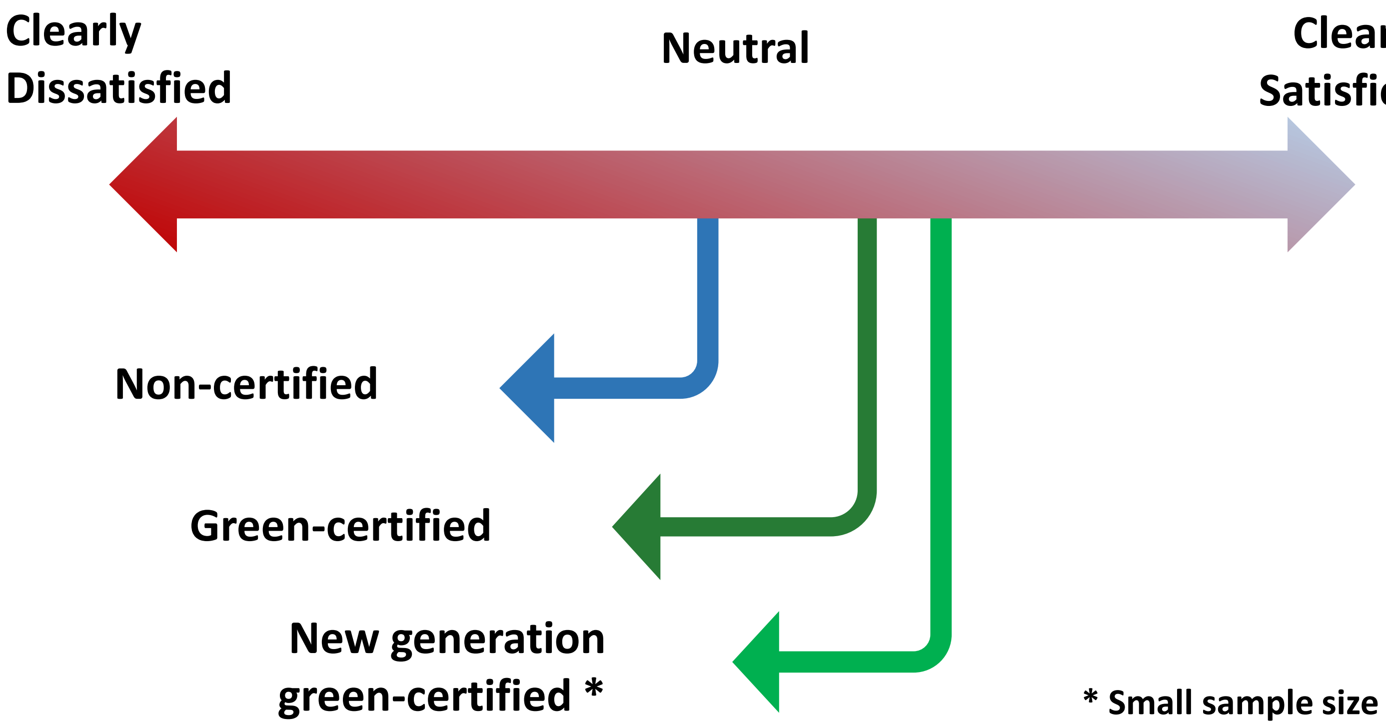
"On average, LEED buildings use 18-39% less energy per floor area than their conventional counterparts……..However 28-35% used more energy than their conventional counterparts ….The measured energy performance of LEED buildings had little (no) correlation with certification level of the building, or the number of energy credits achieved by the building"

Newsham G et al. 2009. Do LEED-certified buildings save energy? Yes, but really…. Energy and Building 41, 897-905 (August)

"The majority of LEED-certified offices are using less energy (site or source) than comparable non-LEED offices (on an individual basis) ……. Collectively, LEED offices (in total) are not using less energy (in particular, source energy) than their non-LEED counterparts."

Scofield J. 2009. Do LEED-certified buildings save energy? Nor really…. Energy and Building 41, 1386-1390 (December)

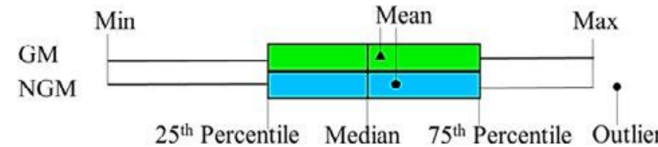
Do green-certified buildings perform better with IEQ?

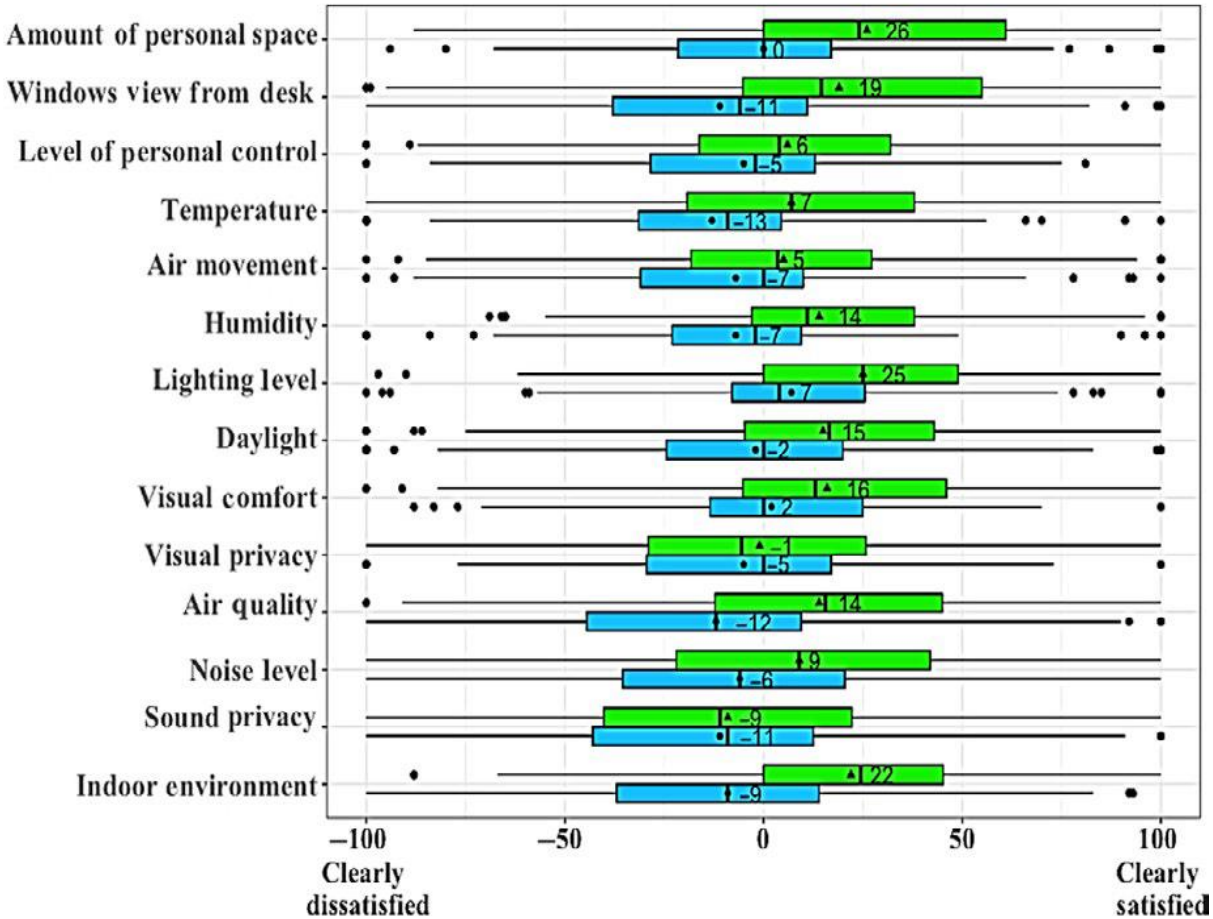


(Adapted from: Lee et al. 2019, Indoor Air; Yildirim and Licina 2021 Building and Environment; Licina et al. 2021 Building & Cities)

How green-certified buildings perform with IEQ?

GM – Green Mark Certified (Gold-Platinum)
NGM – NonGreen Mark

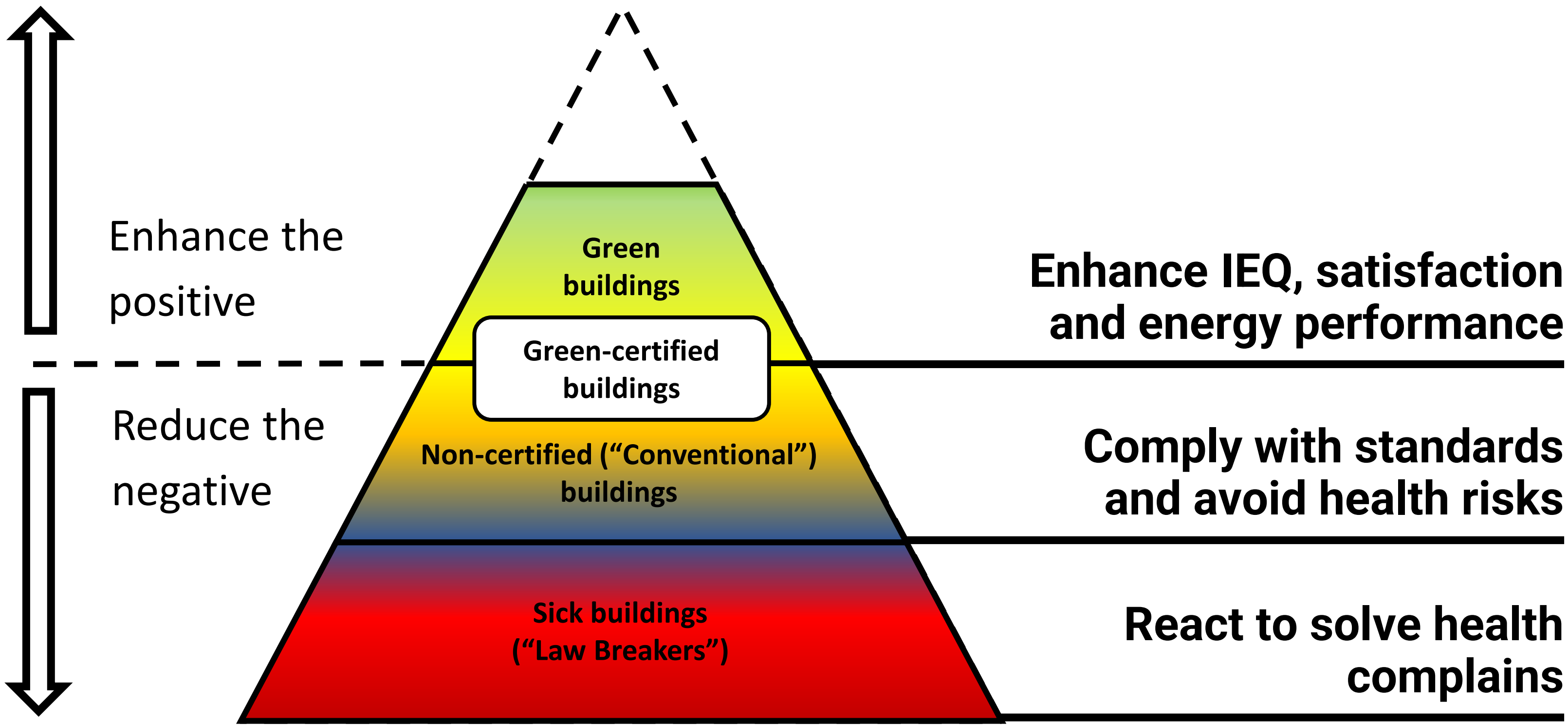




Take-away points:
-Somewhat better performance
-Still below high expectations

(Source: Lee et al. 2019, Indoor Air)

