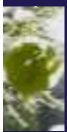

From Energy Efficiency Towards Sufficiency Strategies For Indoor Environmental Design

Runa T. Hellwig
Professor of Building Climatology
Dep. of Architecture, Design and Media Technology,
Aalborg University

Guest lecture under 'Indoor Environmental Quality' of the profile Energy in Urban Development of the Energy Area of Advance, Chalmers University
Göteborg, 27th September 2019

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Introduction

- Overview on our achievements in sustainable transformation of our indoor built environment
- Address performance gaps in important sustainability evaluation criteria
- Discuss sustainability strategies
- Outline new perspectives on more sufficient ways of how to design and operate indoor spaces

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Pre-fabricated timber frame low-energy houses

Low-Energy House 55 kWh/(m²a) | Ultra-Low-Energy House 38 kWh/(m²a)

1996-1999

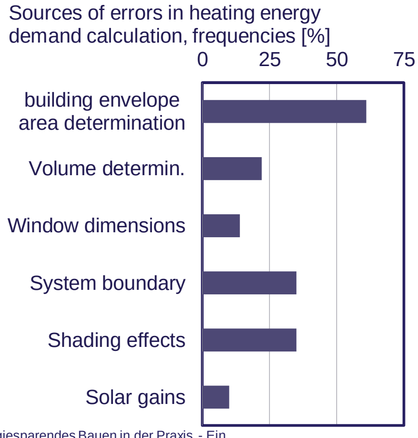
Zero Heating Energy House
Heating & domestic hot water with renewables

Source: Kluttig, H.; Erhorn, H.; Hellwig, R. (1997): Weber 2001 - Energiekonzepte und Realisierungsphase. Bericht WB 92/1997 des Fraunhofer-Instituts für Bauphysik, Stuttgart.

1996-1999 Concepts for Future Oriented Pre-Fabricated Houses (Weber-Haus)
Architect: Rolf Disch,
Research: Fraunhofer Institute for Building Physics
contracted by Hans Weber Hausbau GmbH, funded by the Federal Ministry of Economics and Technology (BMWi)

Stuttgart's first low-energy housing estate 1997-1999 ca. 1000 dwelling units

- Quality management in planning
- Quality management on the construction site



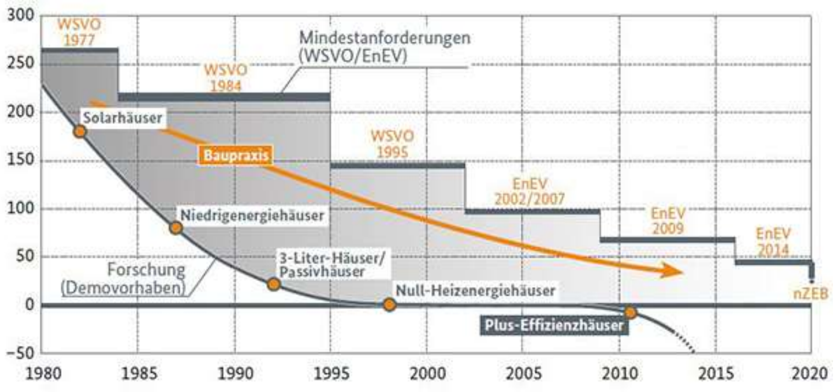
Scientific Consulting of the Construction of a Low-Energy Housing Area "Auf dem Burgholzhof" in Stuttgart
Research: Fraunhofer-Institute for Building Physics
contracted by the City of Stuttgart, Germany

Erhorn, H.; Broll, J.; Hellwig, R.; Kluttig, H. (1998): Energiesparendes Bauen in der Praxis - Ein Erfahrungsbericht über die Entwicklungsmaßnahme Burgholzhof in Stuttgart mit ca. 1000 Wohn-einheiten in Niedrigenergiebauweise. wksb 43. Jahrgang, No 42, pp. 45-52.

