Arbeitsbereich
Energieeffizientes Bauen

universität innsbruck

MATLAB Expo 2017

Building and HVAC Simulation in MATLAB/Simulink – FFG Project SaLüH!

Fabian Ochs, Dr.-Ing.
Dietmar Siegele, DI, MSc
Georgios Dermentzis, DI
Eleonora Leonardi, MSc
Toni Calabrese, MSc
Felix Bartagnoli

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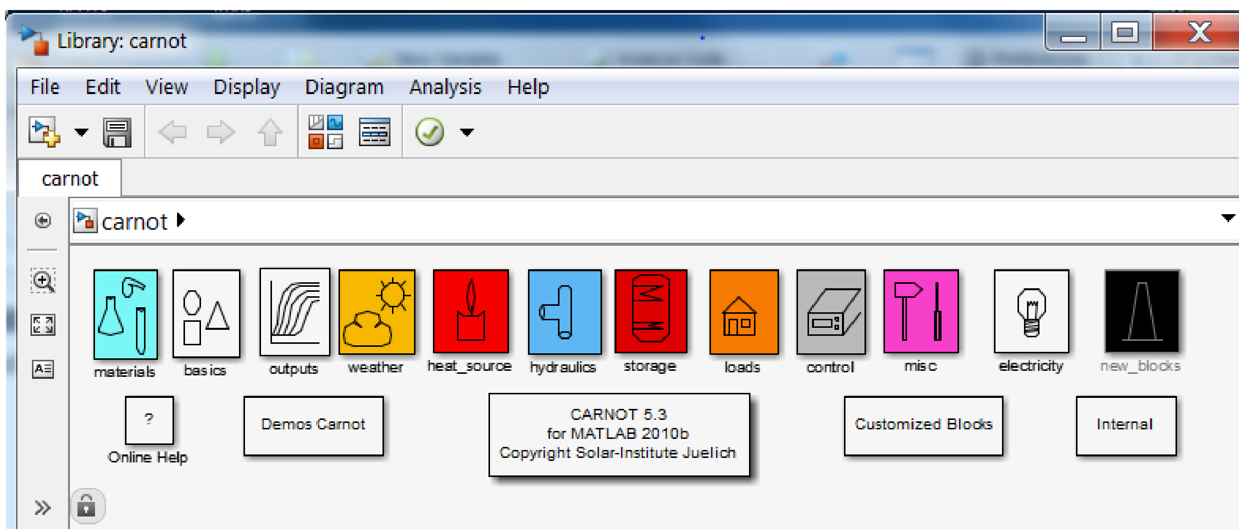
Building and HVAC Simulation in MATLAB/Simulink

- Thermolib
- Hambase/Hamlab (van Schindel TUE) + Comsol
- Simbad (CSTB)
- International Building Physics Toolbox www.ibpt.org
- **Carnot Toolbox**
- …

Simulink, Carnot Blockset

User/Developer (next User Meeting Feb. 2018)

- Companies such as Vaillant, Viessmann
- SIJ, FH Aachen
- FHNW, HS Rapperswil
- FH Ingolstadt
- RWTH Aachen
- Uni Bayreuth
- TU Darmstadt
- TU Dortmund
- ASIC
- Uni Bologna
- Uni Innsbruck
- …

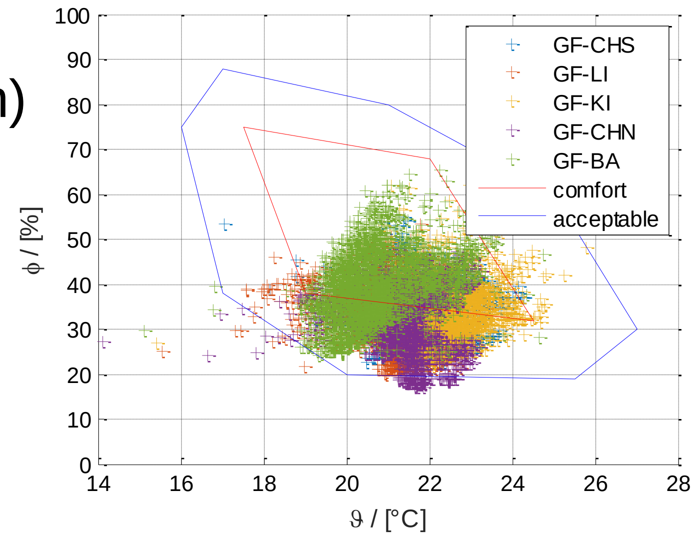


Scope of Building and HVAC Simulation

Investigation of

- Thermal Comfort (operative temperature ϑ_{op}, relative humidity)
- Indoor Air Quality (IAQ): CO_2, VOC, PM, etc.
- Visual Comfort / glare protection (in non-residential buildings)

- Building Performance - Heating Demand (HD), Cooling Demand (CD), Heating Load (HL), Cooling Load (CL)
- System Performance (+ Control Optimization)
- (On-site) use of Renewables, load matching
- Primary Energy Savings / Reduction of CO_2-emission
- Economic Analysis (LCC)



Renovation of small Flats with decentral Ventilation and Heating System and DHW Heat Pump (FFG Project)

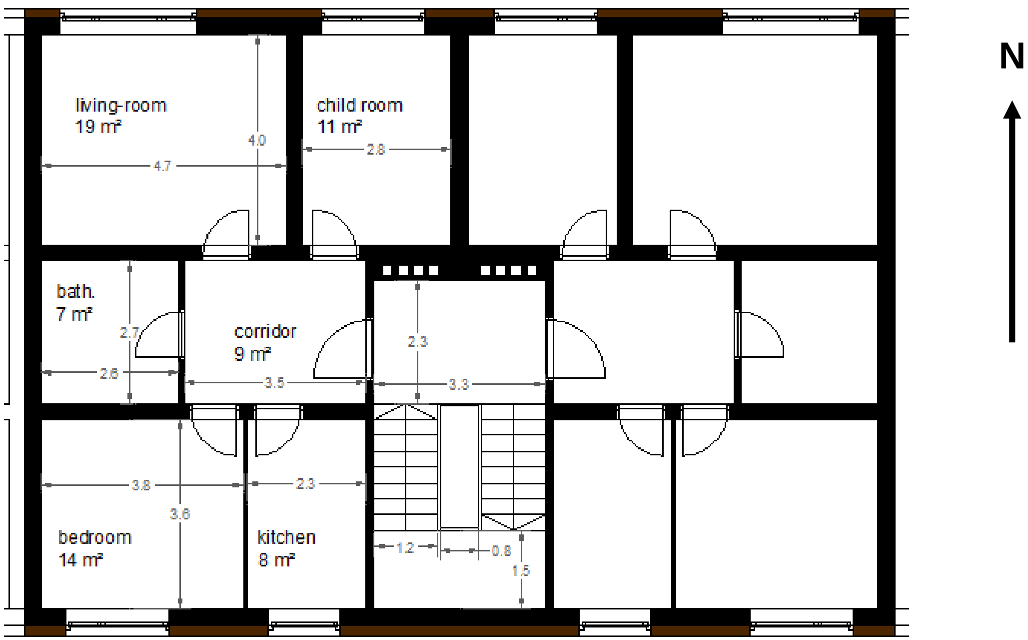
SaLüH!
Sanierungsansätze für Lüftung, Heizung und Warmwasser

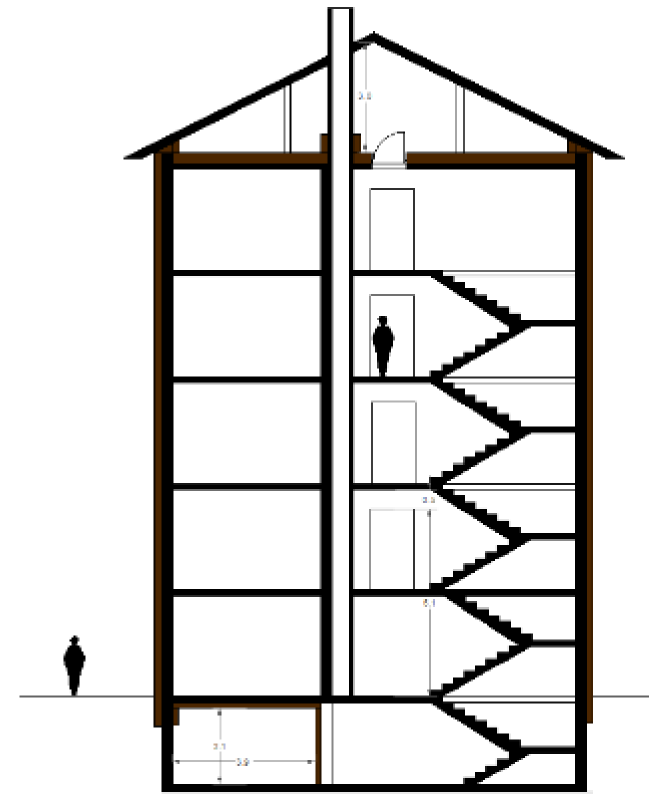
- Most buildings are poor energy performance buildings
- Renovation plays a key role in achieving required reduction of CO_2-emissions
- Envelope solutions are available (insulation, windows, etc.)
- Renovations in MFHs are frequently done flat-wise
- Non-disruptive solutions for renovation the HVAC system are required
- Heat Pumps represent an alternative to electric heating and DHW preparation (in case gas or district heat not applicable)

Example of a small flat in a typical Multi Family House (MFH)

SaLüH!
Sanierungsansätze für Lüftung, Heizung und Warmwasser

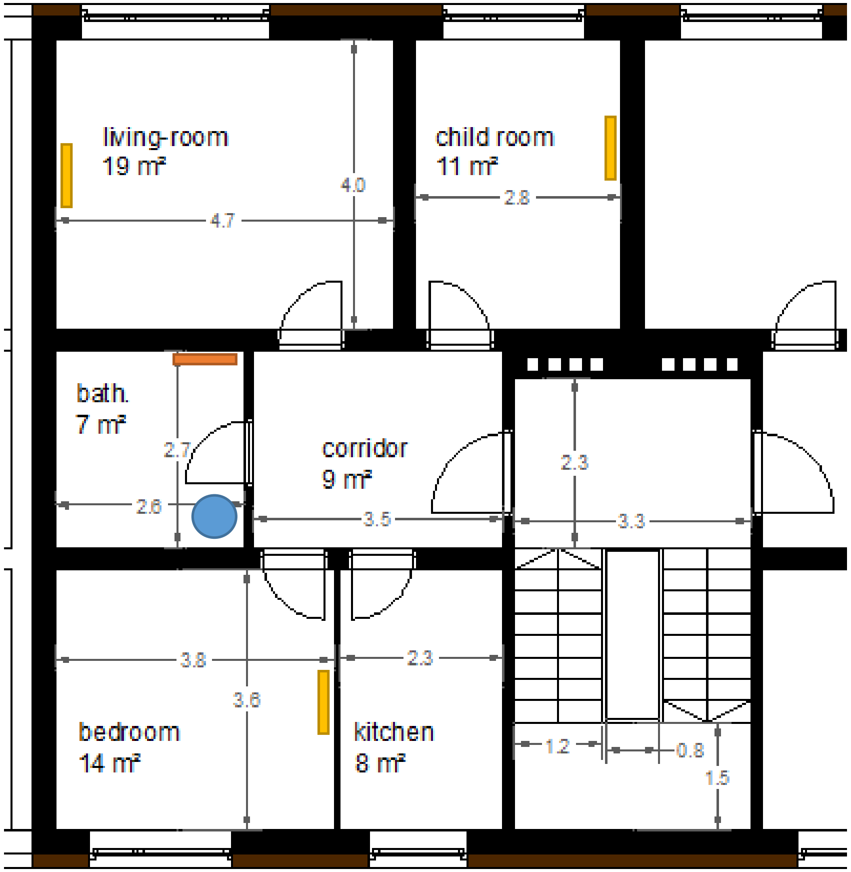
Floor Plan and Section





3 rooms, kitchen, bathroom, ca. 70 sqm

Example of a small flat in a Multi Family House (MFH)