Current building stock



(Adapted from: Licina et al. 2021, Buildings and Cities, 2:1)

Increasing practice of "greenwashing"

- **100'000 new chemicals, mostly indoors**

  (Sources: Weschler 2009; Wang et al. 2020, Rudel and Perovich, 2009; Bornehag and Nanberg 2010)

- **300 studied for health and safety**

  (Source: Allen and Macomber, 2020)

- **Marketed as green but lack evidence**

  (Source: Dahl 2010, Environ. Health Perspectives)

- **Innocent until proven guilty**

  (Source: Allen and Macomber, 2020)

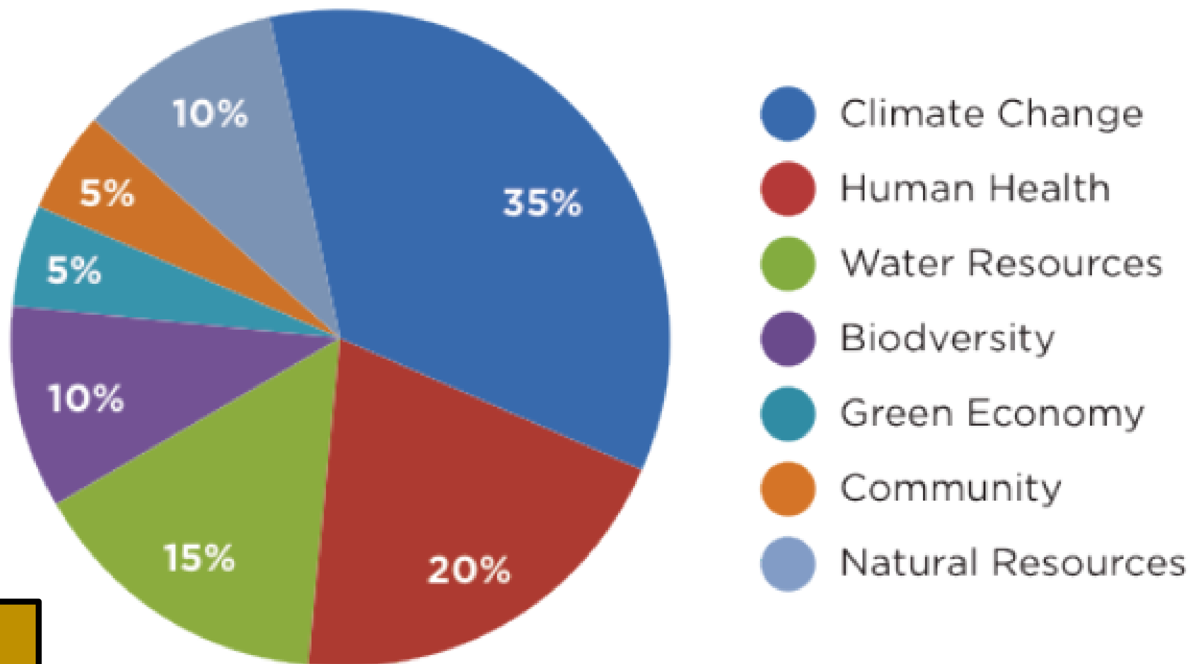
Challenges of current green rating systems

Significant gap between relative emphasis on energy related features and those that focus on occupant health

Low credit percentage related to IEQ

- LEED: now 20% (it used to be 15%)
- All programs: only ~10%

Projects achieve certification without an emphasis on IEQ



(Sources: Doan et al. 2017; Licina et al. 2019; Teichman et al. 2015; Wei et al. 2020 BAE; LEED V4)

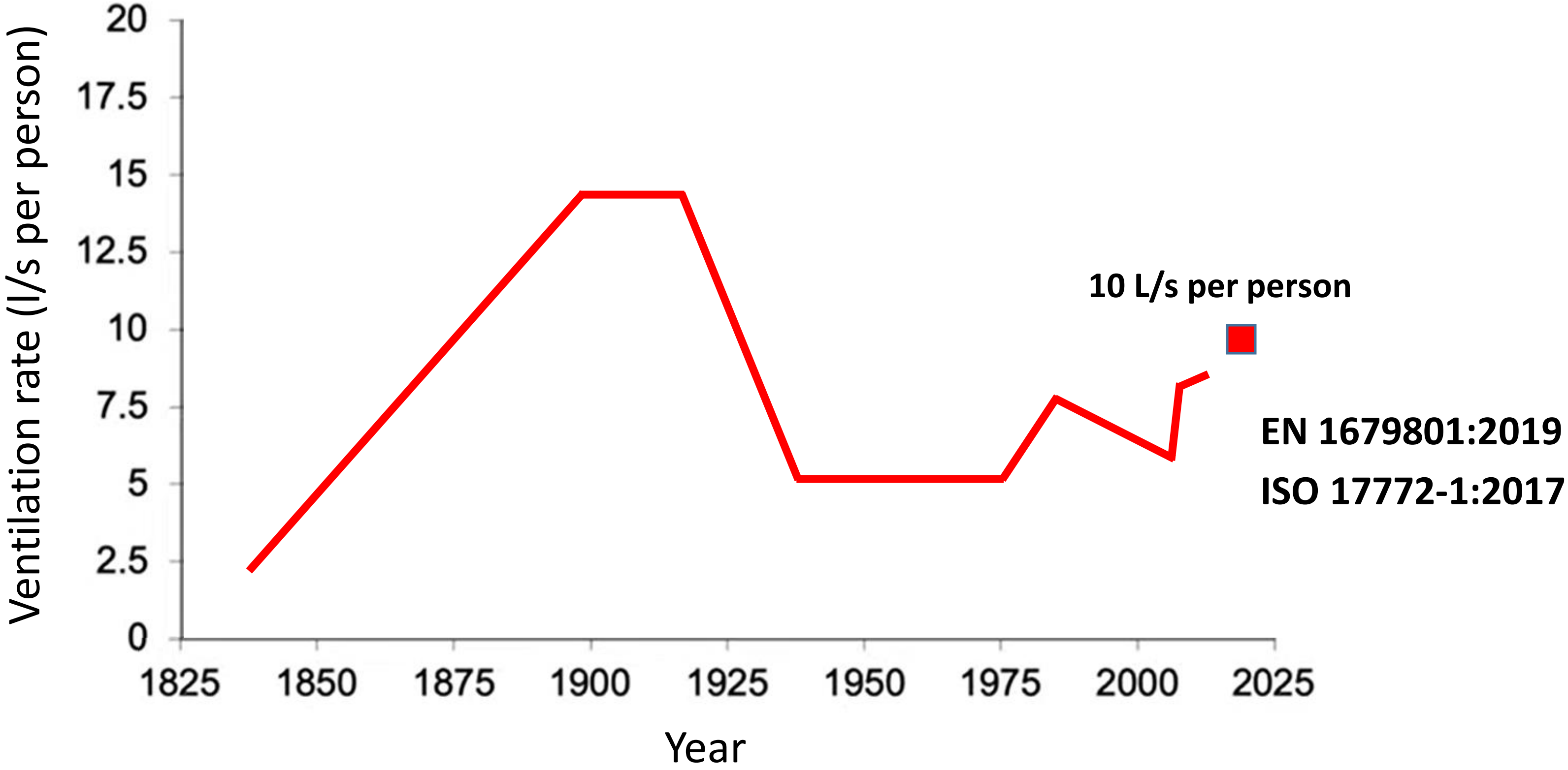
Why has energy rules since the 1980s?

Potential causes for lower focus on humans relative to energy

- **Wide-spread belief that GHG emissions reduction and energy efficiency are the most important requirements, and the main externalities, for building performance**
- **Energy is metered and billed while the economic impact of productivity and health effects are hard to estimate (especially when people inhabit different buildings)**
- **Misaligned incentives between occupants, building owners, designers and other stakeholders. Industry (and individuals) can pay the cost but don't necessarily receive the benefits**
- **Traditional belief that human health benefits happen only indirectly, e.g., via reduction of environmental impacts. And hard to motivate people about chronic health endpoints that may occur decades in the future**
- **Lack of education for HVAC designers on indoor environmental quality and its comprehensive influences on humans beyond thermal effects**
- **Short-term vision implying that focusing on indoor environmental quality is associated with additional energy and investment costs**

(Source: Licina et al. 2021 Buildings & Cities)

Historical requirements for ventilation



(Adapted from: Jansen 1999; ASHRAE Journal; ASHRAE Standard 62.1)

Challenges of current green rating systems

Minimum acceptability requirement (typically 80% satisfaction) and neglecting individual preferences

Objectives to minimize adverse health effects

No objectives to promote human health beyond the avoidance of adverse health outcomes

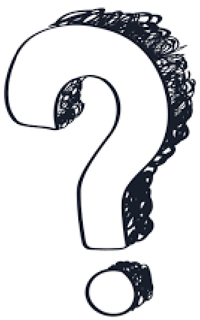
Relationship between green rating systems and standards/codes:

- **39% rely on ASHRAE, 23% rely on CEN**
- **Others rely on local regulations**
- **Optionally, green rating systems encourage incremental improvements beyond the baseline conventional standards**

(Sources: Wei et al. 2015; Persily, 2015)