Research, legislation and building practice, Example: Germany

Primary energy demand of residential buildings, kWh/(m²a)

WSVO, EnEV: German building energy performance legislation



Source: Fraunhofer IBP

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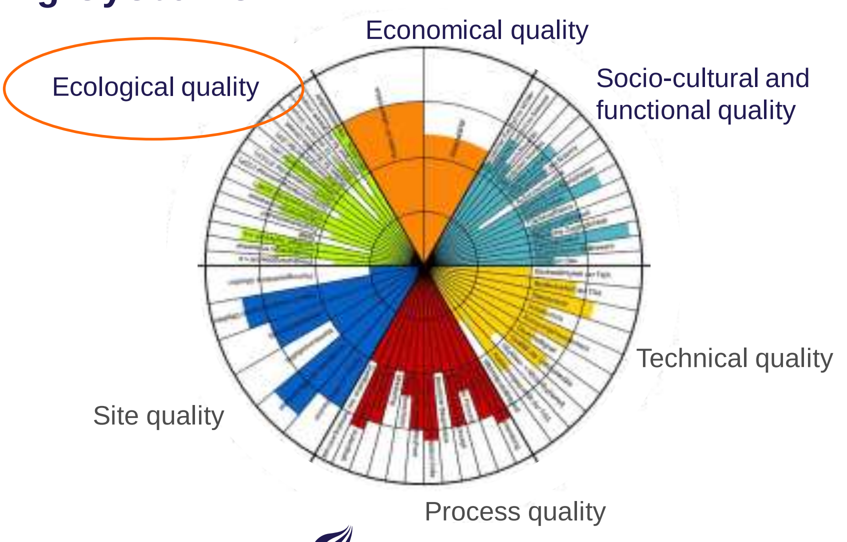
Sustainability rating systems Criteria groups



Source: Gerd Hauser, Wolfram Haupt, Technical University Munich, 2009

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Ecological quality - Life Cycle Assessment

- „Ökobilanz" – Life Cycle Assessment
- 1994 at the Fraunhofer-Institute for Building Physics
- With Life Cycle Assessment – here: focus on energy use
- With a manufacturer of pre-fabricated timber-frame houses and a process analysis of the manufacturing process

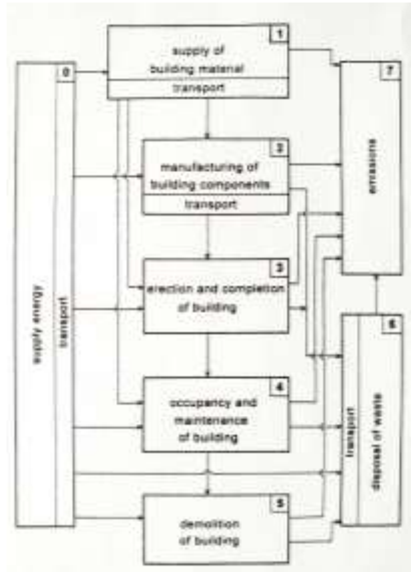

Diagram from: Hellwig, R.; Erhorn, H. (1996): Life cycle assessment of a prefabricated timber-frame house. In: Conseil International du Bâtiment (CIB): Energy and mass flow in the life cycle of buildings, Proceedings, Wien. pp 321-327

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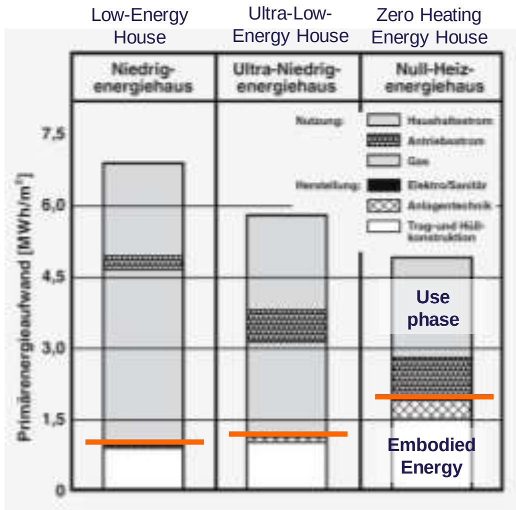
Pre-fabricated timber frame houses: life cycle analysis primary energy