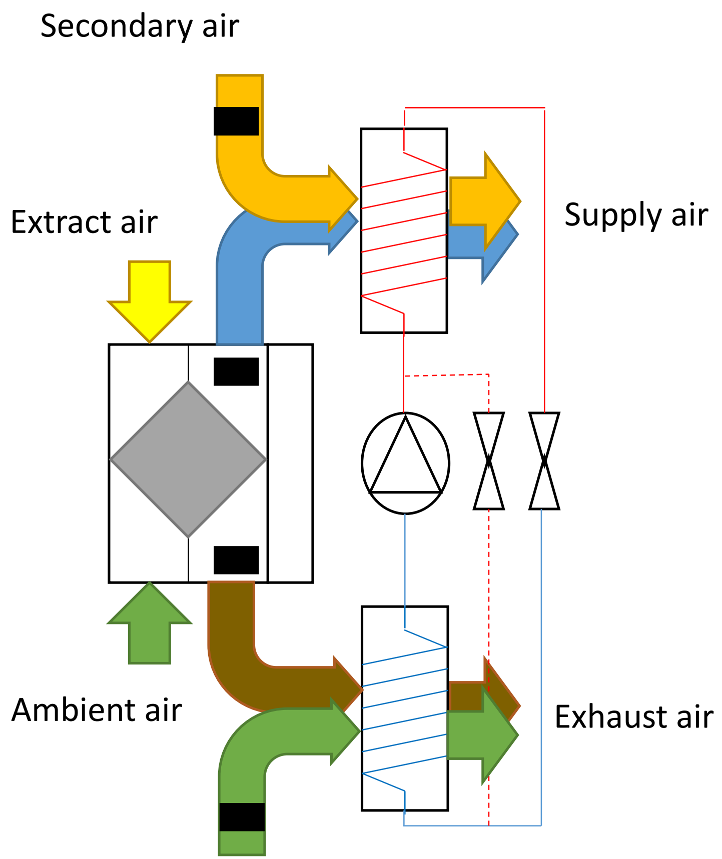


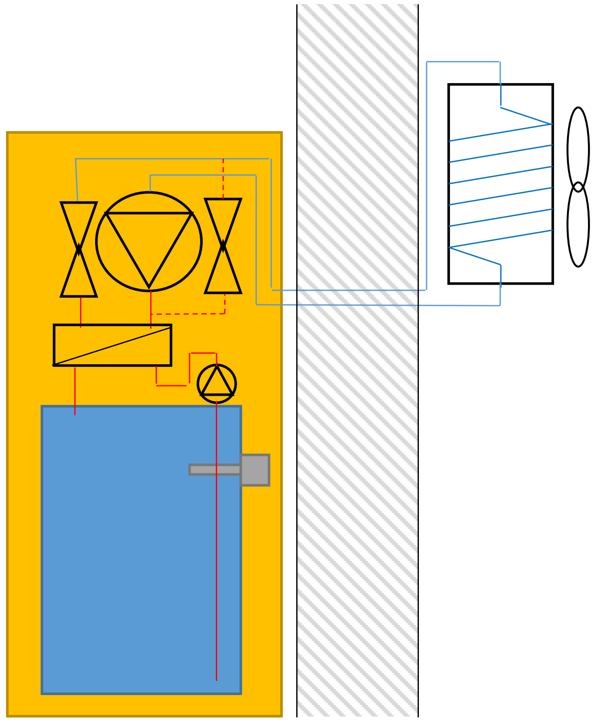
- Flat-wise Renovation
- Frequently no heat emission system
- No space for technical installations
- As a consequence:
  Frequently electric heating and DHW preparation

Compact Heat Pumps for Renovation

SaLüH! Sanierungsansätze für Lüftung, Heizung und Warmwasser

Exhaust Air Heat Pump with ERV





Compact DHW Heat Pump with optionally facade integrated modular storage

„XL“ compact units for „large“ PH

Effiziento HTZ 4

VP 18 Compact von Nilan

x^2 von drexel und weiss

Zehnder ComfoBox

LWZ 304 SOL von Stiebel Eltron

AEREX BW 175

Not applicable in small flats!

Markus Meyer, Kompakt und komfortabel Lüftungs-kompaktanlagen und Alternativen für das Passivhaus

Mini-Split / Multi-Split

Example of Mini-Split Systems

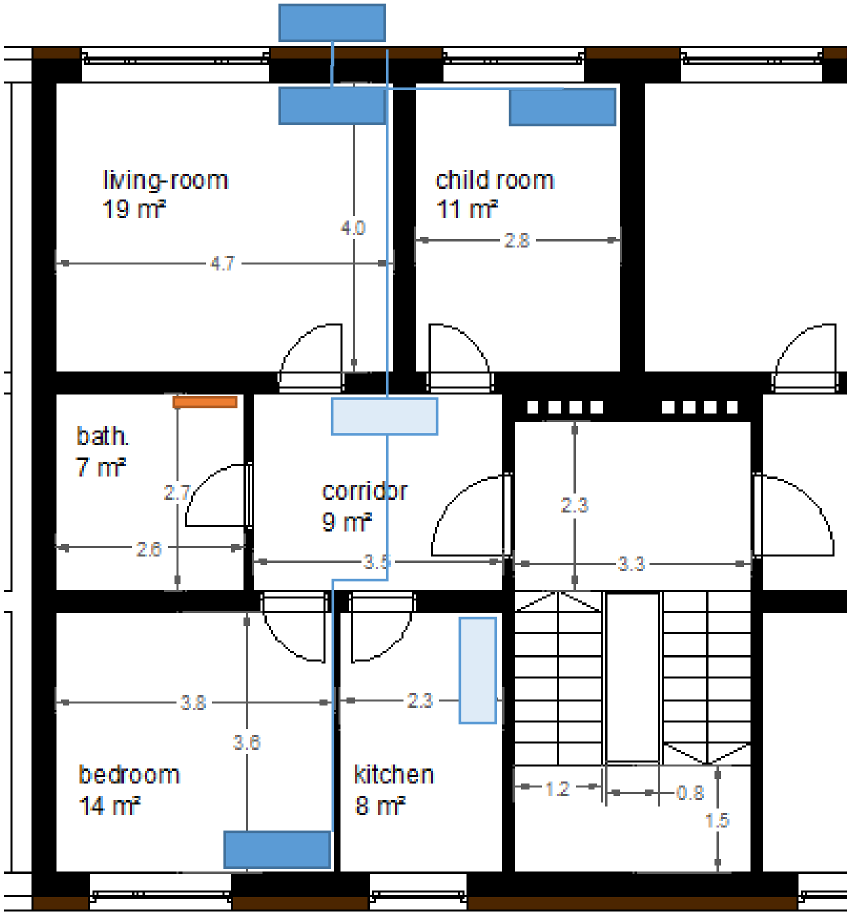
http://www.mitsubishicomfort.com/

http://www.toshiba-klima.de/

Single Split / Multi Split

- Heating and cooling with one device
- Various indoor unit designs
- Rel. good performance (SCOP > 3)
- Heating capacity from 2.5 to 12 kW
- Flexible design
- Rel. high cost for multi-split
- Challenging heat distribution for single split
- in combination with radiant heater

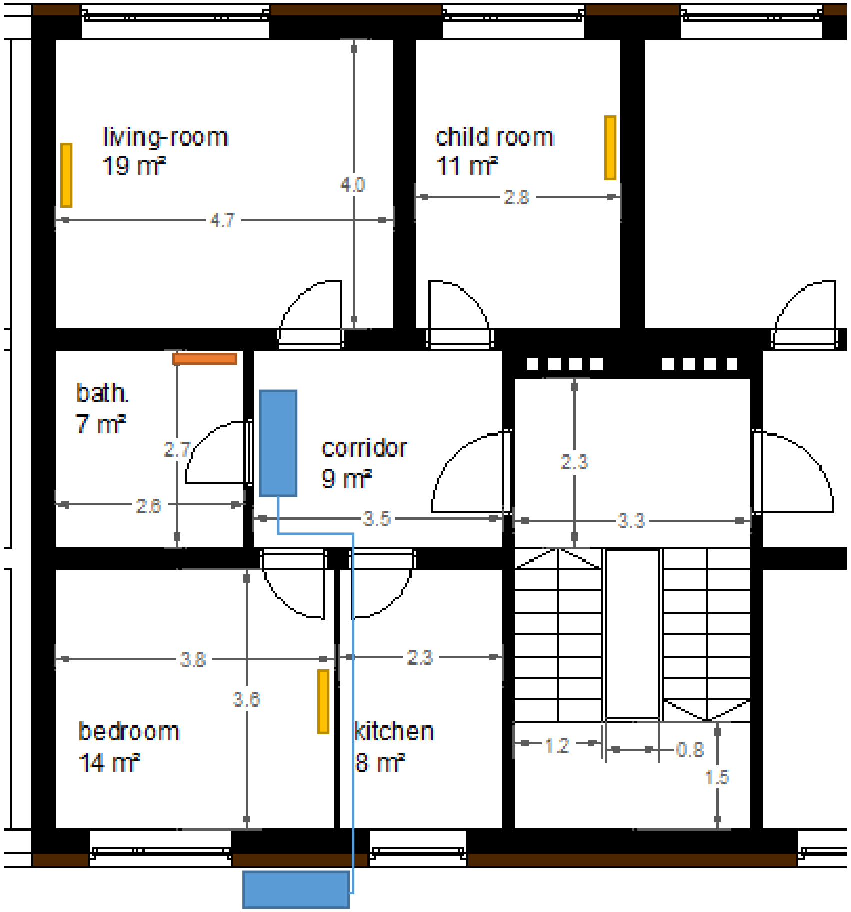
Multi-Split Unit



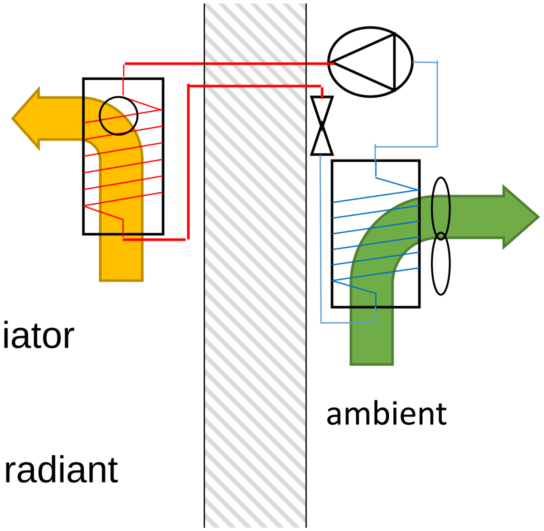
Multi-Splits:
several indoor and one outdoor unit:
+ Individual temperature control
- Performance
- rel. high cost

additional bathroom radiator
(towel dryer, convector, radiant heater)
MVHR not depicted
VRF for simultaneous heating and cooling
(heat recovery)

Heating with single Split Unit (Overheating of Corridor)

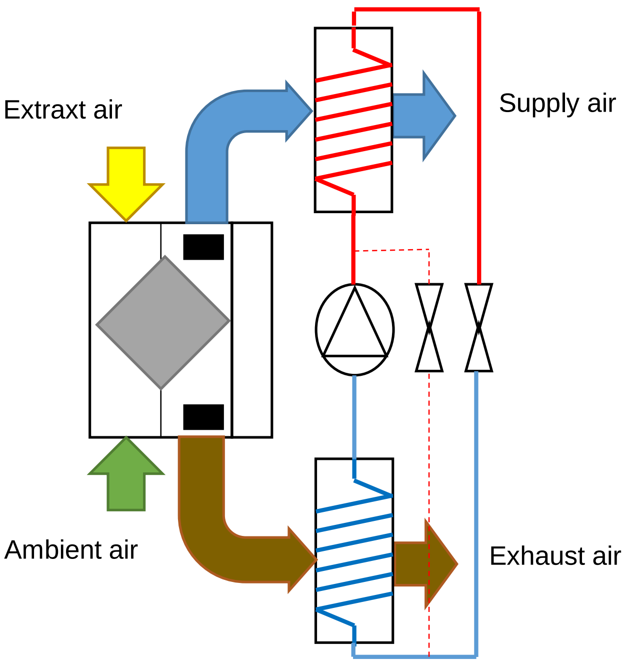


Mini-Split
with radiant heater
+ low sound emissions outside
+ Individual room control
- Performance (electric heating)



additional bathroom radiator
Electric post heater for individual room control (towel dryer, convector, radiant heater)
MVHR not depicted