Performance measurement

- Optional (for extra credits)
- Prescriptive & episodic



Prescriptive, episodic

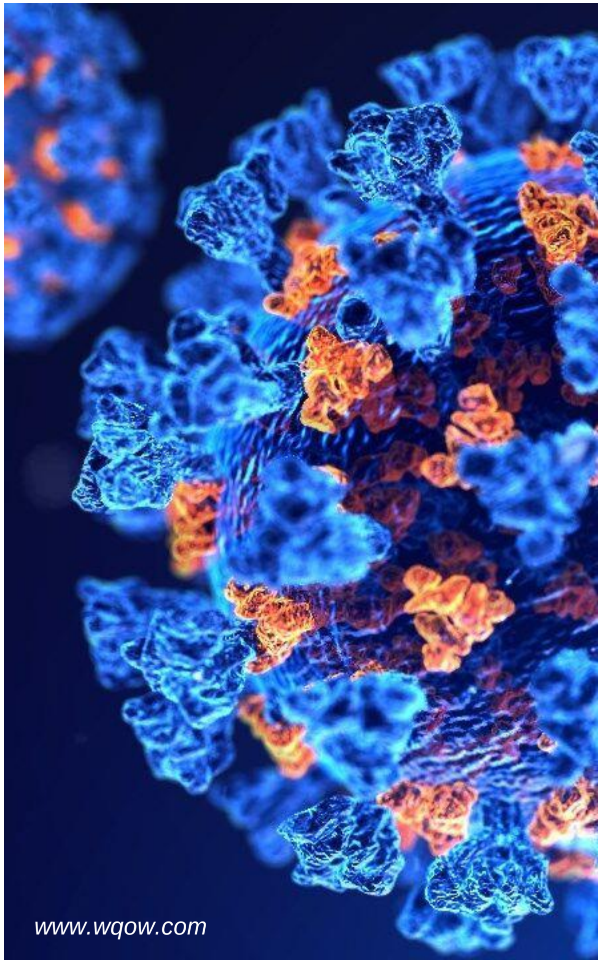
- Little (or no) data
- Slow, indirect feedback
- “Generic” solutions
- Rare, expensive knowledge

Performance-based, continuous

- Ubiquitous data
- Fast and iterative feedback
- Place-based solutions
- Widespread expertise

(Sources: Morawska et al 2018 Environment International; Schieweck et al. 2018 R&S Energy Reviews; Licina et al. 2021 Buildings & Cities)

Planetary challenges

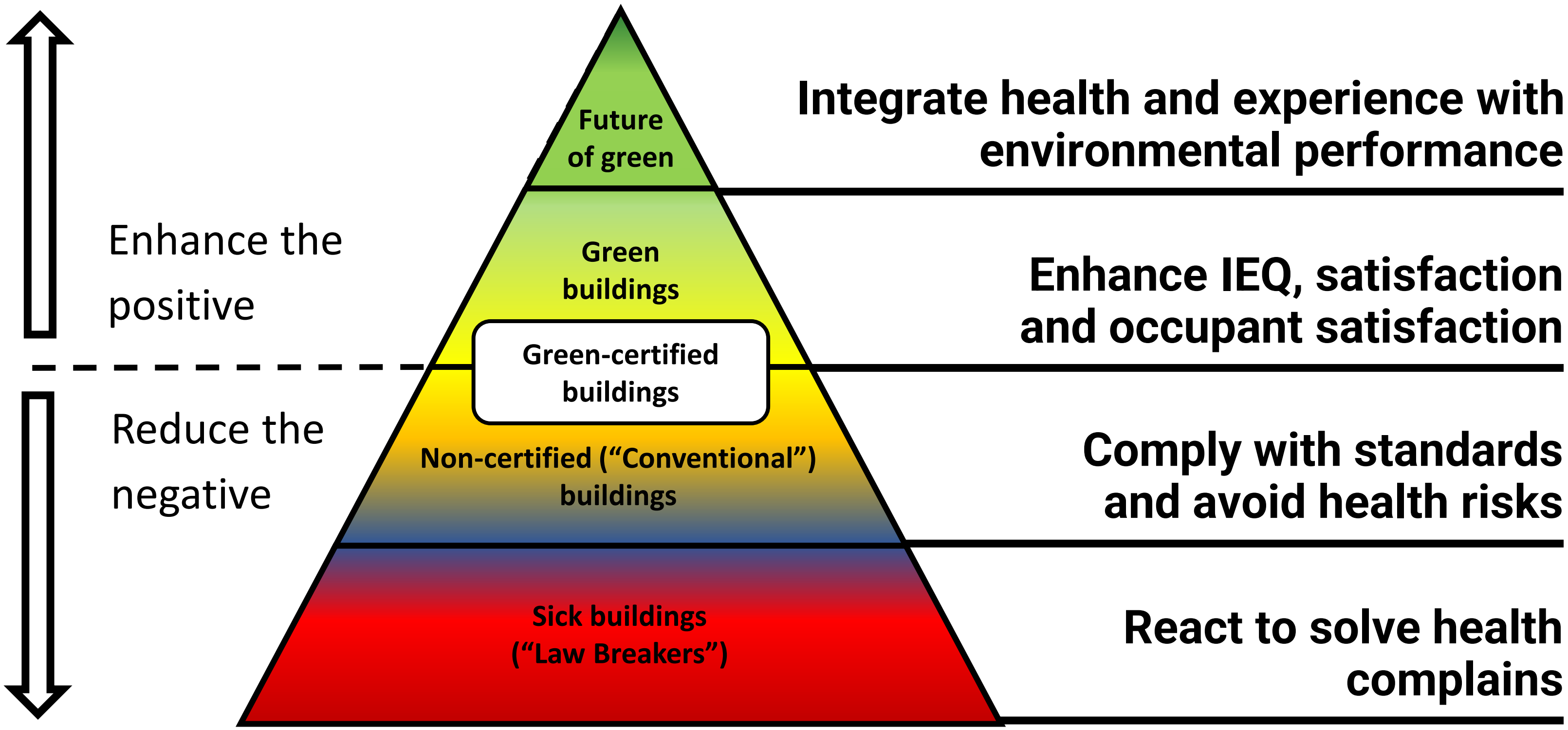


What we know

Key challenges

The envisioned future

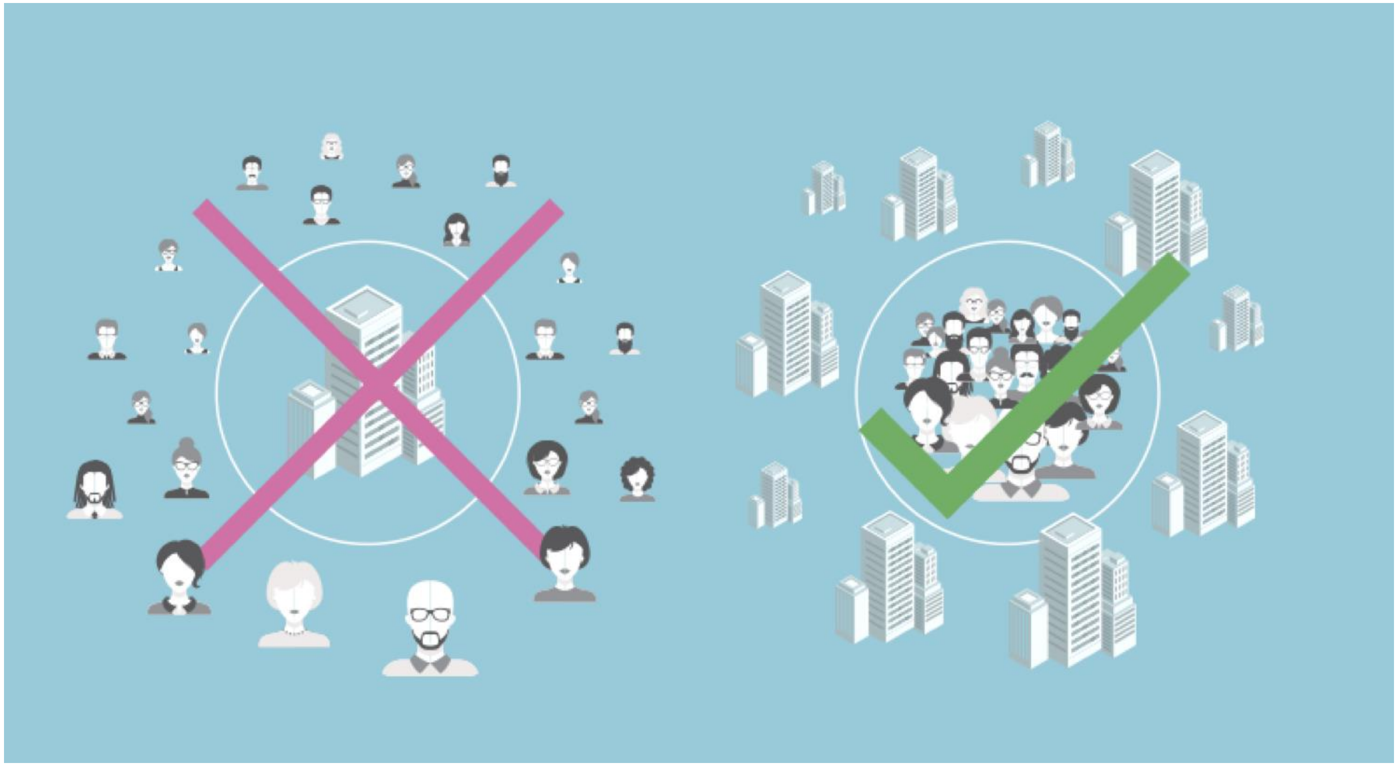
Envisioned future of green buildings



(Adapted from: Licina et al. 2021, Buildings and Cities, 2:1)

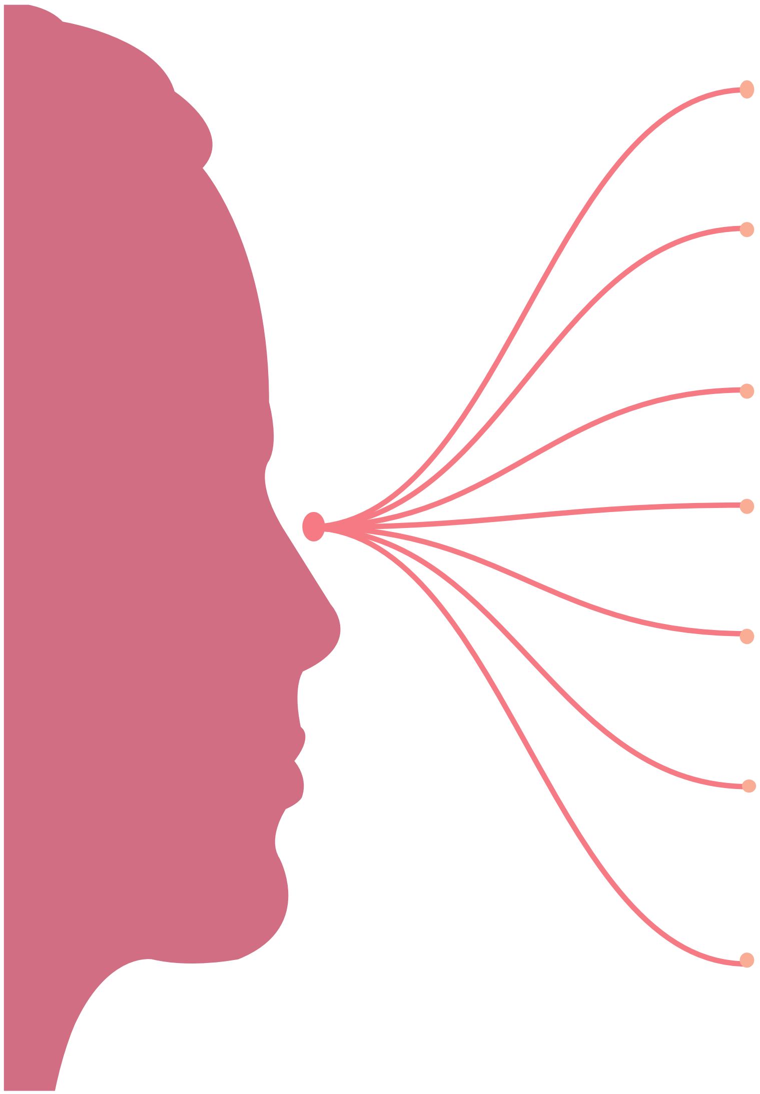
Closing thoughts…

- Building are primarily for people! Is that taken into account when energy savings measures are implemented?