- Energy embodied in the construction increases with level of insulation and building service systems
- Use phase (Heating, hot water, household appliances) becomes less dominant



Hellwig, R.; Erhorn, H. (1997): Primärenergieaufwand für die Erstellung und Nutzung von Wohngebäuden in Holzfertigbauweise mit unterschiedlichem Dämmstandard. In: Conférence Internationale Energie Solaire et Bâtiment (CISBAT): Energie Solaire et Bâtiment, Lausanne.
Graph: Hellwig, R.; Erhorn, H. (1998): Primärenergieaufwand für die Erstellung und Nutzung von Wohngebäuden in Holzfertigbauweise. IBP-Mitteilung 25 (1998), No.335, 2 pp. . ISSN: 9990-1390

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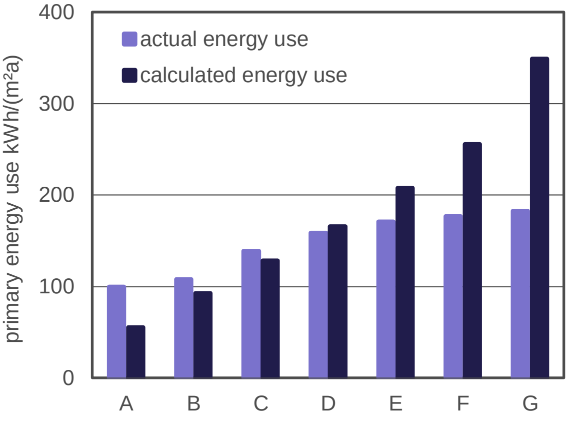
Energy performance gap – Example Danish data

- Actual and calculated energy use per m² of detached houses, grouped by energy label, mean values, variance not shown (N=135.311)
- G-labelled houses: Actual energy use is almost half of the calculated energy use
- A-labelled houses: Actual energy use is higher than calculated
- Users adjust behaviour according to level of energy-efficiency



Data used in graph:
Gram Hanssen, K.; Hansen, A.R. (2016): Forskellen mellem målt og beregnet energiforbrug til opvarming af parcelhuse. SBI forlag. https://sbi.dk/Assets/Forskellen-mellem-maalt-og-beregnet-energiforbrug-til-opvarmning-af-parcelhuse/sbi-2016-09-1.pdf

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Sustainability criteria in rating systems

- Development of thermal comfort assessment criteria set for the German sustainability rating system

Project at the Fraunhofer Institute for Building Physics, 2007-2008
Development of Evaluation Criteria for the Assessment of Thermal Comfort in Winter and in Summer within the Frame of a New German Sustainability Rating System
contracted by the Federal Ministry of Transport, Building and Urban Development, Germany

Source: Gerd Hauser, Wolfram Haupt, Technical University Munich, 2009

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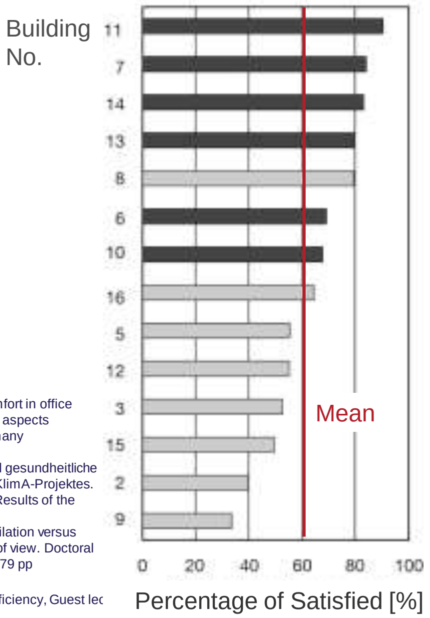
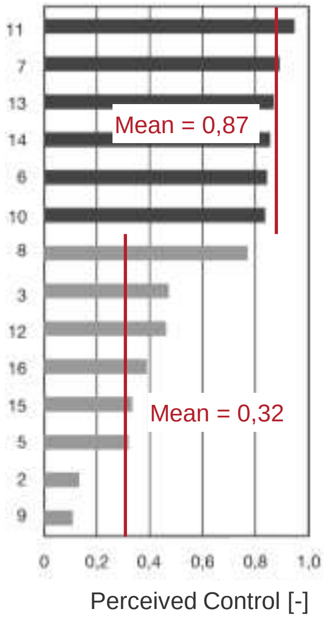
Satisfaction with Temperature – Perceived Control





