
Energy Consumption and User Comfort In Cold Climate NZEHs



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ASHRAE Annual Conference , June 28th 2011

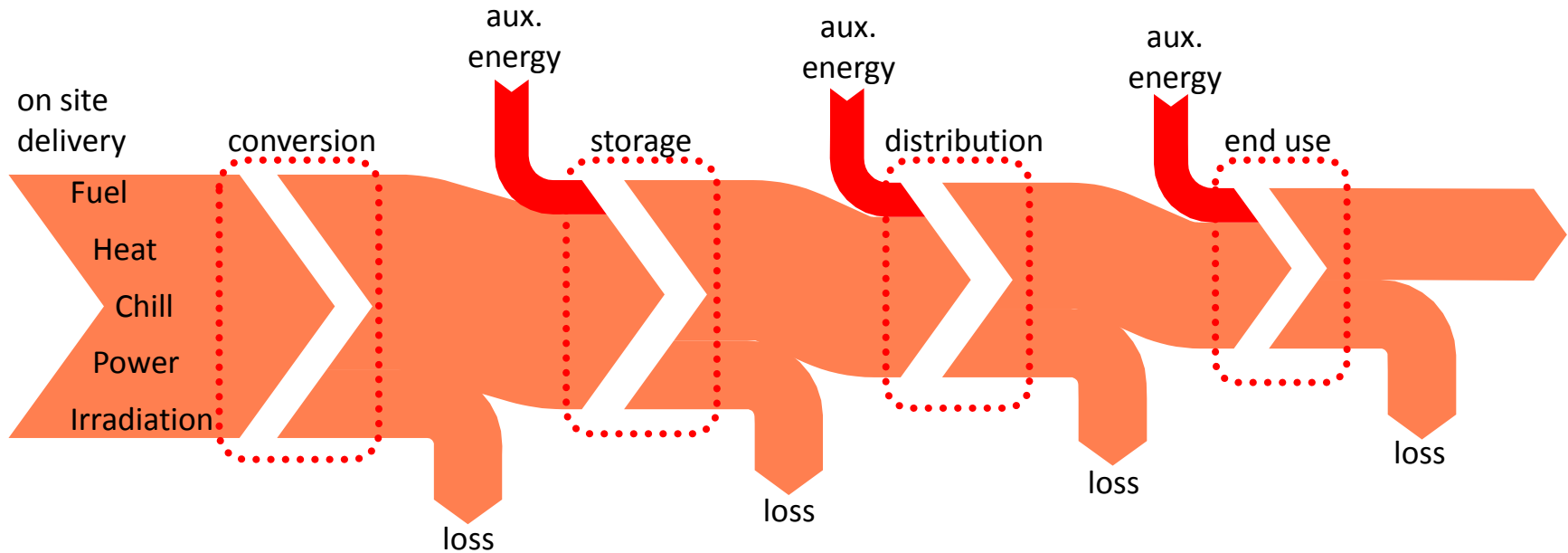
Agenda

- monitoring - background
- introduction of monitored buildings
- energy consumption and indoor comfort in summer
- energy consumption and indoor comfort in winter
- conclusion – outlook