- **Envisioned future of green buildings: Integrated management of human experience and energy performance**

Summary of what we learnt so far today…



- Building codes & standards define minimum requirements that must be met
- Green building rating systems are voluntary and encourage building, designing and operating better buildings than standard ones
- Newer generation of green rating systems have been putting more attention to indoor environmental quality
- These requirements are also pushing existing building codes and standards to improve
- Green-certified buildings seem to provide improved indoor environmental quality; however, there are still relatively far from there we would like to be
- Green-certified buildings seem to save energy compared to standard buildings; however, their energy use varies widely
- The envisioned future of green buildings must include integrated management of human and environmental performance

Interested in more info?

- World Green Building Council: https://www.worldgbc.org/our-regional-networks/europe
- GBCI: www.gbci.org
- GreenBuild conferences: https://informaconnect.com/greenbuild/
- Minergie: www.minergie.ch/fr/
- Online shows on IEQ and energy: https://global.healthyindoors.com/s/online-shows/
    - My interview: https://global.healthyindoors.com/c/indoor-environments/12-19-22

STRETCH !

GROUP DEBATE

Prioritizations and Trade-offs between Energy and Occupant Needs in Buildings

Structure of the debate

Group Formation: Divide into 6 groups with diverse student backgrounds.

Roles: Assign at least 1 spokesperson in each group to present views.

Questions:

- 3 key questions, 2 groups per question.
- One group advocates for a direction; the other argues against it.
- Prepare arguments and rebuttals.

Process: Groups summarize key arguments, followed by cross-group debates to challenge and deepen understanding.

Discussion Rounds (10 mins prep + 20 mins debate)

Conclusion and Group Reflection (10 mins)

- Summarize discussions and lessons learned.
- Reflect on challenges and nuances of the topic.

3 Rounds (10 mins prep + 20 mins debate)

Round 1: Groups 1 and 2 discuss and present arguments for and against the first question - "*Mechanical cooling in a global context: Can we get rid of it or is it an absolute necessity?*“

Round 2: Groups 3 and 4 focus on the second question - "*Building design for likeability or environmental performance?*“

Round 3: Groups 5 and 6 delve into the third question - "*The role of technological innovations versus education & occupant behavior in optimizing energy use and ensuring occupant comfort?*"

EXAM 2

BRIEFING

Exam II Details

- **When**: **December 12, 9:15-11:00**
- **Exam duration: 100 min**
- **Content**: Based on materials presented in second half of the course (weeks 8-12)
  - Week 8: Heat transfer, solar geometry, solar heat gain, daylighting
  - Week 9: Building envelope, thermal performance of building elements
  - Week 10: Heating and cooling demand in buildings
  - Week 11: Thermal systems for heating and their effect of human comfort
  - Week 12: Thermal systems for cooling and their effect of human comfort
- **Format**: **Open book, no internet**
- **Location**: **CE 1106**
- Arrive to the exam room earlier, by **9:10** at the latest

Exam II Details

- **Format of questions:**
  - **Multiple choice questions**
  - **Calculations:** be sure to understand the calculation exercises from class and clicker questions, elaborate on how you arrived at a particular result
  - **Open ended questions**
- **Language**: English only
- **Total number of points**: **35 pt**
- **Number of questions**: **~15**

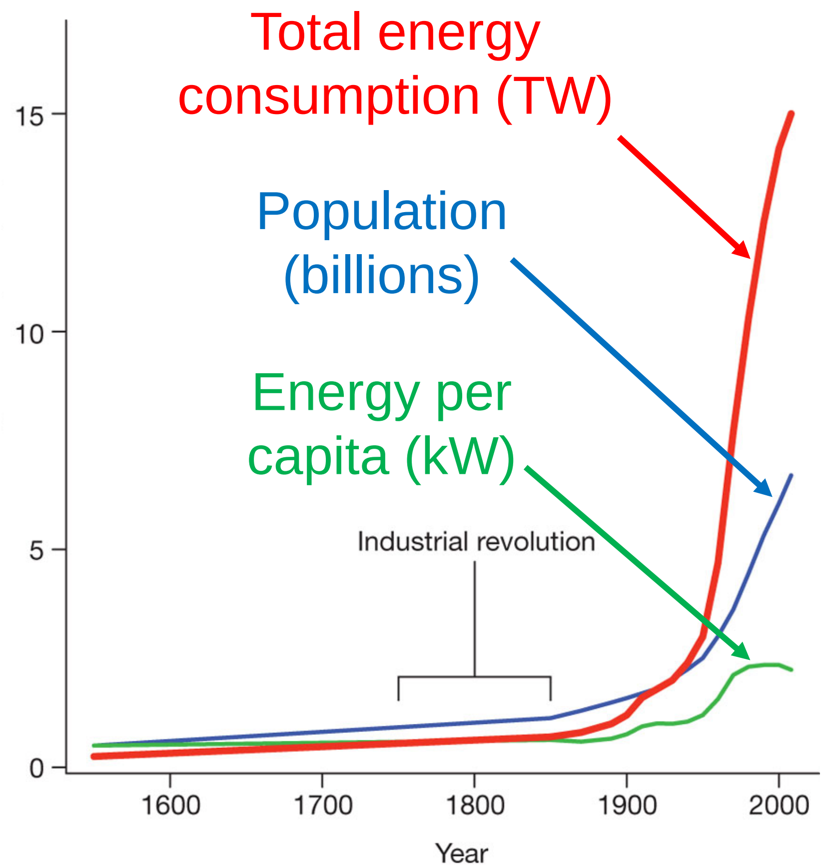
COURSE REVIEW

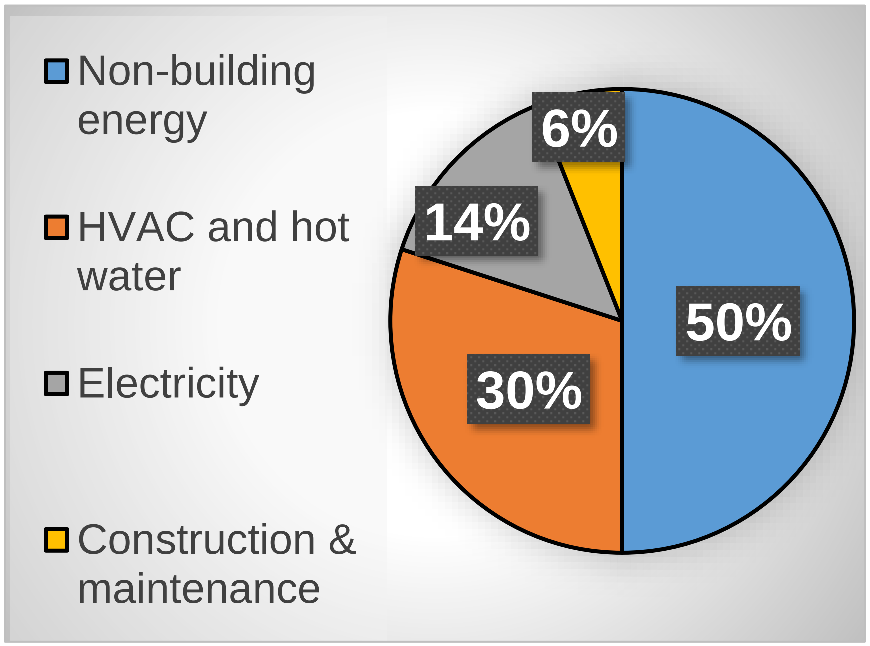
+

Q&A

Review from the W01: Buildings and Climate

- 8 billion humans emit to the atmosphere ~8 billion tonnes of fossil carbon per year
- Lots of the environmental impact is related to buildings