Mechanical ventilated

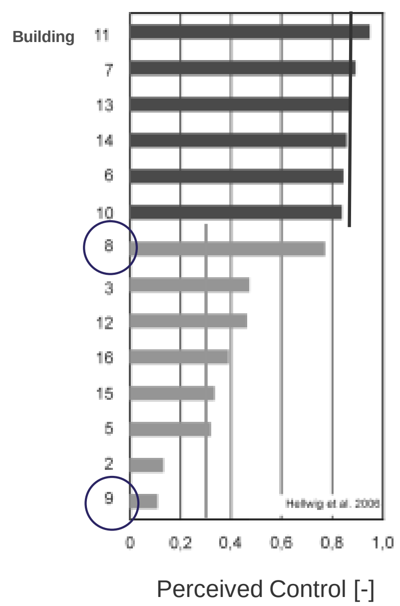
Naturally ventilated

N ~ 4490

Project at University Hospital Jena, 2004-2006: Thermal comfort in office buildings under consideration of the impact of environmental aspects funded by Rud. Otto Meyer-Umwelt-Stiftung Hamburg, Germany

Data: ProKlimA study, Bischof et al.,(2003) Expositionen und gesundheitliche Beeinträchtigungen in Bürogebäuden – Ergebnisse des ProKlimA-Projektes. (Expositions and impairments of health in office buildings – Results of the ProKlimA-project) Fraunhofer IRB Verlag, Stuttgart
Results: Hellwig, R.T. (2005): Thermal comfort - natural ventilation versus air-conditioning in office buildings from the occupant's point of view. Doctoral Thesis, University of Technology Munich, November 2005. 179 pp

Perceived control over the indoor climate in offices - building design



Mechanical ventilated

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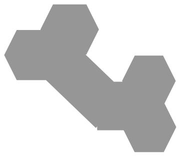

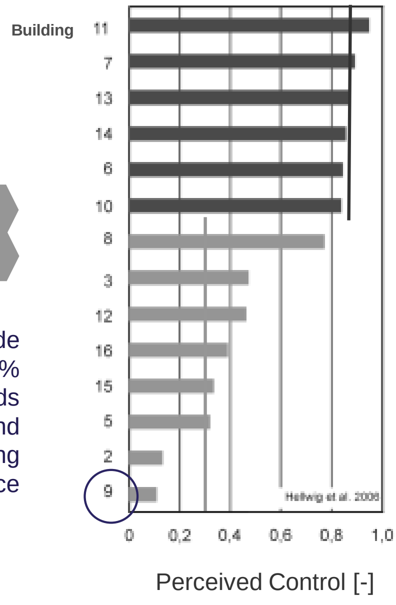

Mechanical ventilated

Naturally ventilated

Sealed windows/facade
Window to wall ratio 55%
Internal blinds
HVAC system for heating and cooling
Open plan office

Project at University Hospital Jena, 2004-2006: Thermal comfort in office buildings under consideration of the impact of environmental aspects funded by Rud. Otto Meyer-Umwelt-Stiftung Hamburg, Germany