Compact Systems for Façade Integration



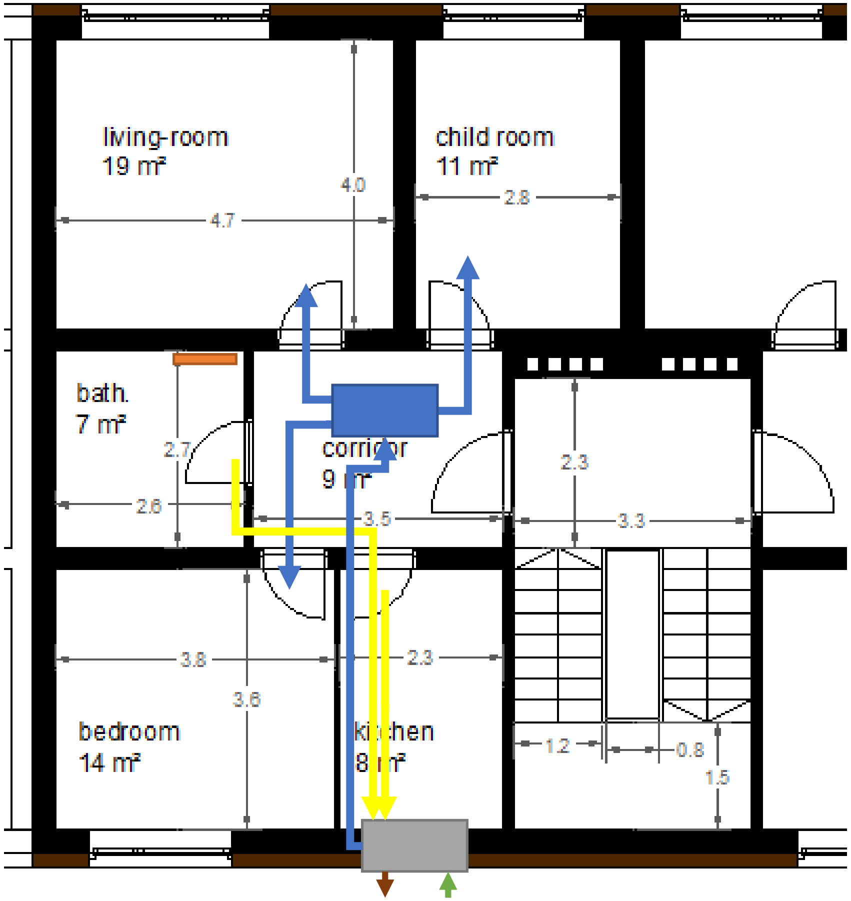
MVHR with exhaust air heat pump (with hot gas bypass for deicing)

Functional Model and …

…iNSPiRe Demo-Building, Ludwigsburg (WB-L, G+M)

EU-project iNSPiRe (fp7)

Supply Air Heat Pump (façade integrated) with radiant heater



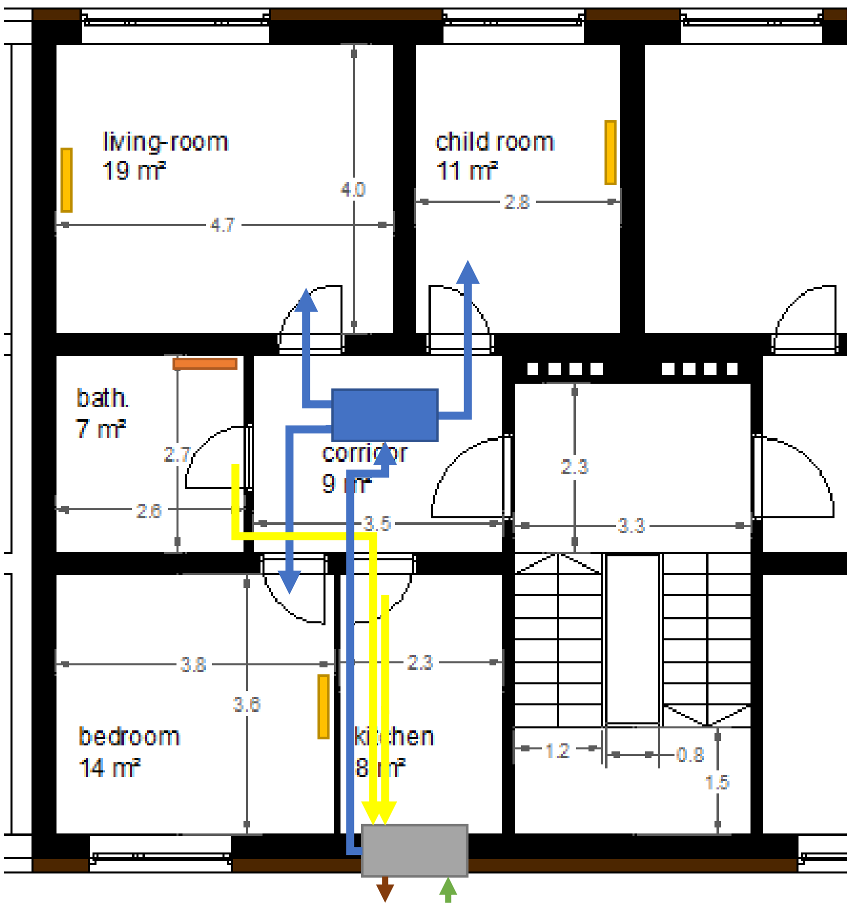
MVHR with Micro-HP

Supply air heating (with MVHR) for PH

+ Rel. low costs
- No individual room control
- Performance

additional bathroom radiator (towel dryer, convector, radiant heater)

Supply Air Heat Pump (façade integrated) with radiant heater



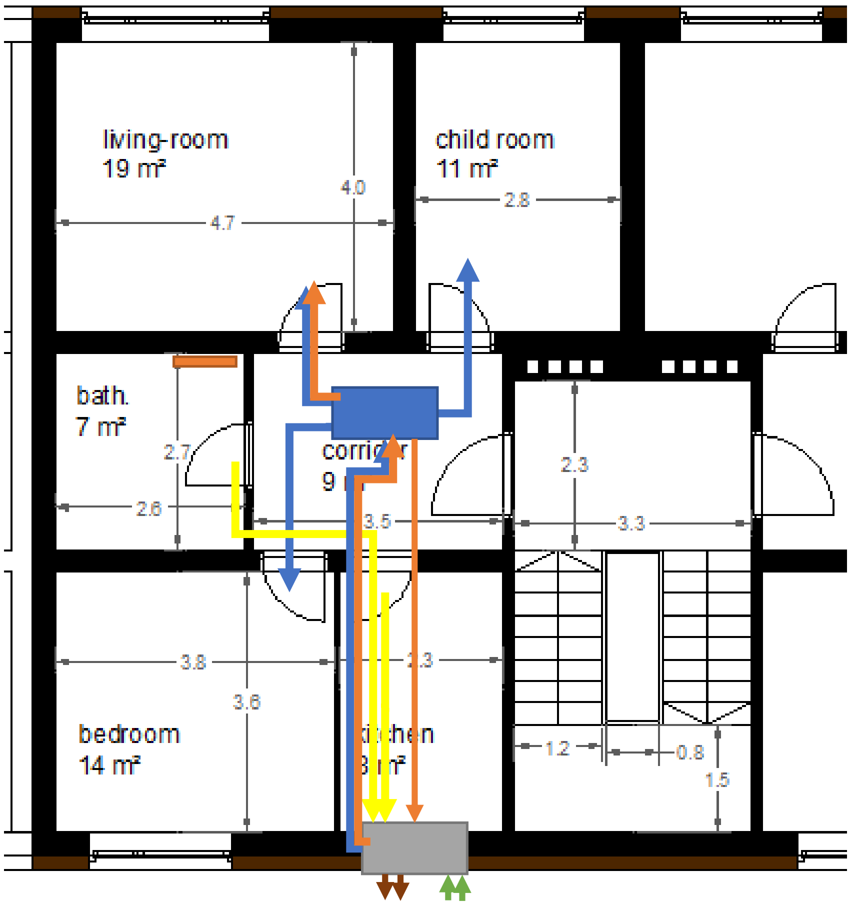
MVHR with Micro-HP

Supply air heating (with MVHR)

+ Higher heating power (EnerPhit)
+ Individual room control
- Higher costs
- Lower performance (electric heating)

additional bathroom radiator
(towel dryer, convector, radiant heater)

Supply Air Heat Pump with recirculation



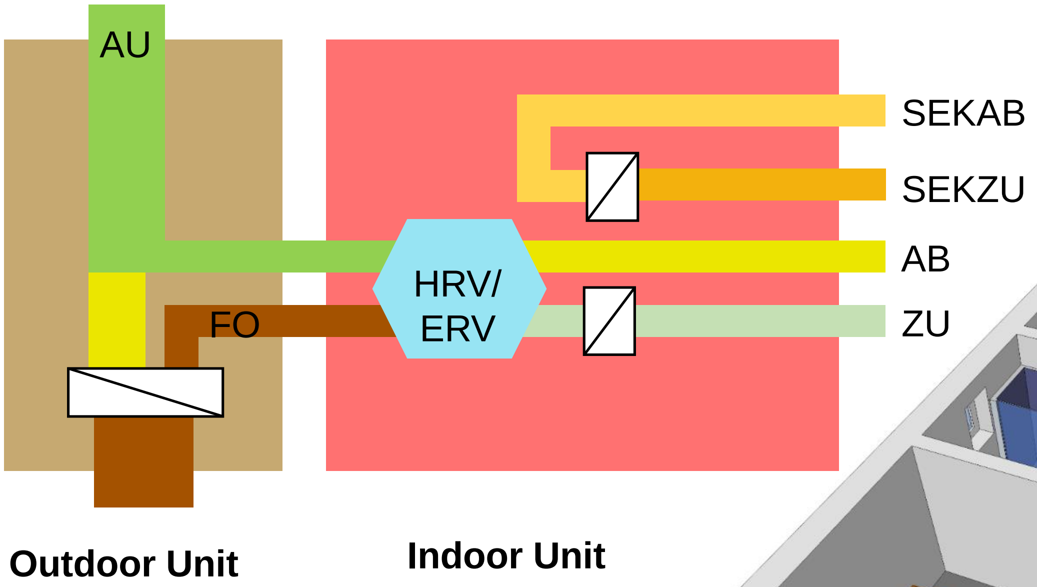
MVHR with Micro-HP with additional ambient air

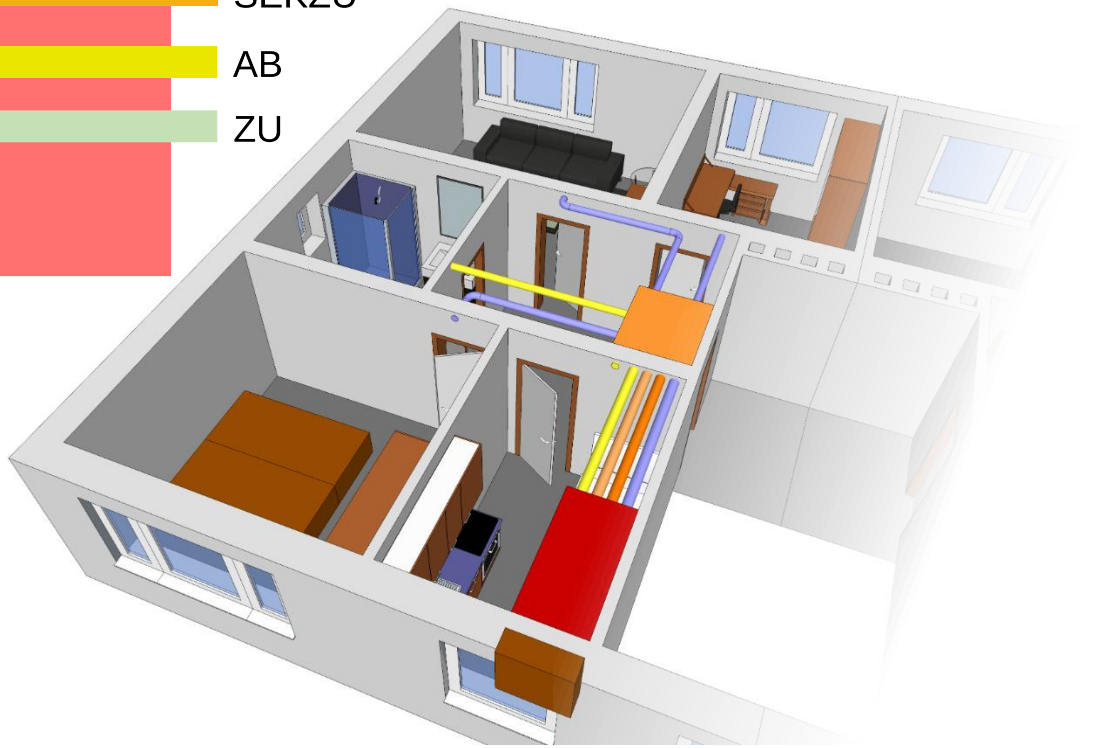
Supply air heating (with MVHR)
for **EnerPHit**