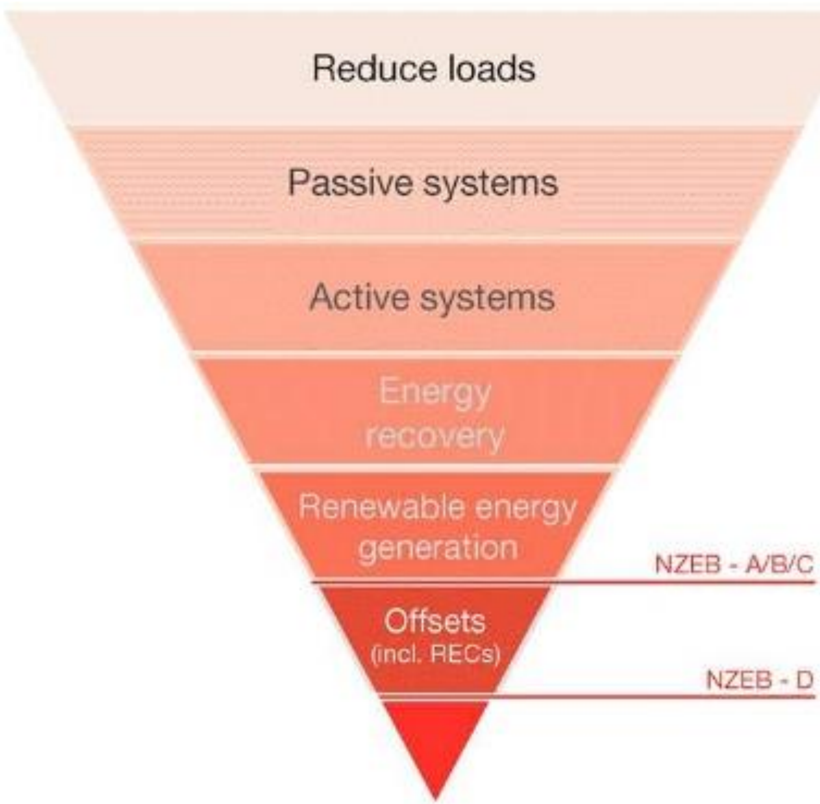


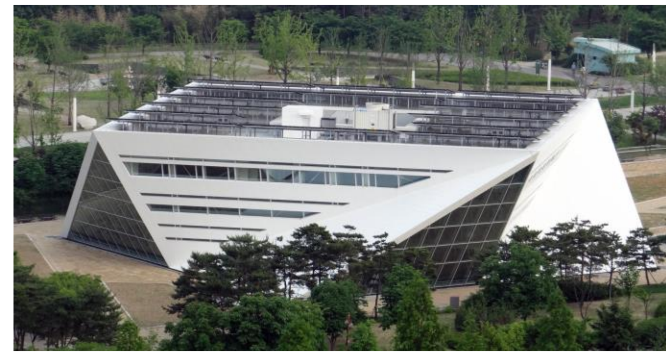


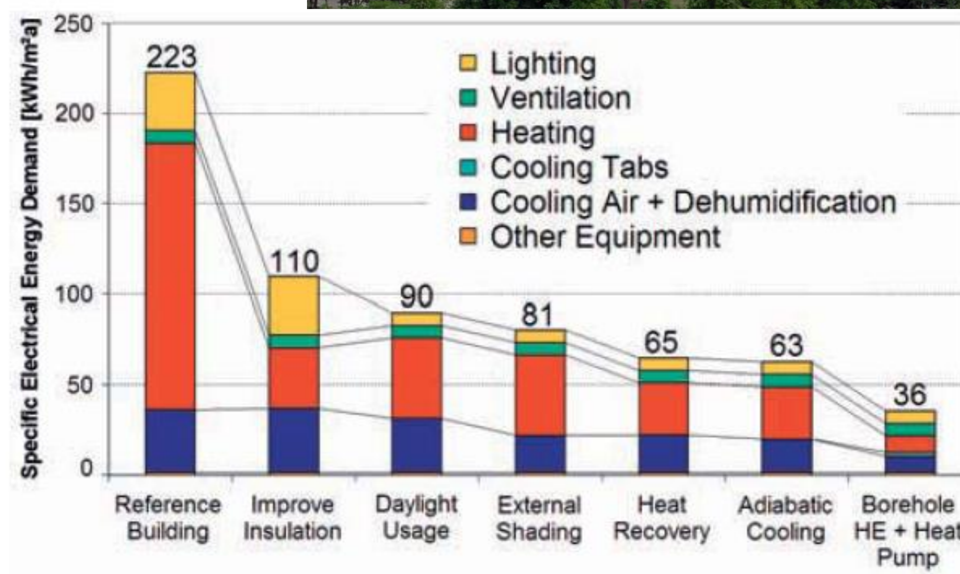
(Sources: Ehrlich et al. 2012, Nature; Swiss Federal Office of Energy)

Review from the W01: Hierarchy of actions

- Net Zero Energy Buildings: Setting priorities







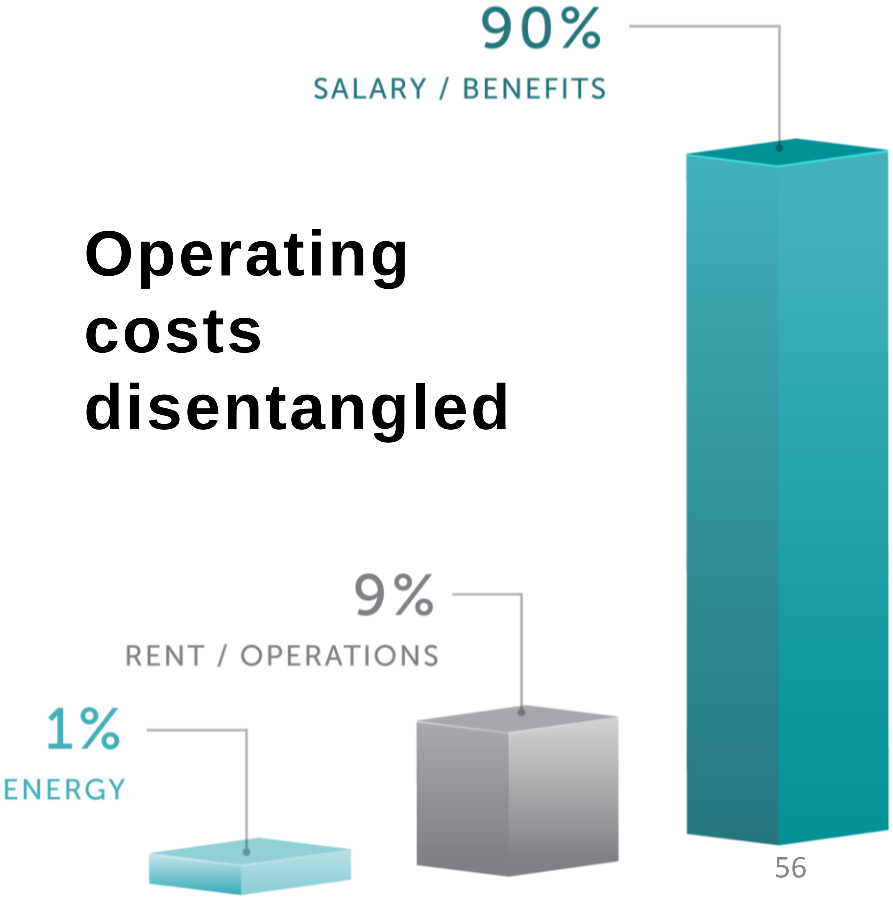
(Source: Two Degrees, Chap 6, McGregor, Roberts & Cousins; Seoul Energy Dream Center – Fraunhofer ISE info folder)

Review from the W01: Value of Humans

- Human comfort – why does it matter?

Comfort vs. Energy?

Operating costs disentangled



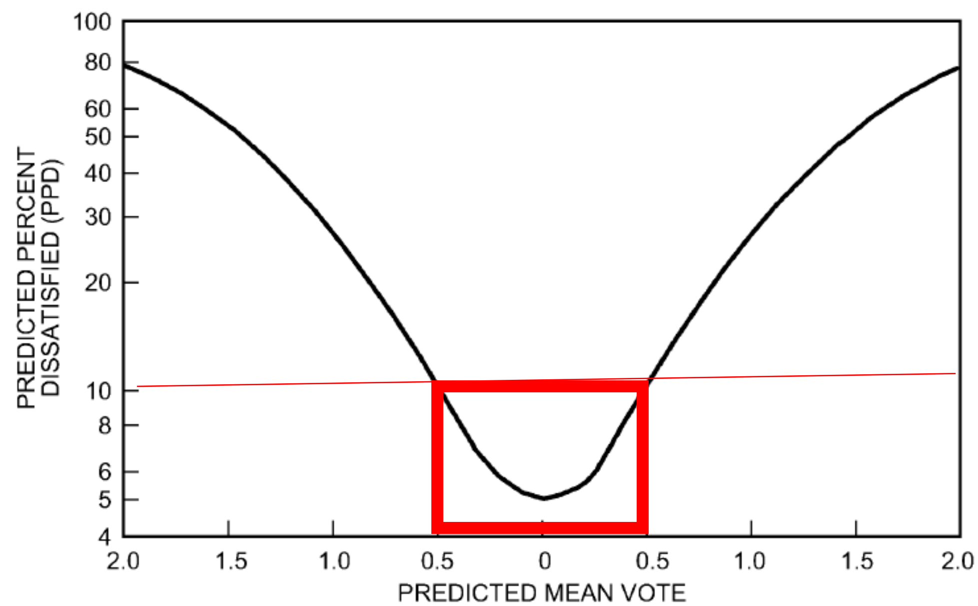
Review from the W02: TC Assessment

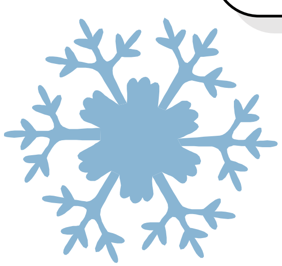
Thermal comfort assessment

- Actual thermal comfort
  - Occupancy surveys
- Predicted thermal comfort
  - PMV/PPD
  - Adaptive

-0.5 < PMV < +0.5

PPD < 10 %





Review from the W02: Overheating

Causes:

- Climate change
- Urban Heat Island (UHI)
- Regulatory requirements related to insulation and airtightness
- Various design and operation (mis)practices
- Occupant (mis)behavior

Solutions: They must start from passive approaches!