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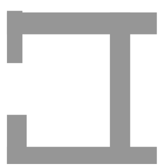
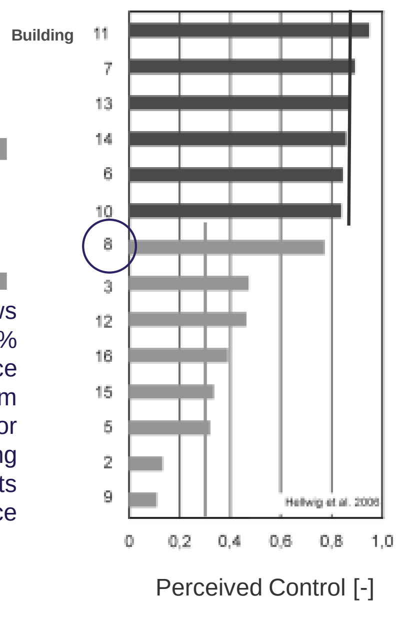
Perceived control over the indoor climate in offices - building design





Mechanical ventilated

Naturally ventilated

Operable windows
Window to wall ratio 25 %
External shading device
Ventilation system
Radiator
No cooling
Small office units
Good stage of maintanace

Project at University Hospital Jena, 2004-2006: Thermal comfort in office buildings under consideration of the impact of environmental aspects funded by Rud. Otto Meyer-Umwelt-Stiftung Hamburg, Germany

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17 schools, 34 classrooms

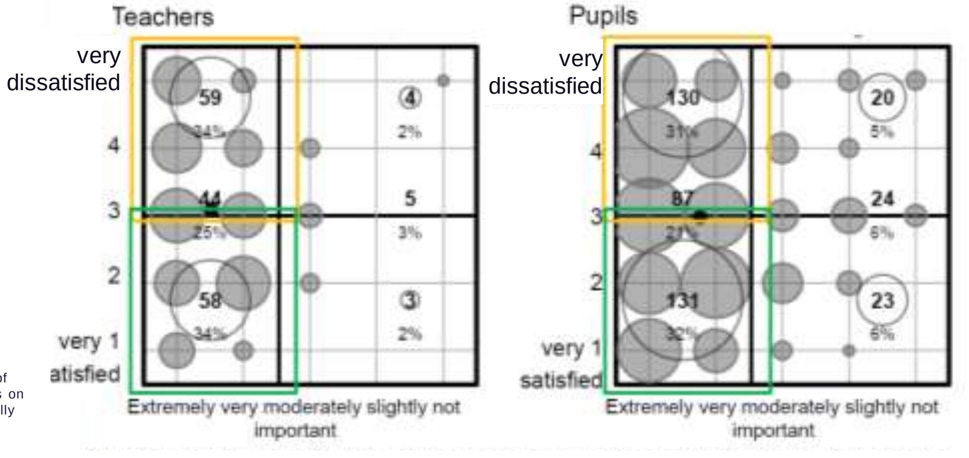
- Indoor climate and user satisfaction
- After retrofitting and implementation of mechanical ventilation
- Survey: May-July 2014

Project at Augsburg University of Applied Sciences: Investigations on the indoor climate in mechanically ventilated classrooms in the administrative district Swabia in Bavaria,Germany. 2013-2015
Funded by Technology Network Bavarian Swabia, Germany

All photos: M. Hackl 2014

Acceptance of mechanical ventilation systems Example: German retrofitted schools

Determining the need for action: ventilation opportunities



Hackl, M.; Maurer, J.; Hellwig, R.T. (2015): Indoor climate and user satisfaction in classrooms after energetic retrofitting. Healthy Buildings Conference Europe, Eindhoven, The Netherlands, 2015, 18.-20.Mai 2015, paper 503, oral presentation. 8pp

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Acceptance of mechanical ventilation systems Example: German retrofitted schools

Operable windows?