+ higher heating power (EnerPHit)
- Higher installation effort (ducts)

additional bathroom radiator
(towel dryer, convector, radiant heater)

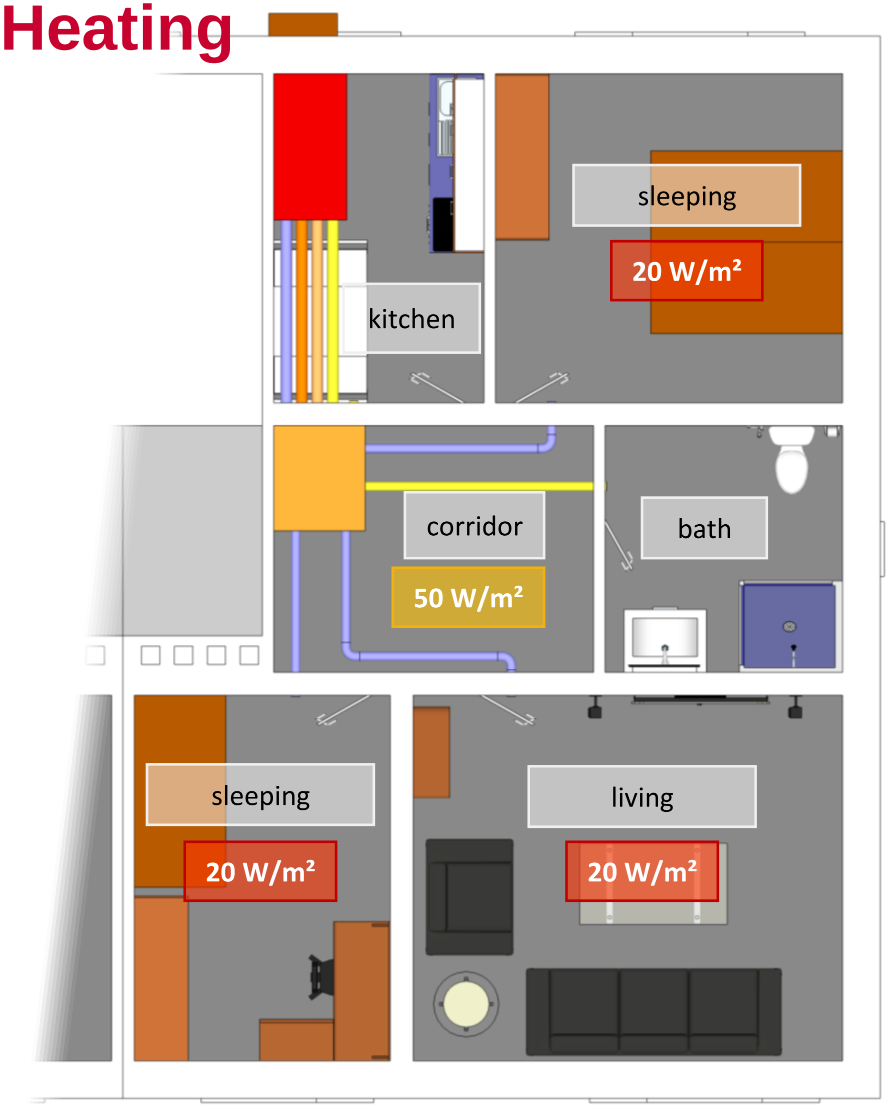
Concept of Ventilation and Heating System



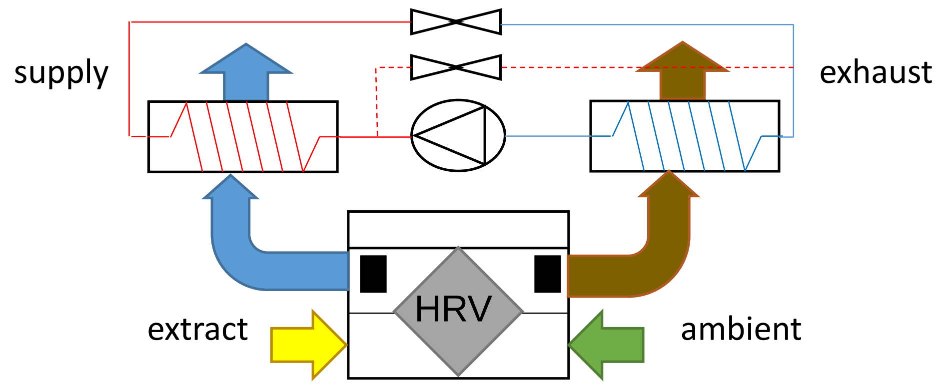


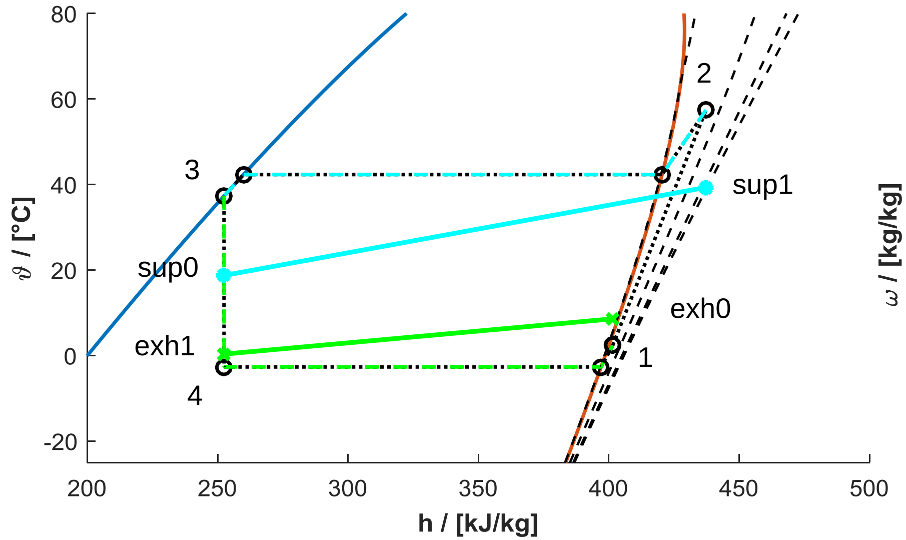
Heating Load and Supply Air Heating

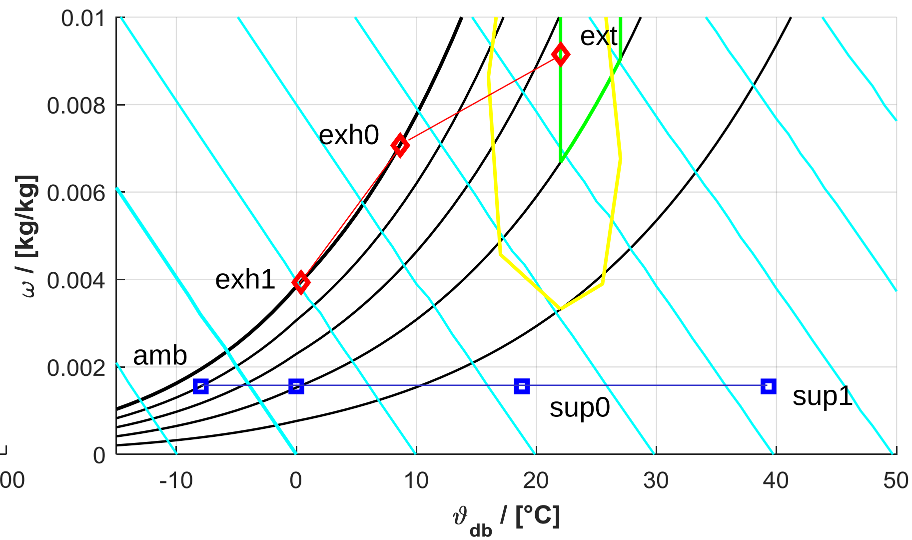
- Maximum heating load with supply air heating per room: 20 W/m²
  - Heating load only via supply air rooms
  - Hygienic flow rate!
- Maximum heating load with recirculation air: > 50 W/m²
  - Overheating: approx. 1 K



Temperature-Enthalpy Diagram and Psychrometric Chart – HRV

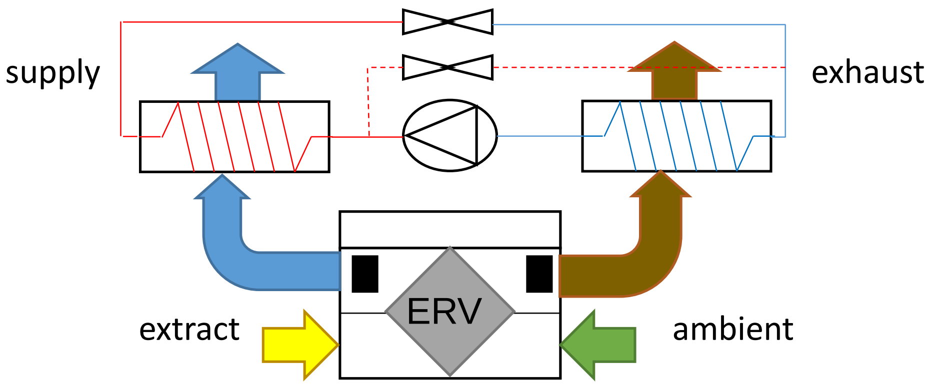


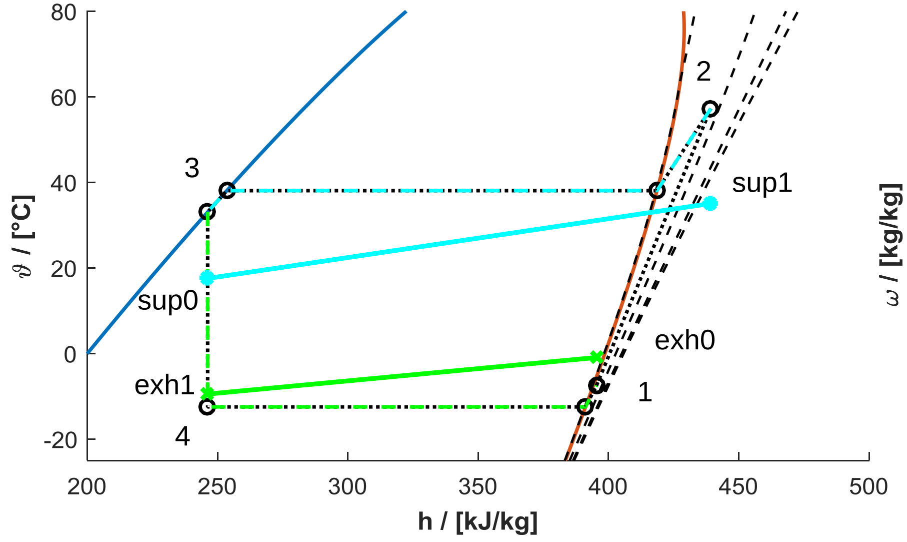


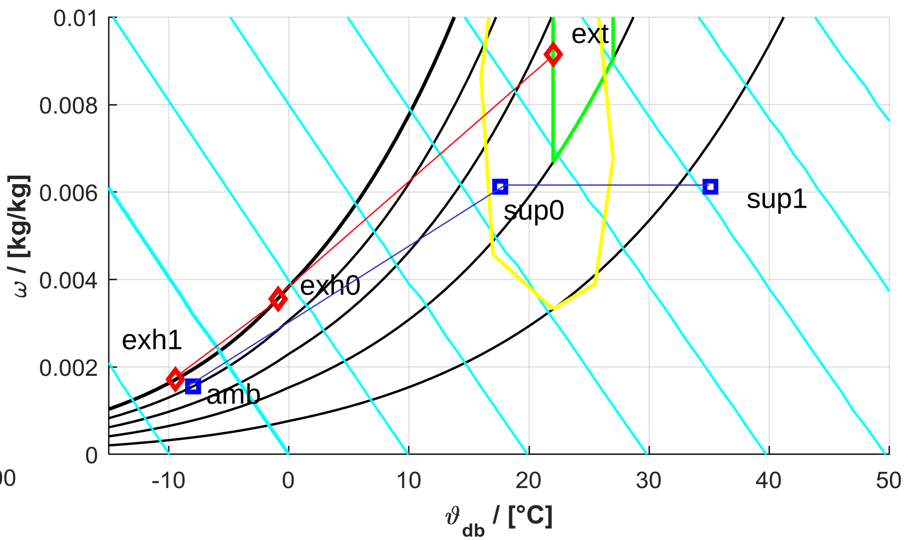


Simulation of refrigerant cycle and moist air properties with MATLAB and CoolProp