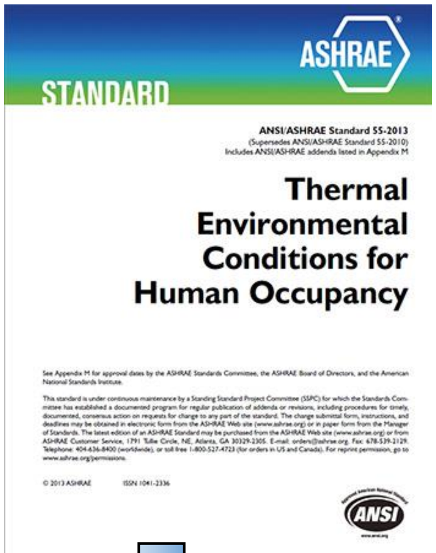
Limit sources of heat gains – External

Limit sources of heat gains – Internal

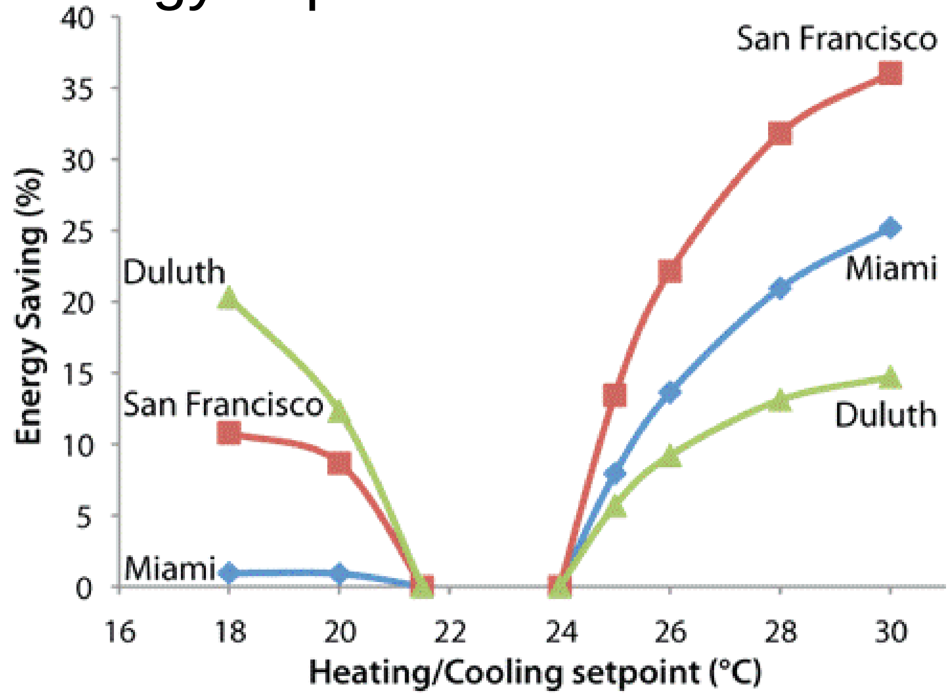
Provide capacity to purge excess heat

Review from the W02: TC and Energy

- Standard requirements and energy implications

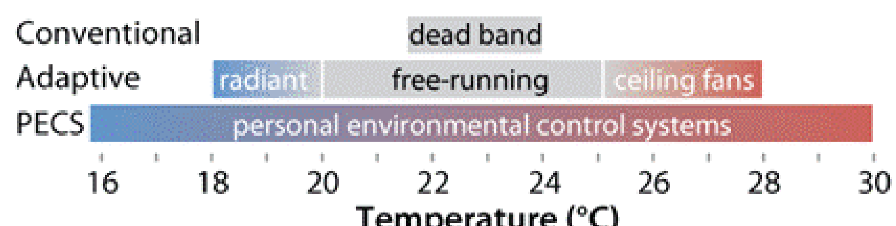


- ASHRAE 55
- ISO 17772
- EN 16798
- ISO 7730



1. PURPOSE

The purpose of this standard is to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space.



(Source: Hoyt et al. 2015, Building and Environment)

Review from the W03: IAQ & Ventilation

Ventilate well

Ventilation rate (dilution)

Room air distribution

Two methods for determining needed ventilation rate:

Prescriptive procedure

Widely used - the minimum ventilation rates determined based on tabular values from the standards (widely used). These are similarly derived as for the thermal comfort PMV/PPD model.

Analytical procedure

Involves calculation of the required ventilation rate based on a mass balance equation (less used)

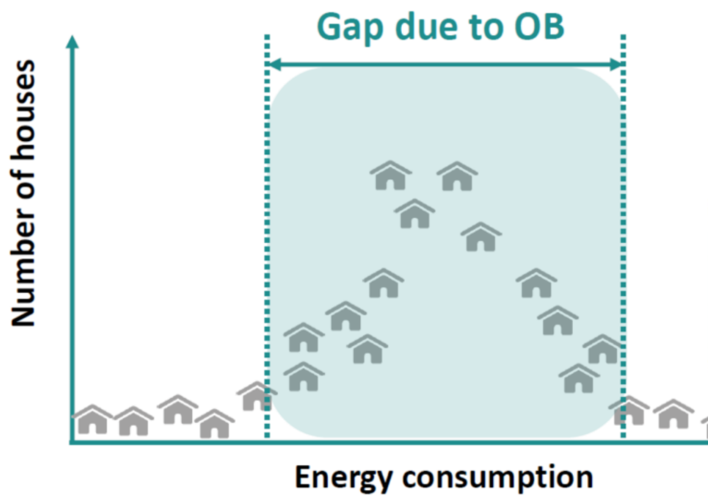
Review from the W04: Strategies that can support both energy efficiency and IAQ

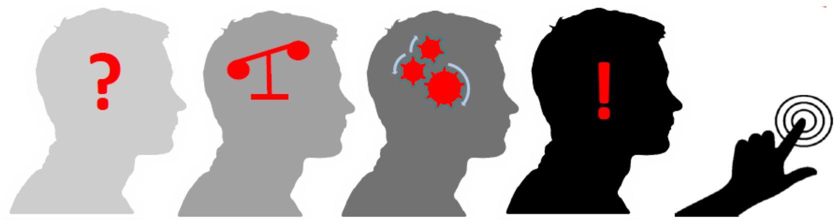
1. Natural ventilation and ventilative cooling (where outdoor air is clean)
2. Mixed-mode (hybrid) ventilation (where outdoor air is clean)
3. Economizer operation
4. Envelop tightness (where outdoor air quality is poor)

We should first always explore potential of passive techniques

5. Improved air distribution (vent. effectiveness)
   - Displacement ventilation
   - Personalized ventilation
6. Heat recovery ventilation
7. Demand controlled ventilation
8. Dedicated outdoor air systems
9. Efficient air filtration and air cleaning