- In 8 (of 34) classrooms some of the windows were locked
- In 4 classrooms windows could only be tilted
- Proportion of operable windows in the glazed part of the façade wa 25 to 100%
- In some schools teachers were ask not to open the windows
- In 16 classrooms previousely operable windows were partly replaced by fixed glass elements
- In schools with high satisfaction the proportion of operable windows in the facade is higher than 70%

Hackl, M.; Maurer, J.; Hellwig, R.T. (2015): Indoor climate and user satisfaction in classrooms after energetic retrofitting. Healthy Buildings Conference Europe, Eindhoven, The Netherlands, 2015, 18.-20.Mai 2015, paper 503, oral presentation. 8pp

Photo Hackl 2014

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What is the role of personal control?

- System Building – HVAC – Automation – User is becoming more complex
- New buildings are equipped with more building automation / smart systems
- 85% of office workers wish to have control over their indoor environment (Germany, ProKlimA-study, N=4394) Hellwig, 2005
- High degree of control is positively correlated to satisfaction
- User´s are more tolerant to a wider range of temperatures if personal control is possible (Nicol and Humphreys 1973, Humphreys 1976, 1978, Auliciems 1969a, 1969b, 1981b, 1981a,b, de Dear et al. 1997)
- Taking a meaningful control action is rewarded by joy – a strong motivator for behavioural actions! (Cabanac 1971)

Hellwig R.T. (2015) Perceived control in indoor environments: a conceptual approach, Building Research & Information, 43:3, 302-315, DOI: 10.1080/09613218.2015.1004150

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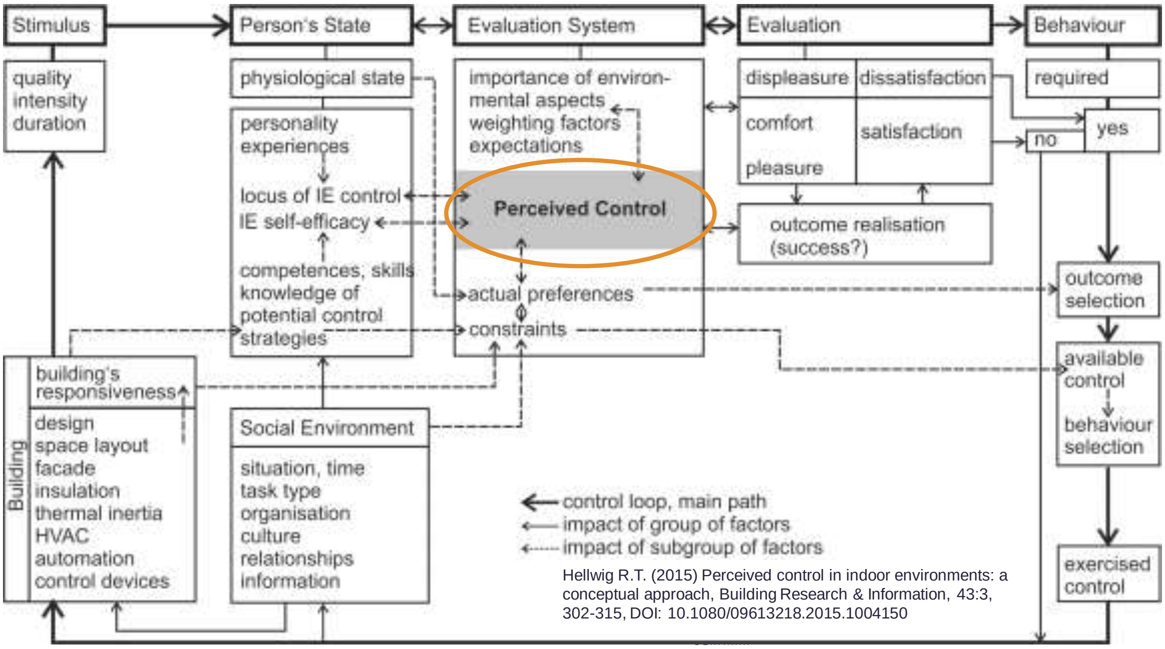
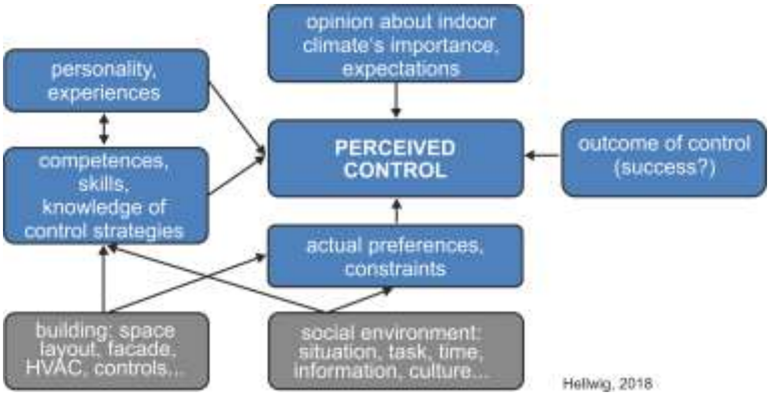
Conceptual Model of Perceived Control