Temperature-Enthalpy Diagram and Psychrometric Chart – ERV



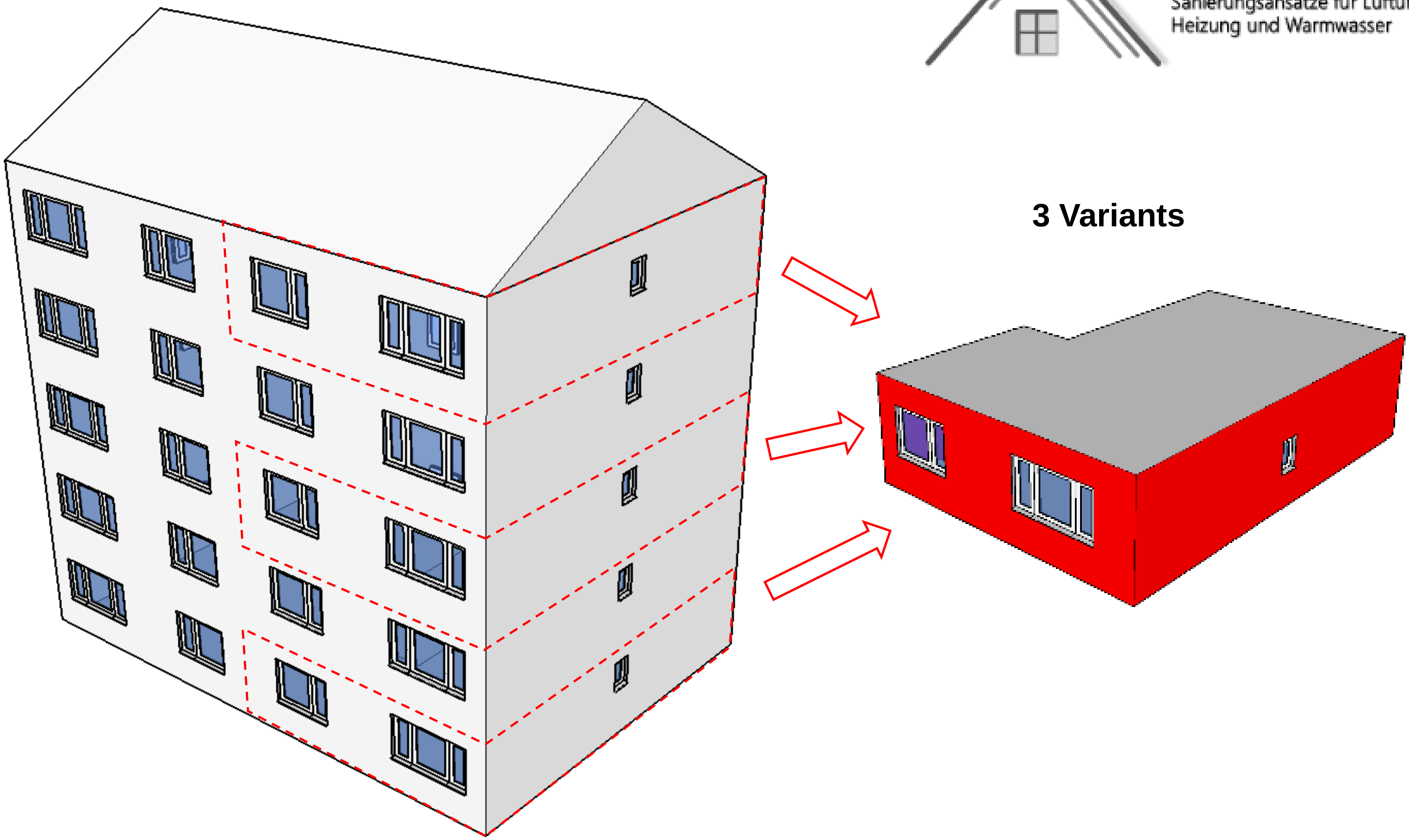




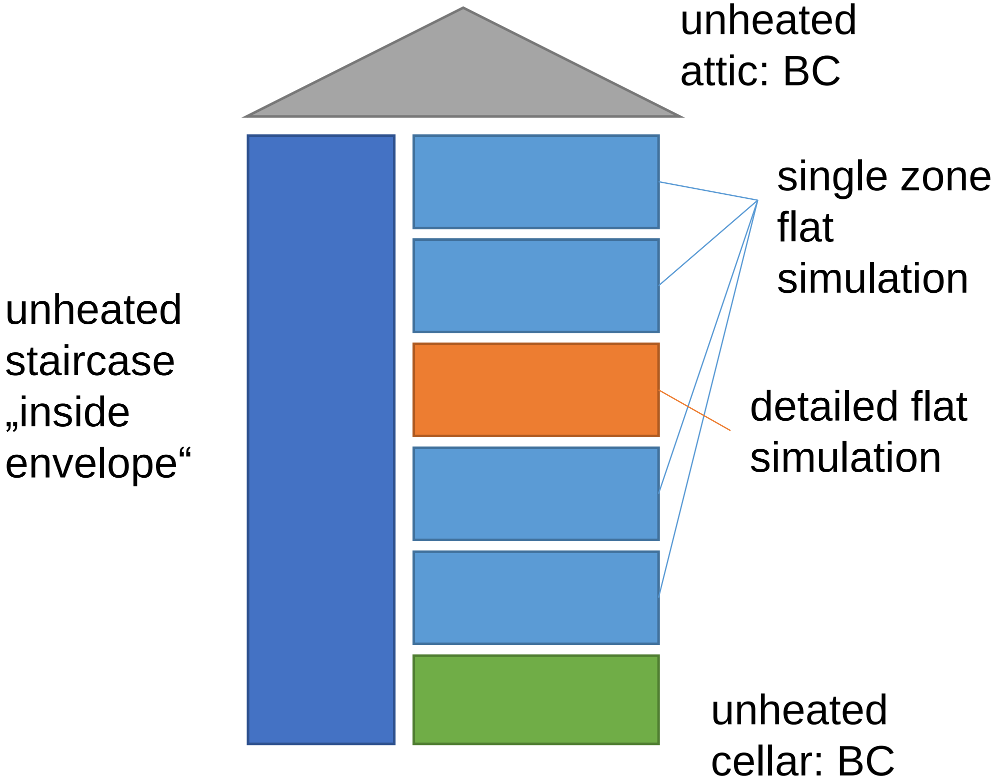
Simulation of refrigerant cycle and moist air properties with MATLAB and CoolProp

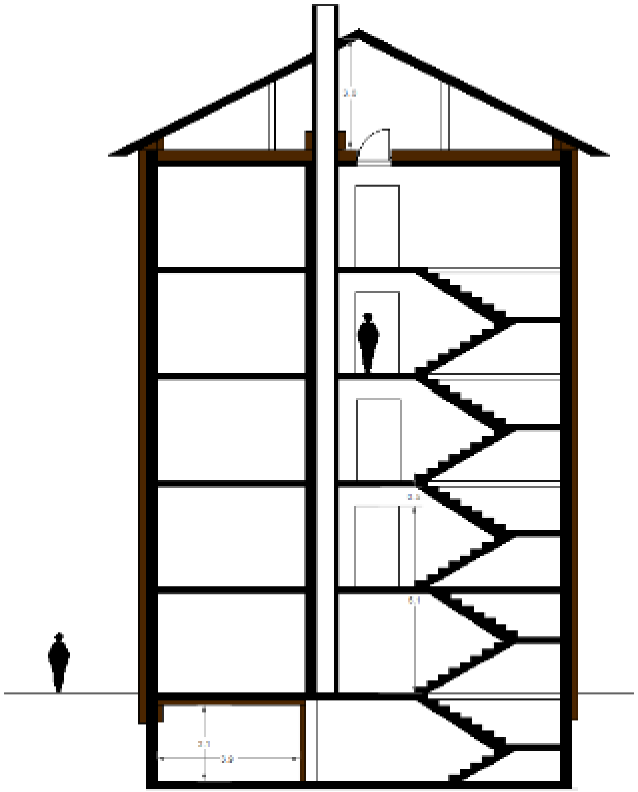
Example: Reference Building/Flat – Project SaLüH!