Review from the W05: Human Behavior



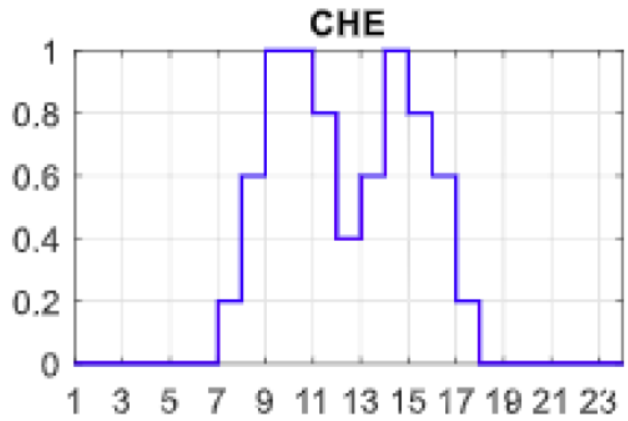


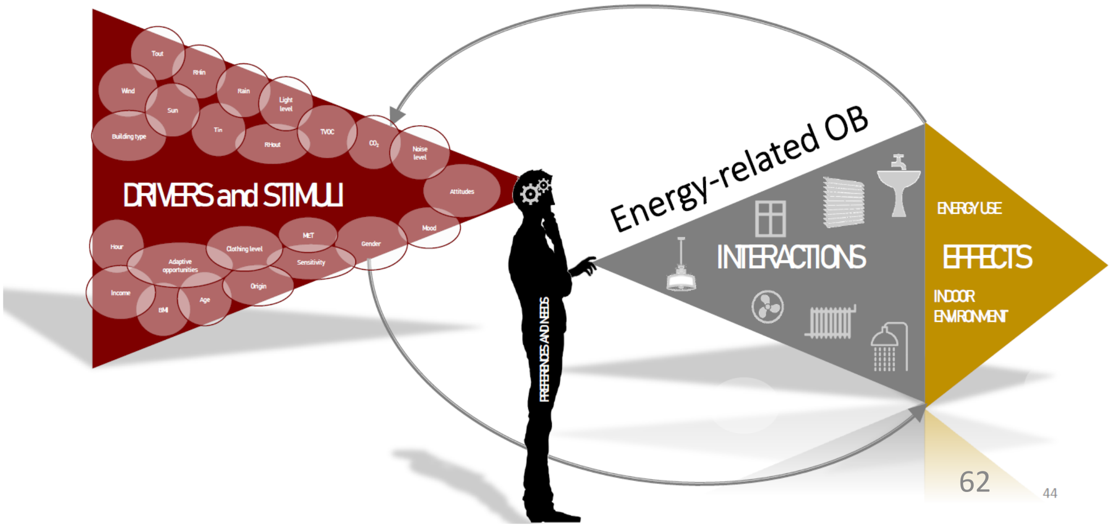
Physiological adjustments

Individual adjustments

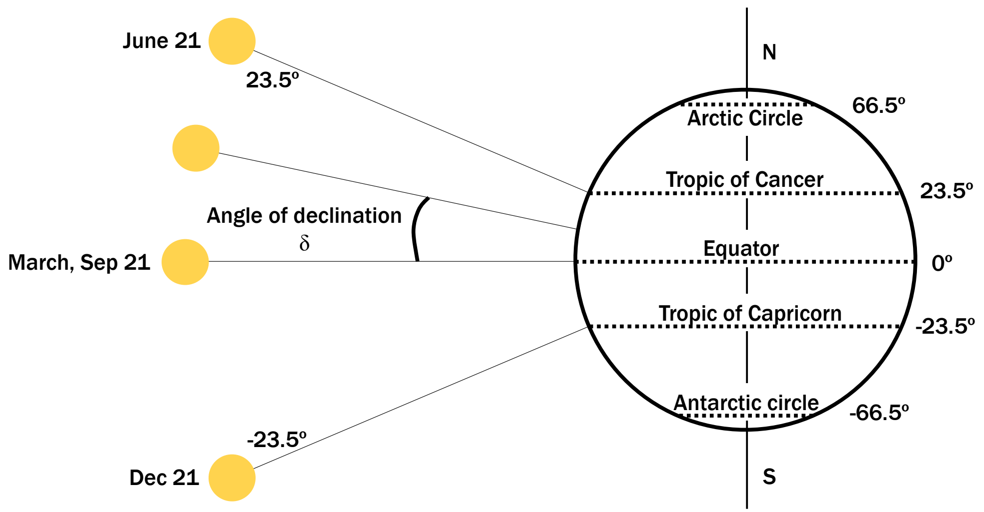
Environmental adjustments

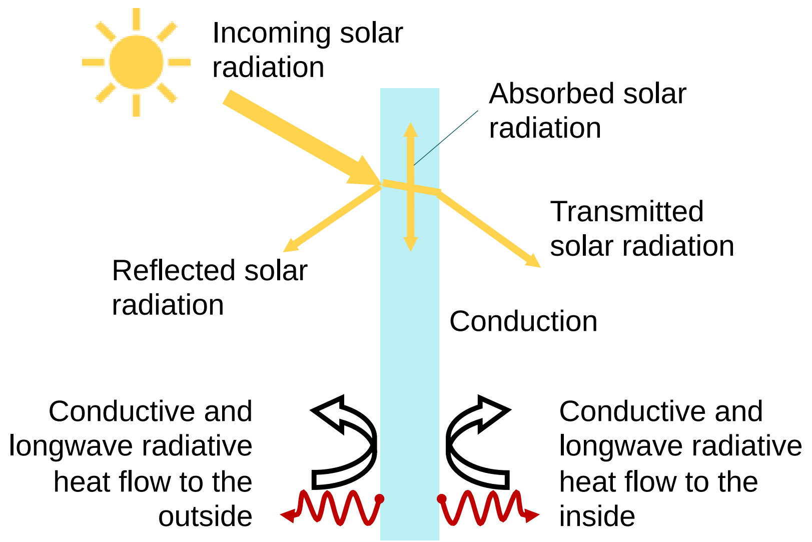
Spatial adjustments

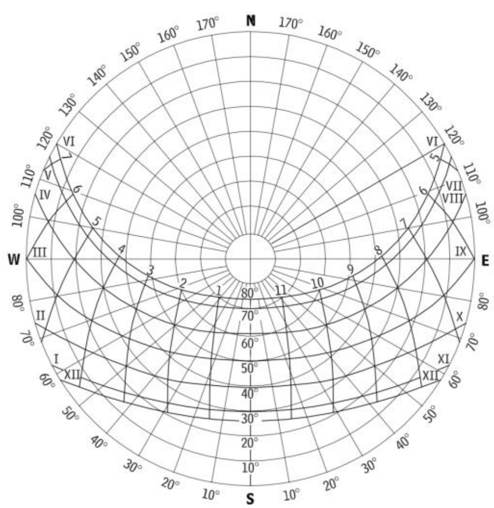




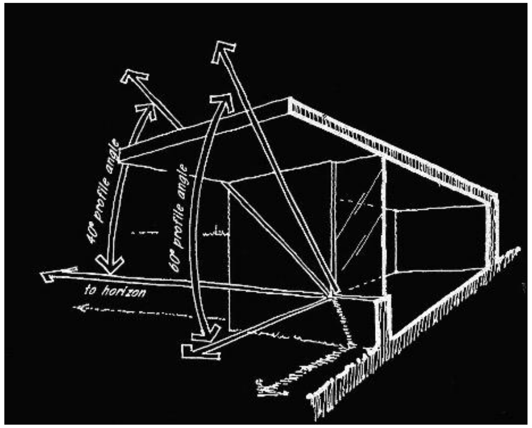
Review from the W08: Heat transfer, solar heat gain, daylighting

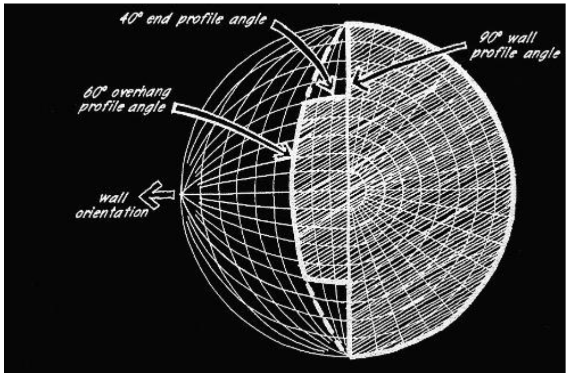






Sun path and shading masks





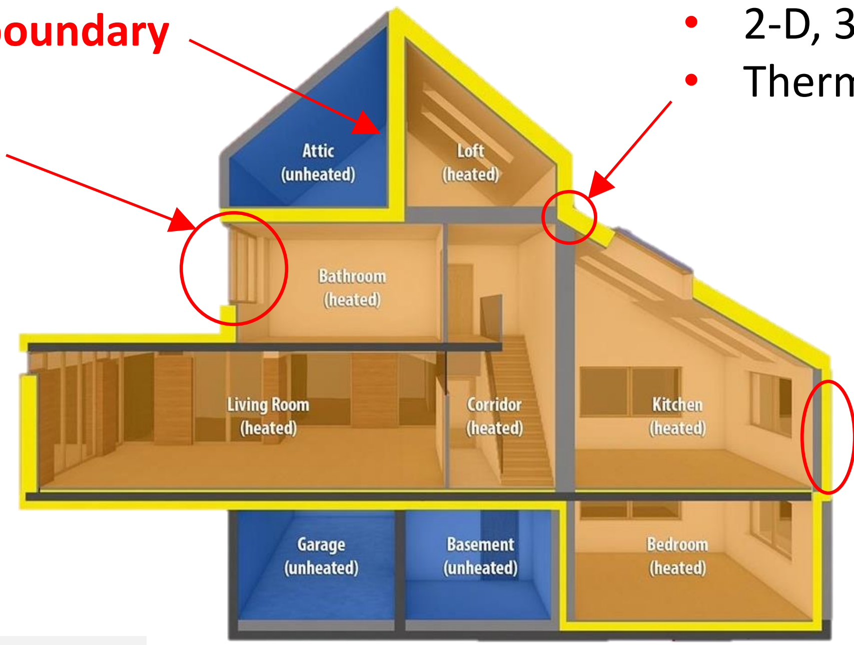
Review from the W09-10: Building Envelope

- An enclosure that maintains *stable indoor environment for comfort of occupants*

Thermal boundary

Thermal Bridges (linear, point)
- 2-D, 3D heat transfer analysis
- Thermal transmittance $\boldsymbol{\psi}$ and $\boldsymbol{\chi}$

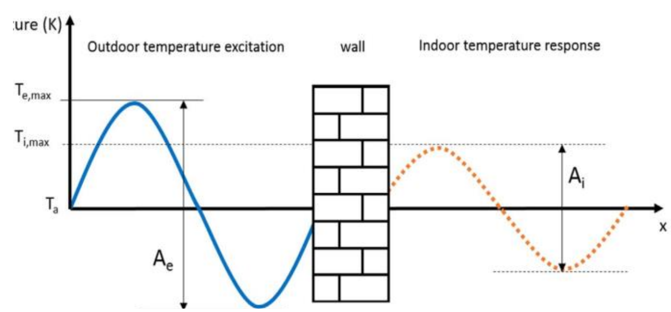
Transparent elements
- Conductive heat transfer (**U_w, U_g, U_f, ψ_f**)
- Radiative heat transfer (**g-value**)
- Infiltration losses



Opaque elements
- 1-D heat transfer analysis
- Insulative capacity (**U-value, R-value**)
- Heat transfer pathways (parallel and in a series)
- Thermal mass effect
- Time lag $\boldsymbol{\varphi}$ and decrement factor $\boldsymbol{f}$
- Diurnal variation of the heat flow

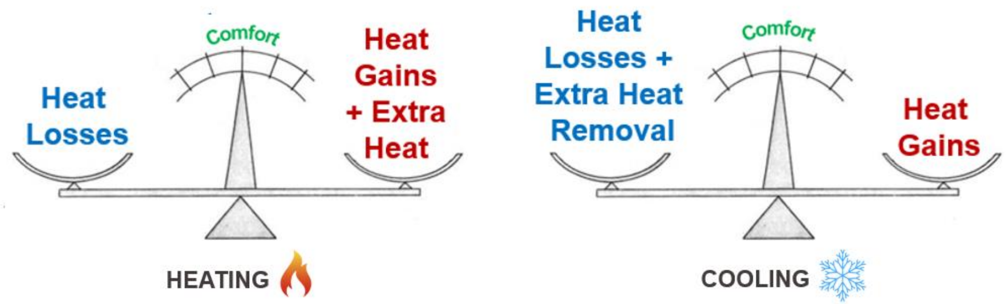
Also…

- **Limiting** (standardized) values of **U-value** for *renovated* and *new* buildings



Review from the W10: Heating & Cooling Demand

Indoor **Heating** and **Cooling** Demand:

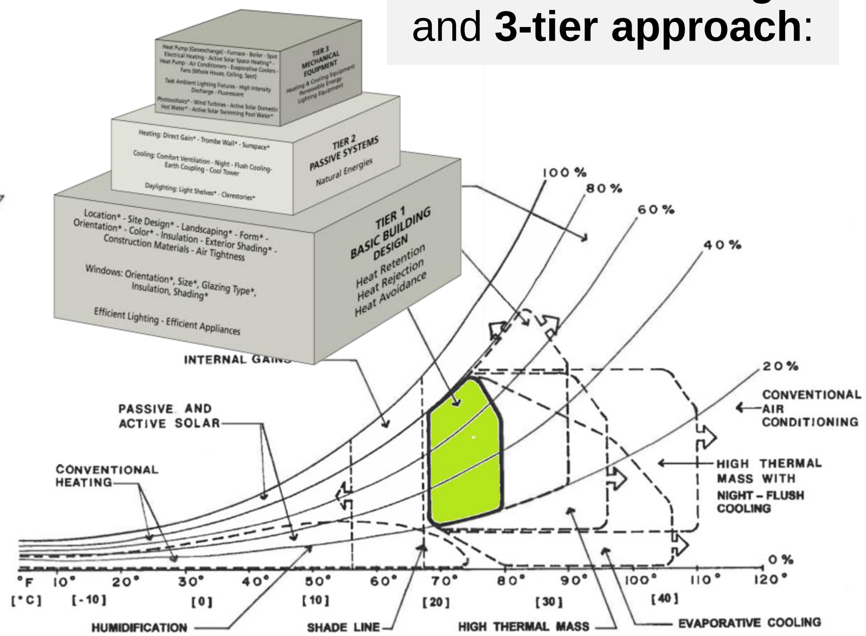


Heating	Cooling
To **minimize** the **demand** (consequently, *minimize operational energy*):	
• Consider dynamics of solar and internal heat gains • Maximize solar heat gains • Consider heat storage capacity of materials • Consider heating modes (radiative vs. convective)	• Minimize solar and conductive heat gains • Consider time lag effect and the heat storage of materials • Minimize infiltration heat gains • Use efficient appliances (minimize internal heat)
To evaluate **maximum demand** for *equipment **sizing** purposes*:	
• Ignore solar and internal heat gains • Ignore heat storage capacity of materials • Consider heat losses to be *instantaneous* • Consider heat transfer as essentially *conductive*	• Separately treat *convective* and *radiative* portions of heat gains • Consider the time lag effect • Consider the heat storage effect

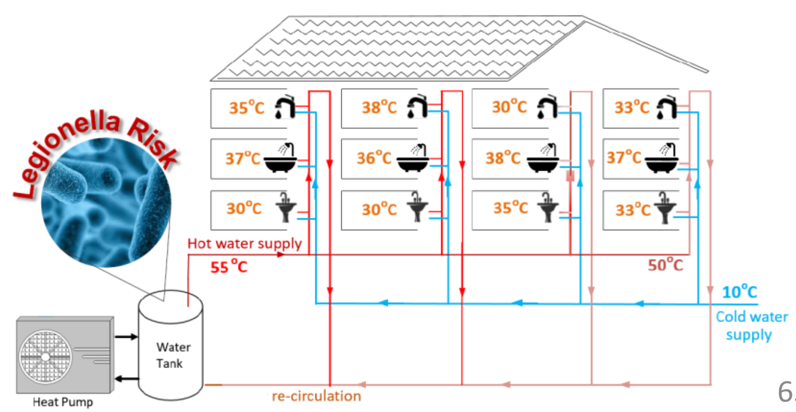
- **Energy demand in buildings** dependent on climatic conditions / generation of buildings / type of buildings / occupants behavior