Hellwig R.T. (2015) Perceived control in indoor environments: a conceptual approach, Building Research & Information, 43:3, 302-315, DOI: 10.1080/09613218.2015.1004150

Conceptual model of perceived control



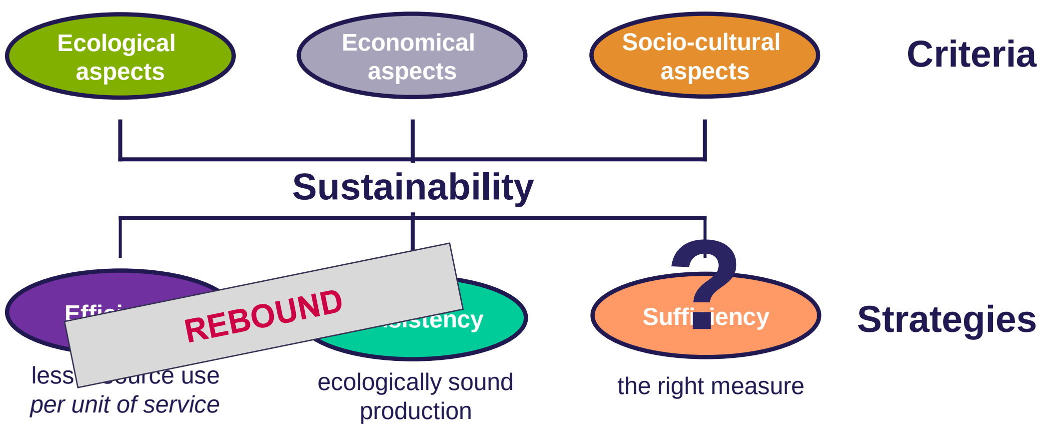
Hellwig, R.T.; Boerstra, A. (2018): Personal Control over indoor climate disentangled. Part 2. Federation of European Heating, Ventilation and Air Conditioning Associations REHVA Journal, 4, August 2018, 20-23, Last accessed: Nov 2018, https://www.rehva.eu/publications-and-resources/rehva-journal/2018/042018/personal-control-over-indoor-climate-disentangled-part-2.html#c3114

Where we are today?

- Our energy saving efforts show effects!
- However, we observe energy performance gaps (rebound effects):
- Changed conditioning schedule (temporal: intermittent/ night set back/ permanent)
- Extended availability of conditioning systems to more rooms (spatial: more rooms)
- Changed occupant behaviour (behavioural: e.g. less clothing)
- Changed temperature regime (extent, “indoor exposure rebound”)
- Indoor Climate – here: thermal comfort - performance gaps in post-occupancy-evaluations:
- Higher dissatisfaction rate than expected
- Tendency that winter energy efficient buildings tend to overheat (not reported here)