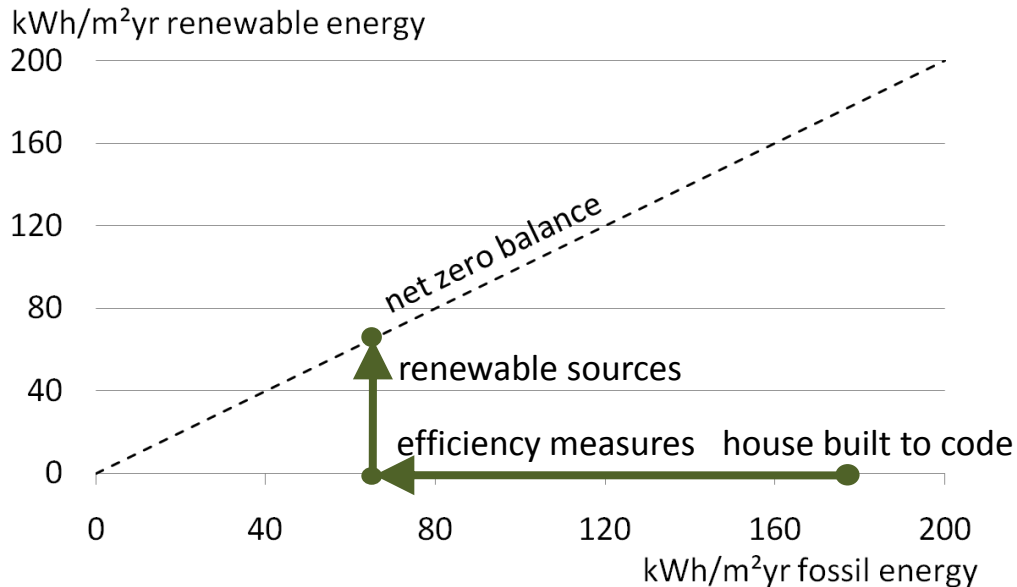
background

monitoring – principles and challenges



background

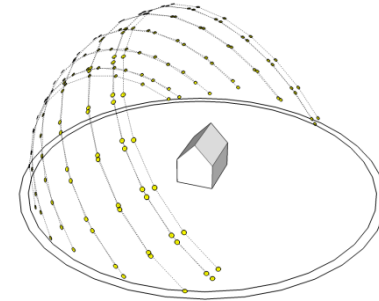
the net-zero balance



key questions:

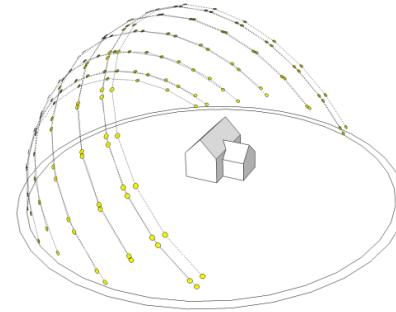
- what is necessary to achieve a net-zero energy balance in cold climates?
- how big is the user influence on a “zero balance”
- how is the indoor comfort in heating and cooling season?

the buildings – Stow, MA



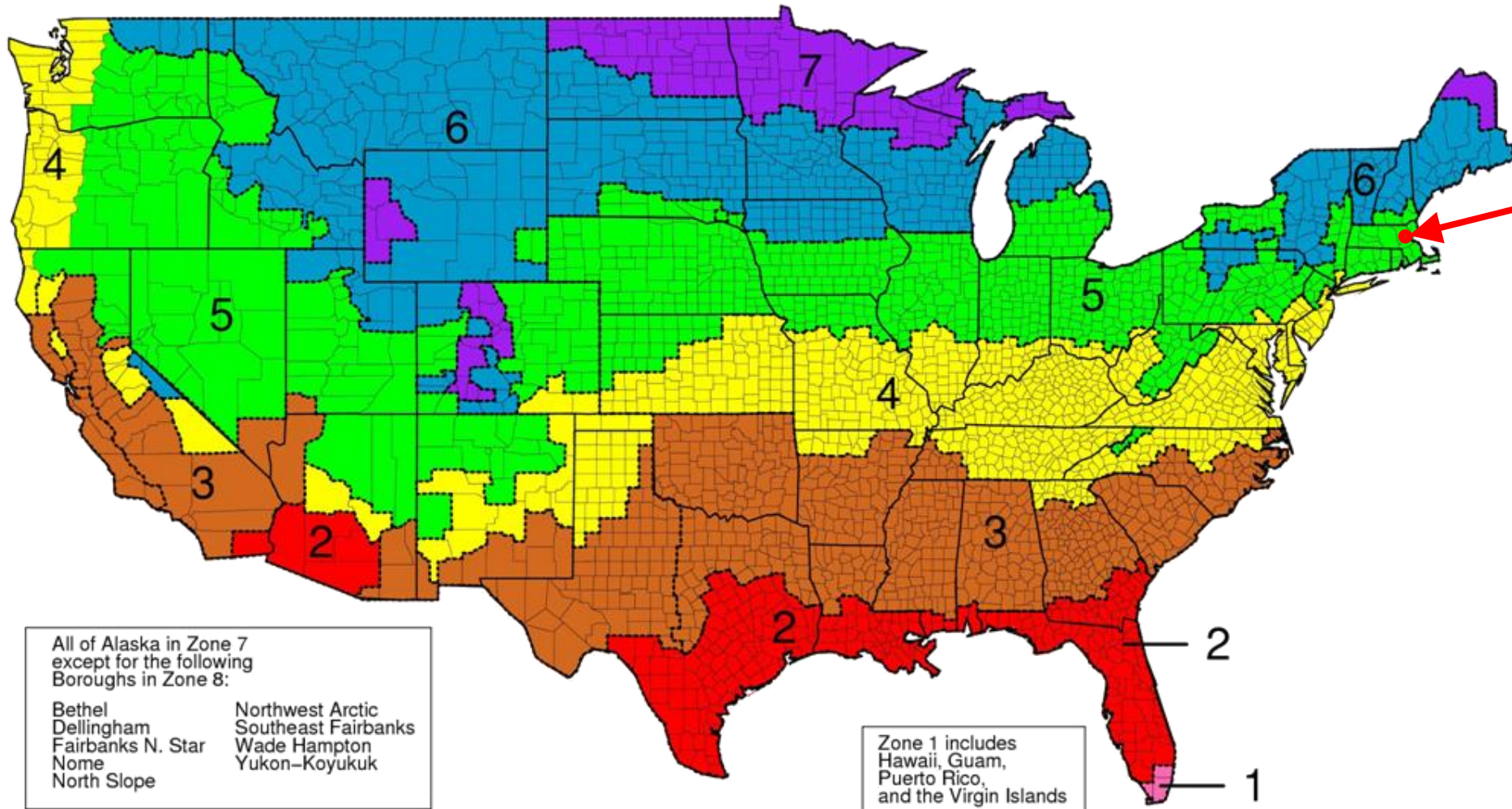
floor area (conditioned ANSI Z765-2003), floors: 4	2964 ft ²	275 m ²
building envelope	R [ft ² ·°F·h/Btu]	U [W/m ² K]
▪ insulation exterior walls to ambient	R65	0.09
▪ insulation exterior walls to ground	R25	0.23
▪ insulation roof	R63	0.09
▪ windows (triple glazed)	R5.1	1.11
calculated demand for space heating	12 kBtu/ft ² yr	37.8 kWh/m ² yr
ventilation	HRV, $\eta_{\text{HRV}} \approx 60\%$	
PV generator	6.3 kW _p	
HERS index	9	