- **Hot water:** temperature of water generation depends on the **legionella risk**, and the **standard demand** depends on the type and number of fixture

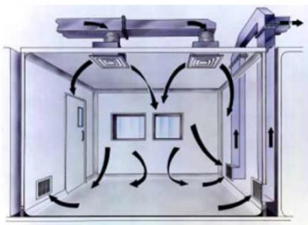
Bioclimatic design and **3-tier approach**:



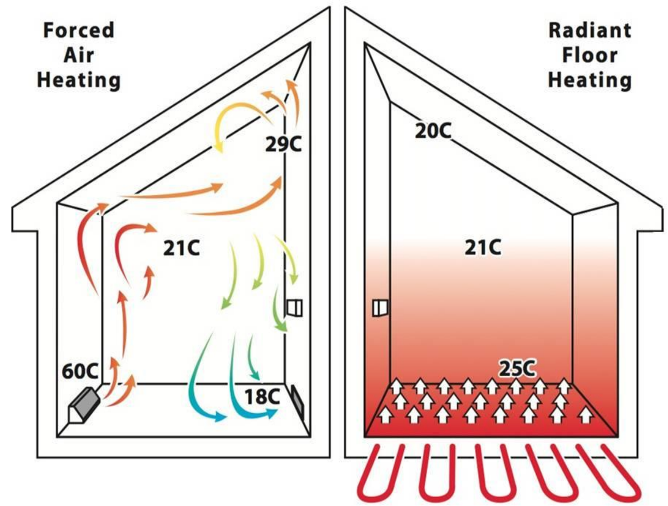
Sanitary hot water demand:



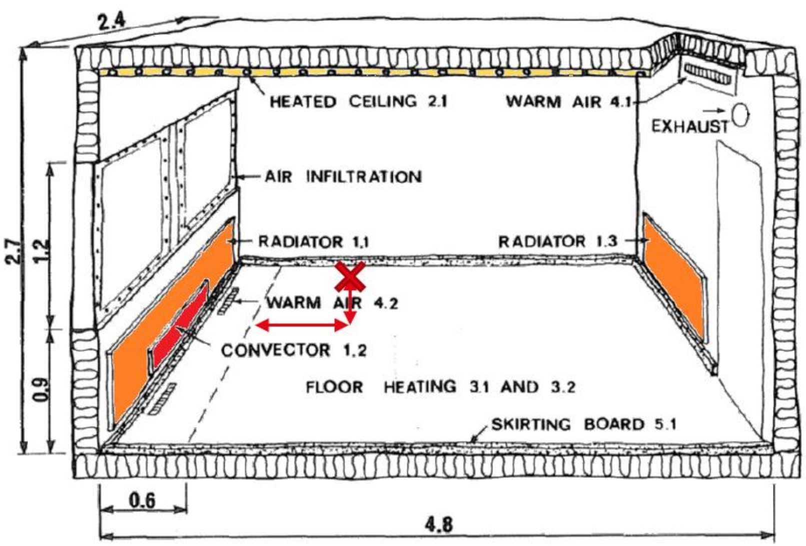
Review from the W11: Heating systems

All-Air Systems		Radiant systems
centralized air conditioning	**localized** air conditioning	**centralized** water conditioning
heat extraction using: **air**	heat extraction using: **refrigerant**, **water**	heat extraction using: **water**
	 *Fancoils*, *indoor units* (air recirculation)	 *Radiant ceiling*
▪ *Air supply through* ***grills*** *(no air deflection)*  ▪ *Air supply through* ***diffusers*** *(diffuses air)* 	 ***Chilled beams*** ***(active** and **passive)*** *thermal conditioning + fresh air supply (active only)*	 *Floor/Wall systems*

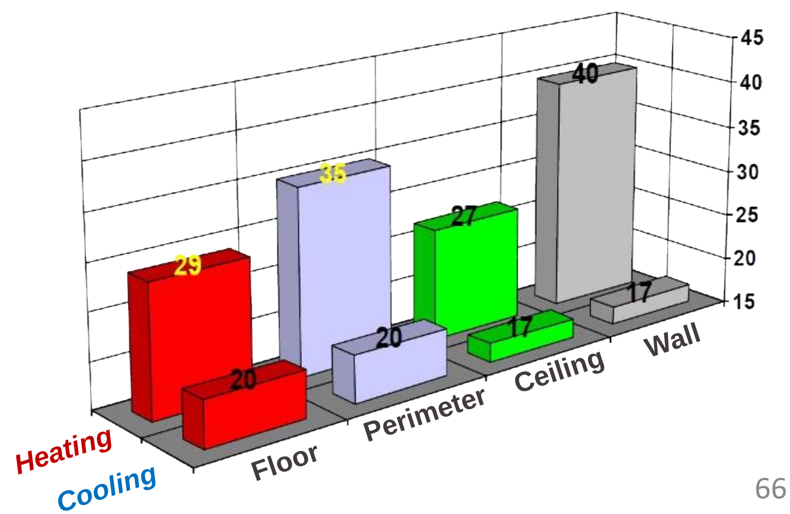
Radiant vs. **all-air** approach:



Emission type vs. **thermal comfort**:

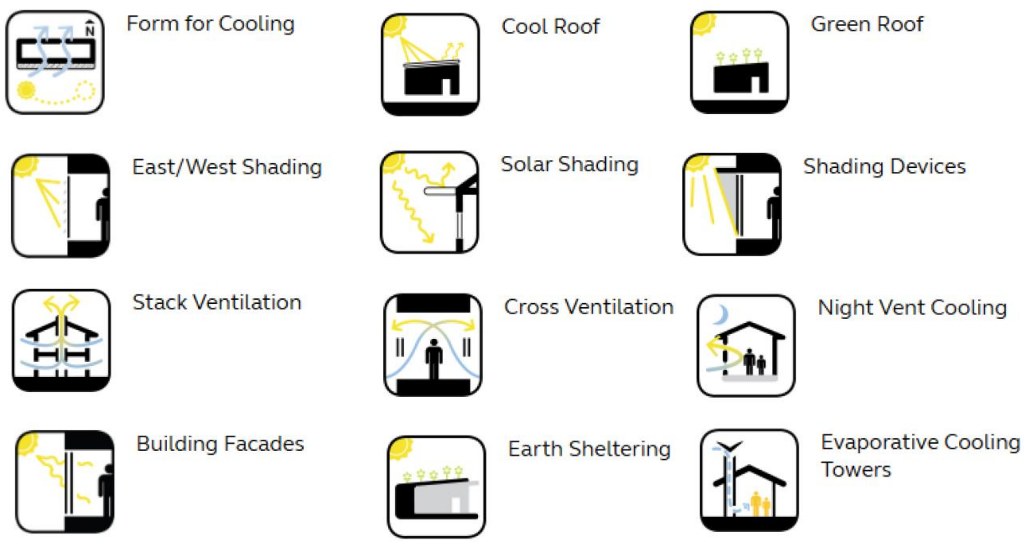


Limiting heat flux for radiant systems:



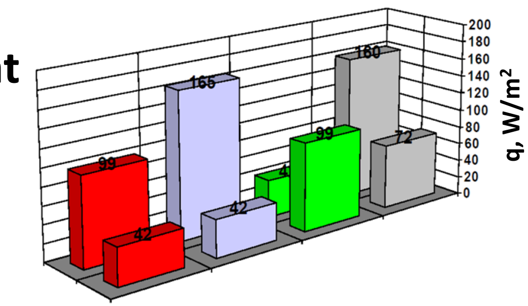
Review from the W12: Cooling systems

Passive strategies:

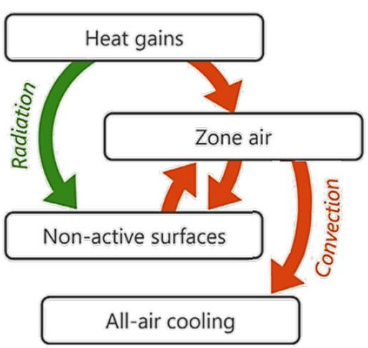


Active systems (chillers, split systems):

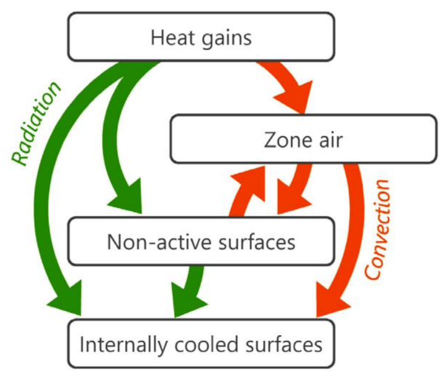
Limiting heat flux for radiant systems:



Radiant vs. all-air approach:

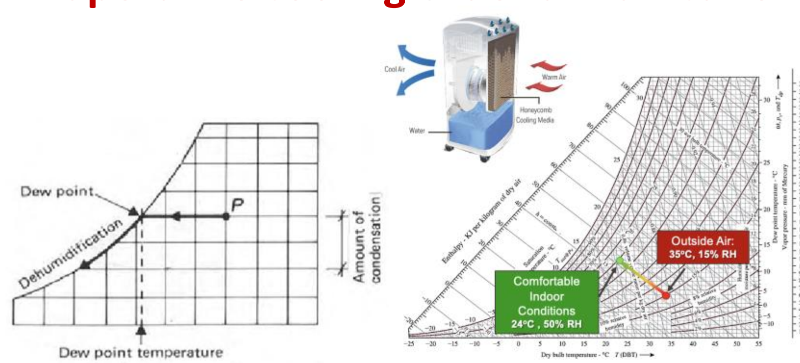


(a) all air cooling



(b) radiant surface cooling

Evaporative cooling & dehumidification:



Course objectives (in our own words)

To understand important concepts of operational energy management in buildings while emphasizing the need for IEQ (thermal comfort and indoor air quality). By the end of the course, you are expected to be able to:

- ✓ Have understanding of role of buildings in influencing climate crisis
- ✓ Talk about determinants and assessment methods for human thermal comfort, indoor air quality and ventilation, and to understand their impact on humans
- ✓ Recognize the contribution of the human behavior towards energy in buildings
- ✓ Energy flows across the building envelope, between emission systems & humans
- ✓ Know what affects efficiency of building elements, standard requirements
- ✓ Understand the difference (comfort-wise, performance-wise) between different approaches for thermal conditioning of indoor spaces
- ✓ Recognize a distinct match between specific indoor emission systems with the heat/coolth generation systems depending on the operational temperature
- ✓ Understand basics of building energy simulation tools
- ✓ Understand tradeoffs between energy saving measures and indoor environmental quality