Hellwig, R.T. (2019): On the relation of thermal comfort practice and the energy performance gap. 1st. Nordic Conference on Zero Emission and Plus Energy Buildings, Trondheim, Norway, 6-7 Nov 2019

Sustainability: criteria vs strategies



Sufficiency is…

- a sustainability strategy addressing the relation between humans and their environment
- associated with moderation or adequacy
- stands for the needs which should be met to enable a good life

Examples:

- using the bicycle instead of the car
- using line drying instead of tumble dryer
- buying seasonal locally produced food rather than buying overseas food
- …

Indoor exposure rebound and sufficiency

- We get adapted to what we are exposed to – outdoors or indoors
- Observed increasing temperatures for heating and decreasing temperatures for cooling leading higher demand for energy

- How much comfort is sufficient?
- How can we determine what is enough in a self-adapting system?

Hellwig, R.T. et al. (2019): Applying adaptive principles – Developing guidance for planning practice. Proceedings Comfort at the Extremes Conference CATE 19, Heriot Watt University Campus Dubai, 10-12 April 2019

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A new understanding of thermal satisfaction


Photos: Hellwig 2005

- Human thermoregulation and the physical principles of heat exchange between humans and their environment form *one* basis of thermal comfort
- But the *complete set of variables* comprises more variables, mainly contextual variables
- There are three principles in thermal comfort*:
- Behavioural adaptation – actively contributing to own satisfaction by changing posture or activity, clothing insulation or "exercise control"
- Physiological adaptation thermoregulatory adjustments, acclimatization processes, exposure
- Psychological adaptation previous experience, expectation, preferences, availability of personal control, social factors and constraints

*Nicol and Humphreys 1973, Humphreys 1976, 1978, Auliciems 1969a, 1969b, 1981b, 1981a,b, de Dear et al. 1997

Hellwig, R.T. et al. (2019): Applying adaptive principles – Developing guidance for planning practice. Proceedings Comfort at the Extremes Conference CATE 19, Heriot Watt University Campus Dubai, 10-12 April 2019

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Ongoing Research IEA-EBC Annex 69

- **Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings** (2015 – 2019, Operating agents: Yingxin Zhu and Richard de Dear)
- **Subtask B2, Lead: Runa T. Hellwig*, Co-Lead: Despoina Teli**
  Provide design guidelines on how to use adaptive comfort for lowering energy in buildings including the usage of personal thermal comfort systems; a main deliverable
- - To improve the overall understanding of the adaptive principles;
  - To explain the adaptive principles' in relation to building energy use;
  - How to interpret the adaptive model in building practice and design
  - To include advice for heated or cooled buildings into the guideline, not limiting the application of the adaptive thermal comfort concept to free running buildings

*Hellwig, R.T. , Teli, D. et al. (2019): Applying adaptive principles – Developing guidance for planning practice. Proceedings Comfort at the Extremes Conference CATE 19, Heriot Watt University Campus Dubai, 10-12 April 2019

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Towards Sufficiency Strategies For Indoor Environmental Design

- **Sufficiency strategies: new area relating indoor built environment design** to behaviour of users
- **E.g. a new understanding of thermal comfort/satisfaction can lead to sufficiency strategies**
- **What is needed is:**
- **an indoor built environment design** which supports adaptation
- **a building service & automation design** which allows for individual control
- **the consideration of diverse climates**, acknowledging both todays and future climates or seasons
- **improved understanding of the impact of qualitative factors in design** addressed in standards
- **Missing links** as e.g. health and temperature, built environment and user interaction

Hellwig, R.T. et al. (2019): Applying adaptive principles – Developing guidance for planning practice. Proceedings Comfort at the Extremes Conference CATE 19, Heriot Watt University Campus Dubai, 10-12 April 2019

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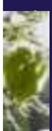

From Energy Efficiency Towards Sufficiency Strategies For Indoor Environmental Design

THANK YOU!

Contact: rthe@create.aau.dk

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