SaLüH!
Sanierungsansätze für Lüftung, Heizung und Warmwasser



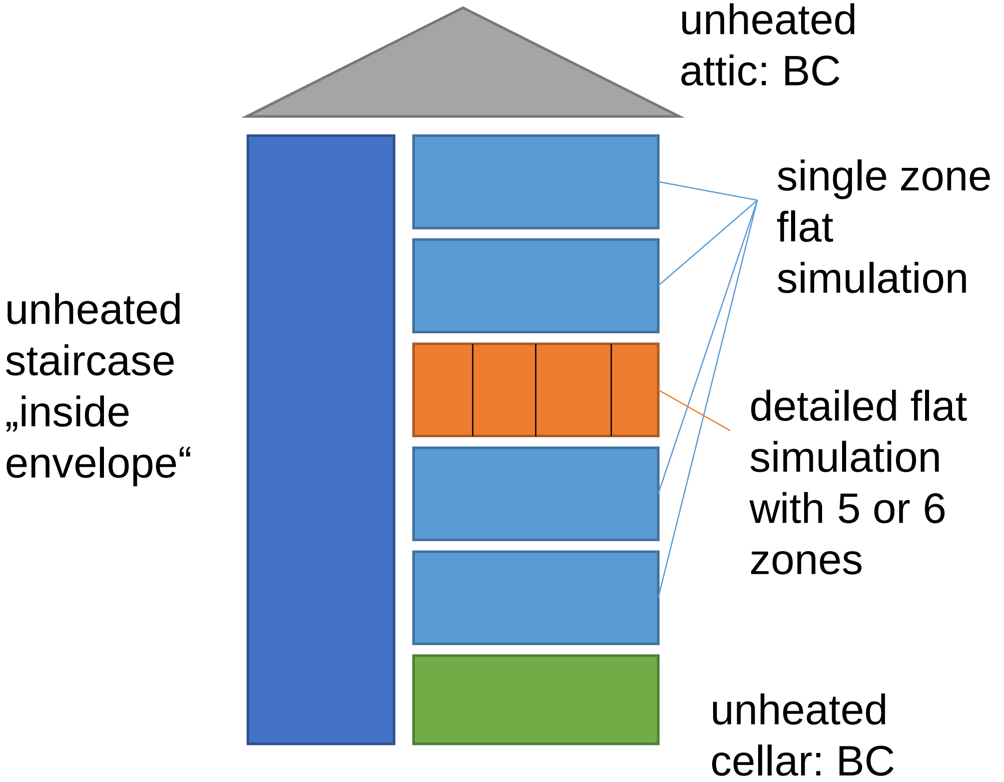
Zoning - Section and simplfied scheme

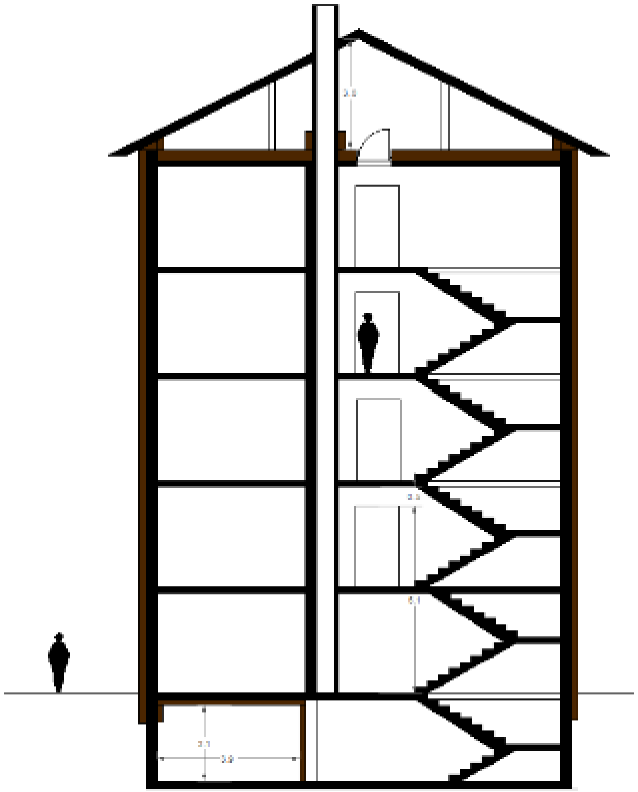




⇒ 2, 3 or more zones

Zoning - Section and simplfied scheme



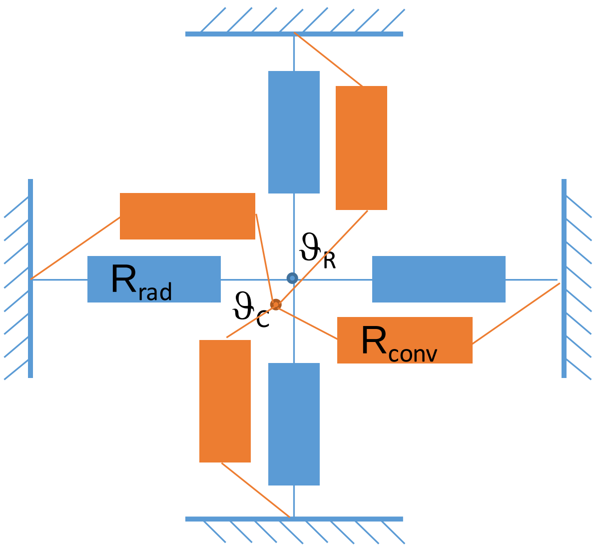


⇒ 5 or 6 zones for flat + 1 or 2 zone for building

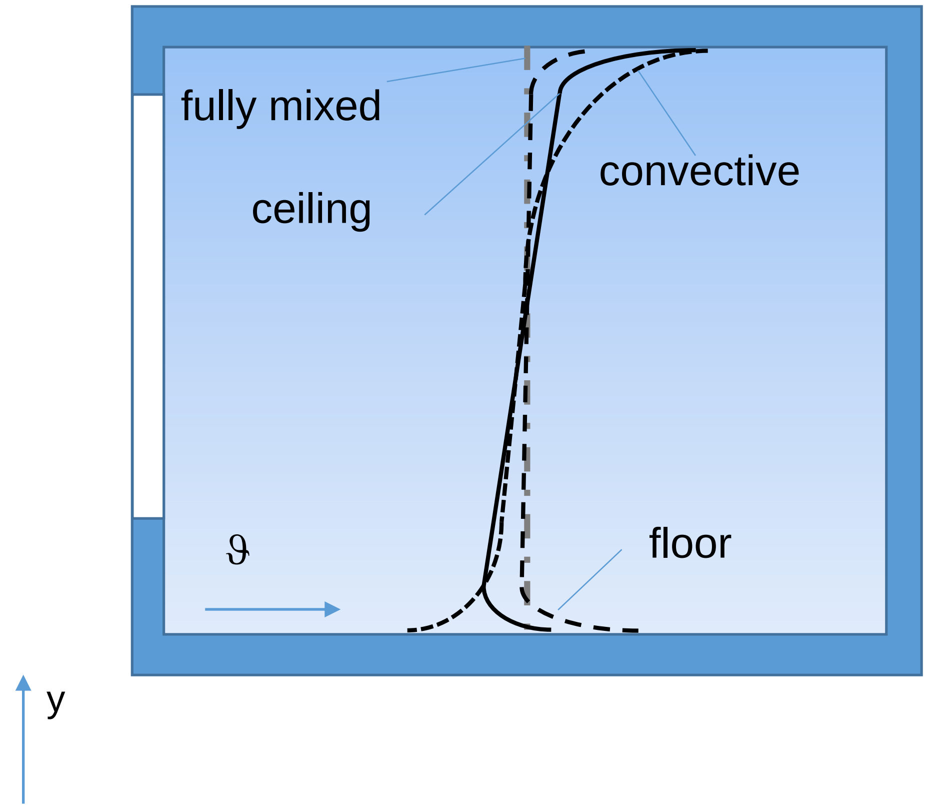
Building Model Physics – Performance and Accuracy

- **Model Physics (Radiation)**
  - Two-Star
  - Star-Node
  - Radiosity (physics)
- **Model Physics (Convection)**
  - Ideally mixed
  - Stratified
  - CFD
- **Model Physics (Transmission)**
  - Transfer Function
  - R-C wall
  - 2D/3D (FD or FE)
- Model Physics (Window)
- **Humidity**
  - Hygrothermal wall
  - Moisture Buffer
- **Air Quality**
  - CO_2
  - VOC
- Heat Emission Model
  - Radiator
  - Radiant Ceiling/Floor
  - Fan Coil)
- **HVAC**
  - Look up Table
  - Black Box Model
  - Physical Model

Model Physics - Convective Node

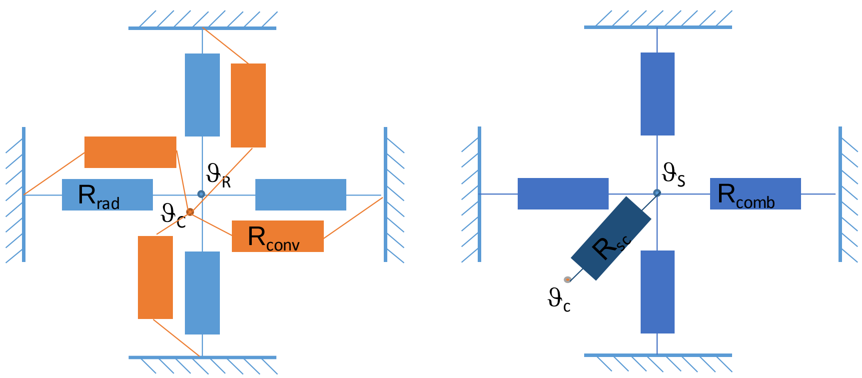


Two star model



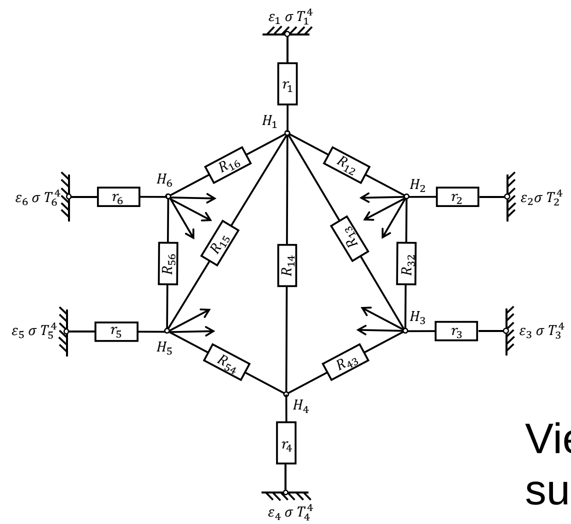
Model Physics - Radiation Exchange

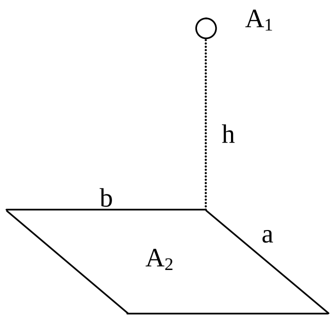
- **Two star and Star node model**
  - Non-physical
  - Radiation exchange with virtual radiation
  - Sufficiently accurate dynamics
  - Sufficiently accurate representation of operative temperature



Two star model
Star-node model

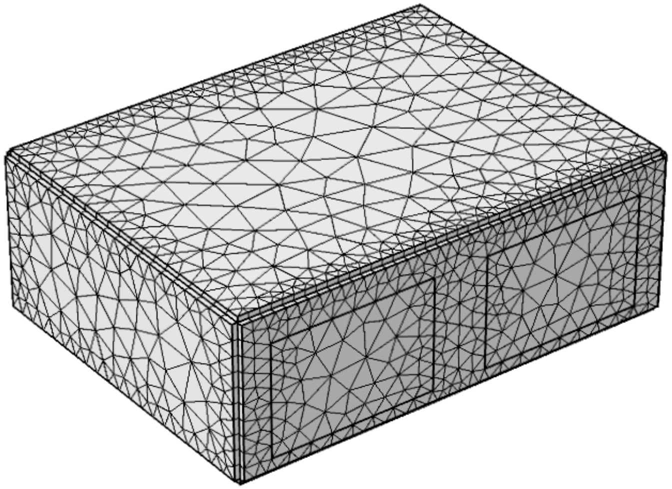
- **Radiosity Model**
  - Physically correct
  - Radiation exchange from surface to surface
  - Spatial distribution of radiative temperature
  - Radiation temperature asymmetry
  - Possibility to predict local comfort

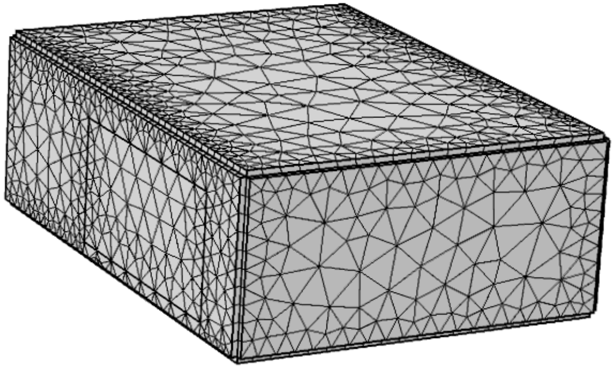




View factor between a surface and a sphere

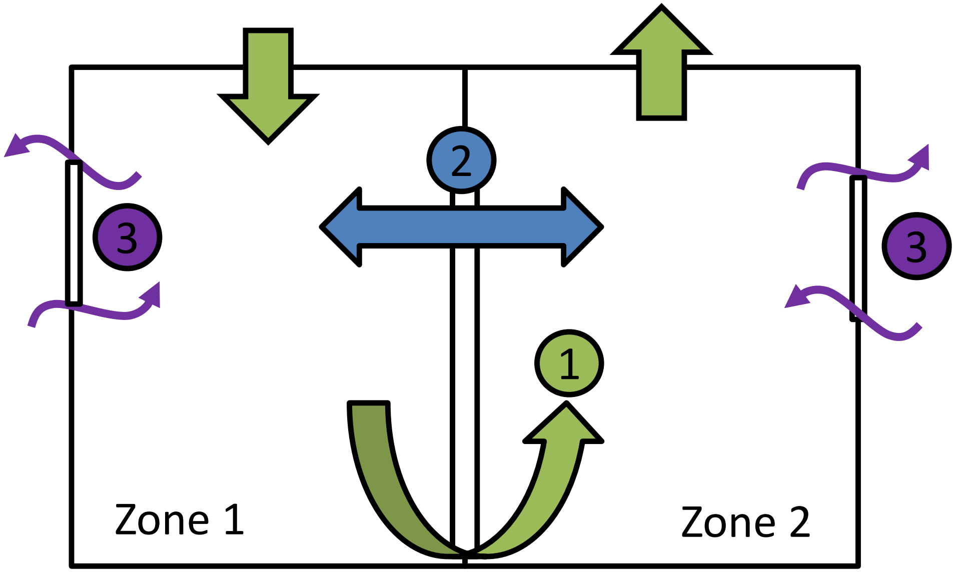
3D-Model in Comsol Multiphysics (FE-Model)





Result: View Factor

Multi-Zone Simulation with Air-Coupling in MATLAB/Simulink



Air exchange between thermal zones

1 Forced Convection between Zones (Ventilation)

2 Natural Convection between Zones (in case of open doors)

3 Infiltration and Exfiltration

$$\dot{m} = C \cdot |\Delta P|^n$$

$$|\Delta P| = |\Delta\rho_{12} \cdot g \cdot H|$$

$$C = 0.5 \cdot C_d \cdot \frac{\sqrt{2}}{2} \cdot H \cdot L \cdot \sqrt{\tilde{\rho}}$$

Hygrothermal Wall Modell

Energy Conservation and Mass Conservation

Coupled system of ODEs

$$\frac{\partial u}{\partial \varphi}\frac{\partial \varphi}{\partial t} = \frac{\partial}{\partial x}\left(D_{m,\varphi}\frac{\partial \varphi}{\partial x} + D_{m,T}\frac{\partial T}{\partial x}\right)$$

$$\frac{\partial h}{\partial T}\frac{\partial T}{\partial t} + \frac{\partial h}{\partial \varphi}\frac{\partial \varphi}{\partial t} = \frac{\partial}{\partial x}\left(D_{e,T}\frac{\partial T}{\partial x} + D_{e,\varphi}\frac{\partial \varphi}{\partial x}\right)$$

solved with MATLAB pdepe function

$$c\left(x,t,u,\frac{\partial u}{\partial x}\right)\frac{\partial u}{\partial t} = x^{-m}\frac{\partial}{\partial x}\left(x^m f\left(x,t,u,\frac{\partial u}{\partial x}\right)\right) + s\left(x,t,u,\frac{\partial u}{\partial x}\right)$$

and MATLAB/Simulink S-function

PDE for Simulink

- Simulink solves ODEs
- Generate system of ODE from PDE with „Method of Lines“
- Update of PDE Parameter with time
- Integration by Simulink

PDE Problem ⇒ Simulink Block

Simulink Block	
States	one for each node
Input	transient BC, Source
Output	Temperature at each node

Source: Ochs et al. 2012, Bausim, Berlin
Prüfert, TUB, 2012

Modelling Ground Heat Exchanger

2D heat equation, cylinder coordinates

$$r\rho c_p \frac{\partial \vartheta}{\partial t} - \frac{\partial}{\partial r}\left(r\lambda \frac{\partial}{\partial r}\vartheta\right) - \frac{\partial}{\partial z}\left(\lambda \frac{\partial}{\partial z}\vartheta\right) = \dot{q}r$$

(PDE)

MATLAB/Simulink

PDE Problem

Method of lines

Level 2 **s-function**

$$\frac{d}{dt}U = M^{-1}\left(F + G + R + KU + QU + HU\right)$$

(Matrix Formulation)

Level 2 S-function

Initialization

States

Input

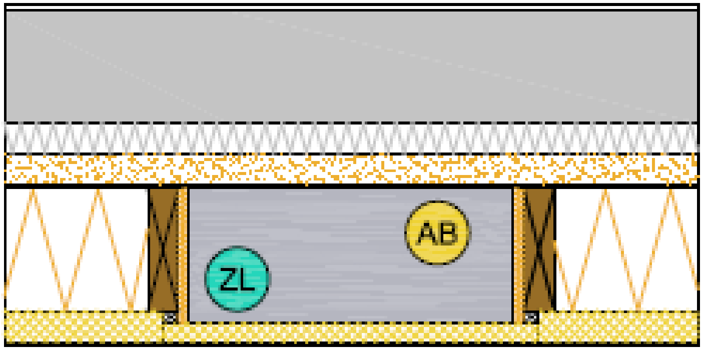
Output

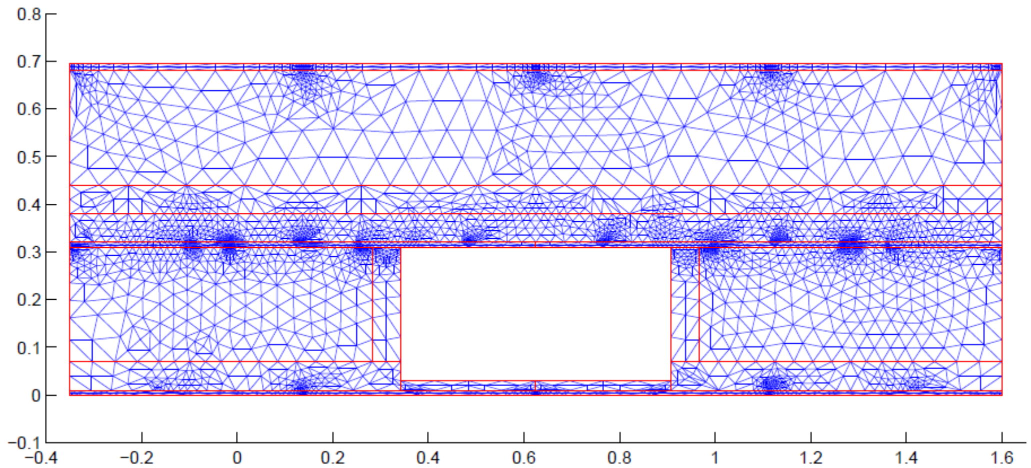
Simulink Block

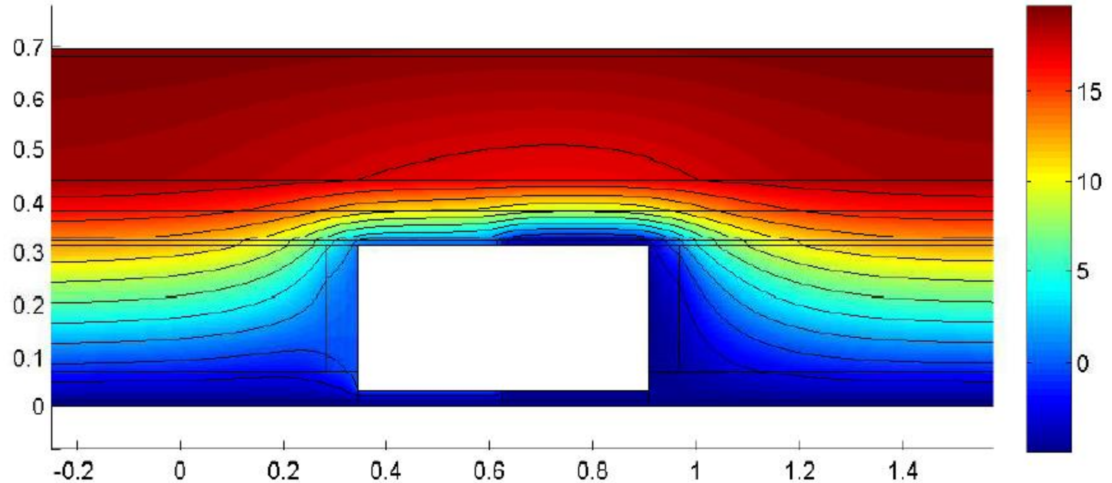
One for each node

Time depended BC, Temperature at single node, heat flux

Example: Facade integrated MHVR



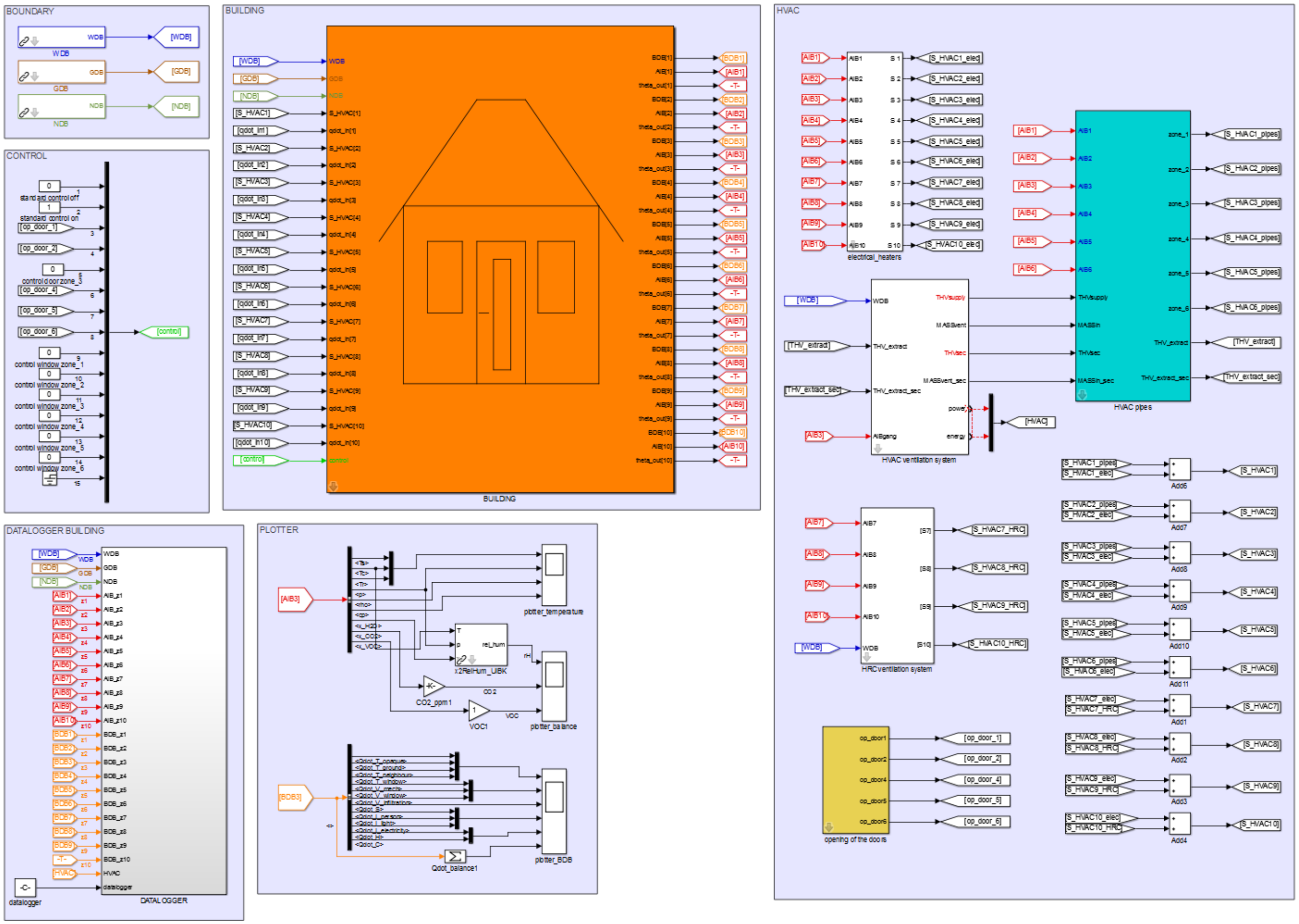




Other examples of 2 D Heat Transfer:

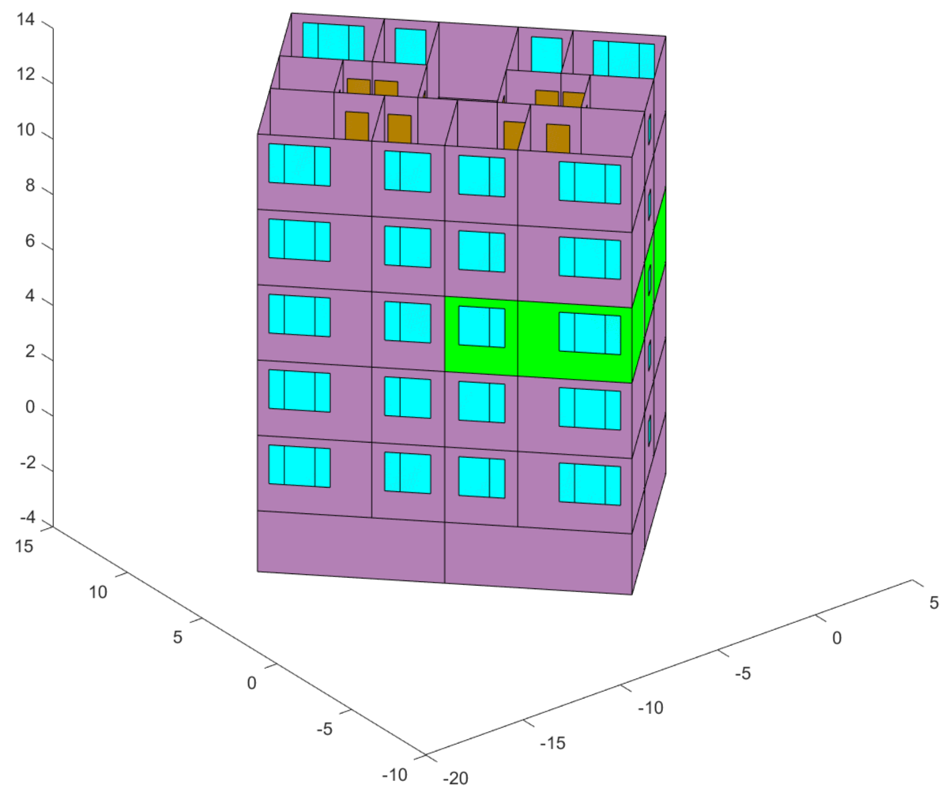
- Ground coupling (2D)
- Thermal Bridges (2D)
- Ground heat exchanger

MATLAB/Simulink Building Model (Object Oriented)



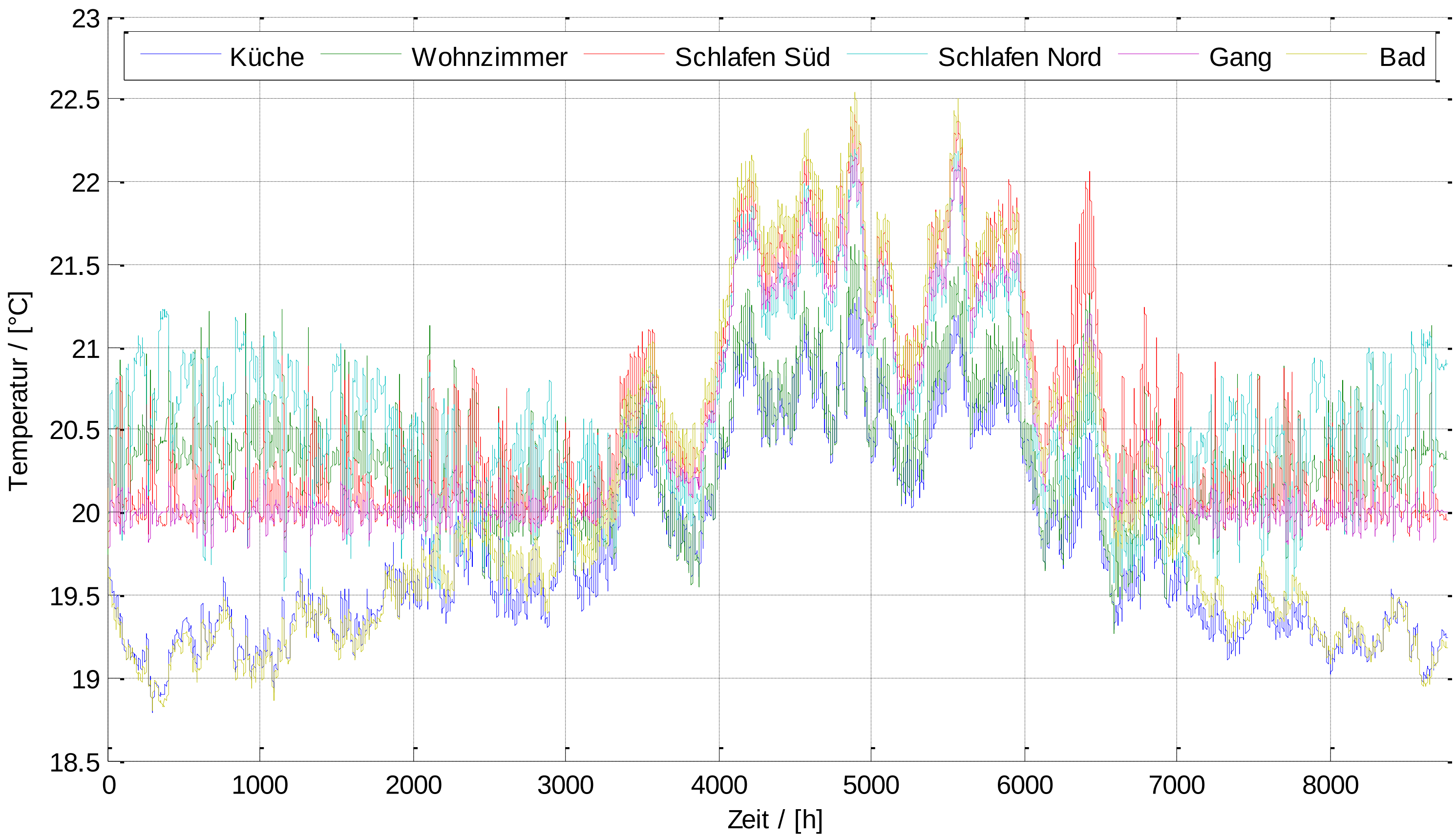
Multi-Zone Building
MATLAB/Simulink

SaLüH!
Sanierungsansätze für Lüftung, Heizung und Warmwasser



Temperature Distribution - SaLüH! Reference Building

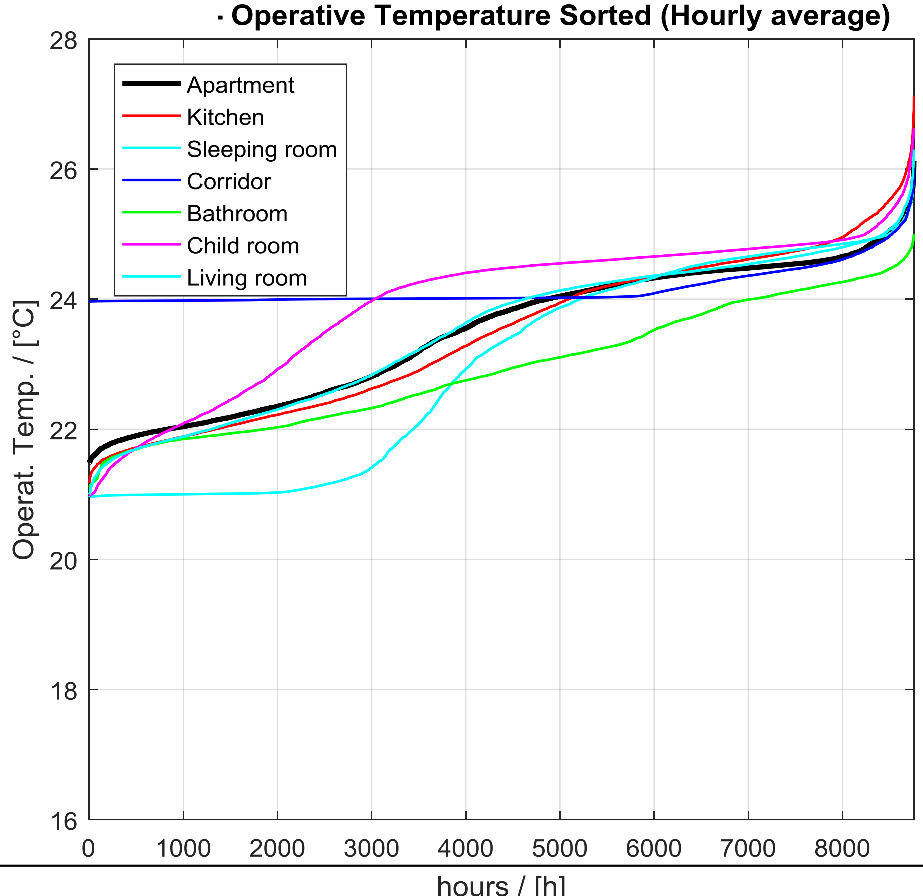
Supply Air Heating (no recirculation), no bath heater



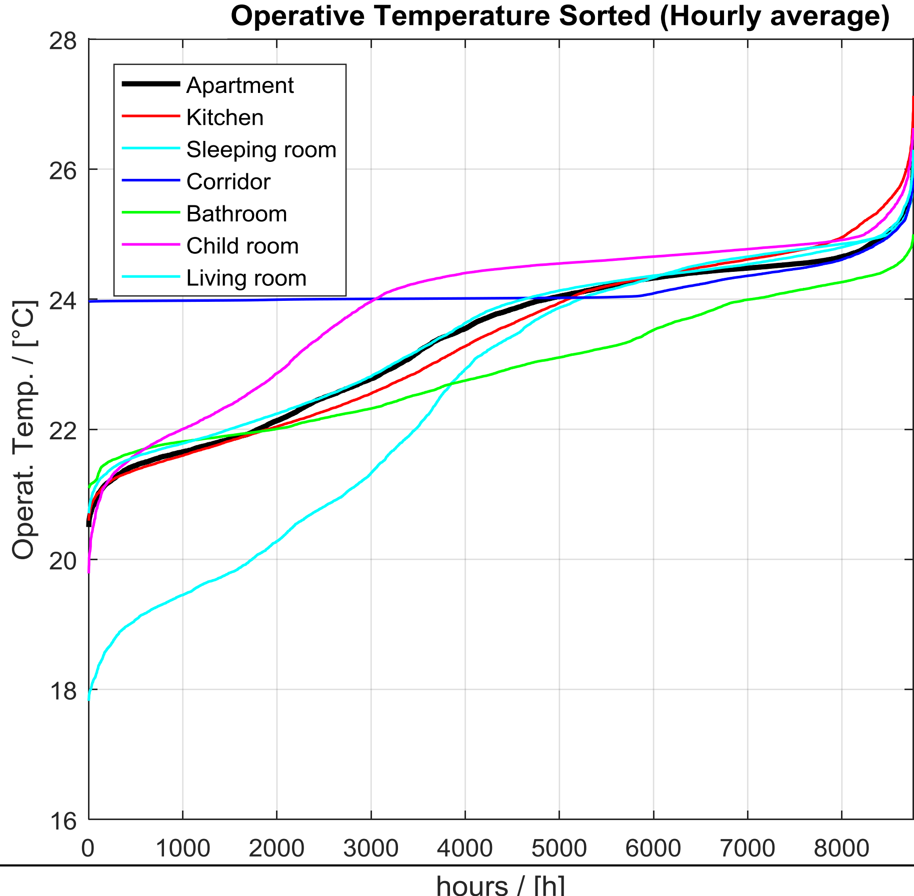
Overheating of corridor

Door air exchange model: BR/CHILD/SLEEP (Closed), KITCH/LIVING (Opened)

Individual (room-wise) post-heater



No individual (room-wise) post-heater



Simulation Results – Heating demand and heating load

Simulation	HEATING DEMAND [kWh/m²a]			HEATING LOAD [W/m²]	
	Supply air	Electr. Heater	Total	Air heating	Electr. Heater
REF	24.8	3.4	**28.2**	13.2	5.1
Corridor Overheating (24 °C)	0.0	48.1	**48.1**	0.0	17.8
Corridor Overheating „symmetric BC“	0.0	23.8	**23.8**	0.0	13.3
Corridor Overheating „symmetric BC“ No room post-heater	0.0	22.9	**22.9**	0	10.6

Door air exchange model:

- BR/CHILD/SLEEP (Closed), KITCH/LIVING (Opened)

Research Projects

- EU iNSPiRe (fp7)
- Landesförderung Tirol k-WP
- FFG SaLüH!
- NHT Vögelebichl
- IEA SHC Task 56
- IEA HPT Annex 49

thanks to …
Siko Energiesysteme (At)
Pichler Luft (At)
Gumpp & Maier (D)
Wohnungsbau Ludwigsburg (D)
Eurac (It)
AEE Intec (At)
Vaillant (D)
NHT (At)

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A detailed report on the review of heat pumps in passive houses is available German language and can be distributed on request.