the buildings – Townsend, MA

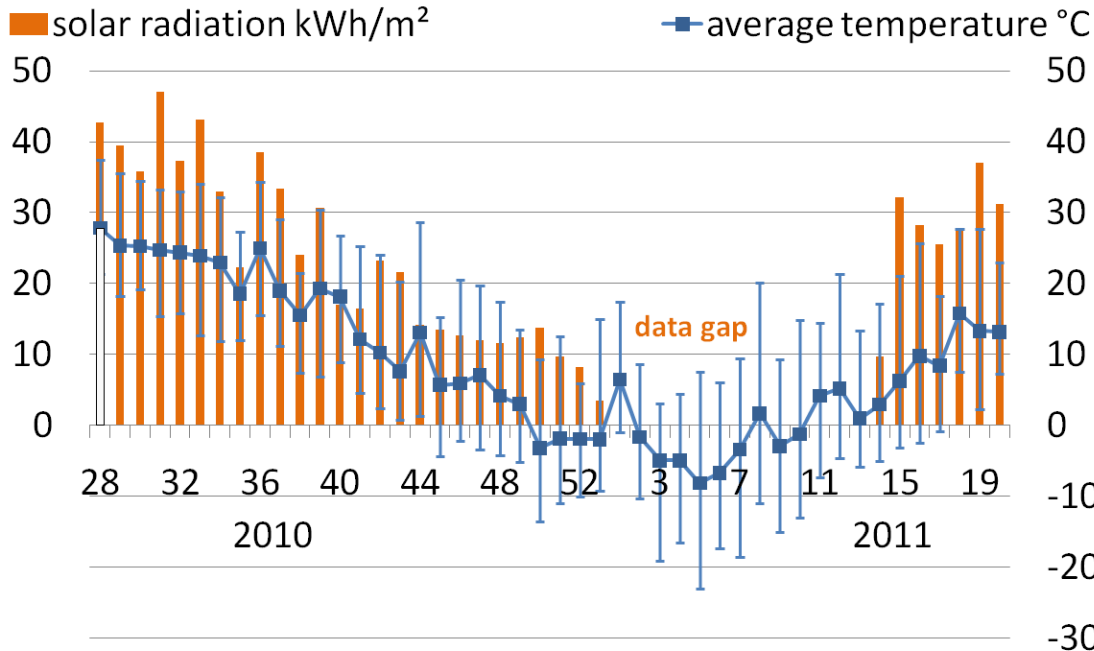


floor Area (conditioned ANSI Z765-2003), floors: 2	1835 ft ²	170 m ²
building envelope	R [ft ² ·°F·h/Btu]	U [W/m ² K]
▪ insulation exterior walls to ambient	R47	0.12
▪ insulation exterior walls to ground	R24	0.23
▪ insulation roof	R63	0.09
▪ windows (double pane)	R4.8	1.2
calculated demand for space heating	19.2 kBtu/ft ² yr	60.8 kWh/m ² yr
ventilation	HRV, $\eta_{\text{HRV}} \cong 60\%$	
PV generator	7.14 kW _p	
HERS index	2	

the buildings - location



ambient conditions and instrumentation



Location: 42°N, 71°W

Ambient temperature and humidity are measured on site.

heating period:

HDD 65 (10/2010 – 04/2011)

3,314 (°C)

5,965 (°F)

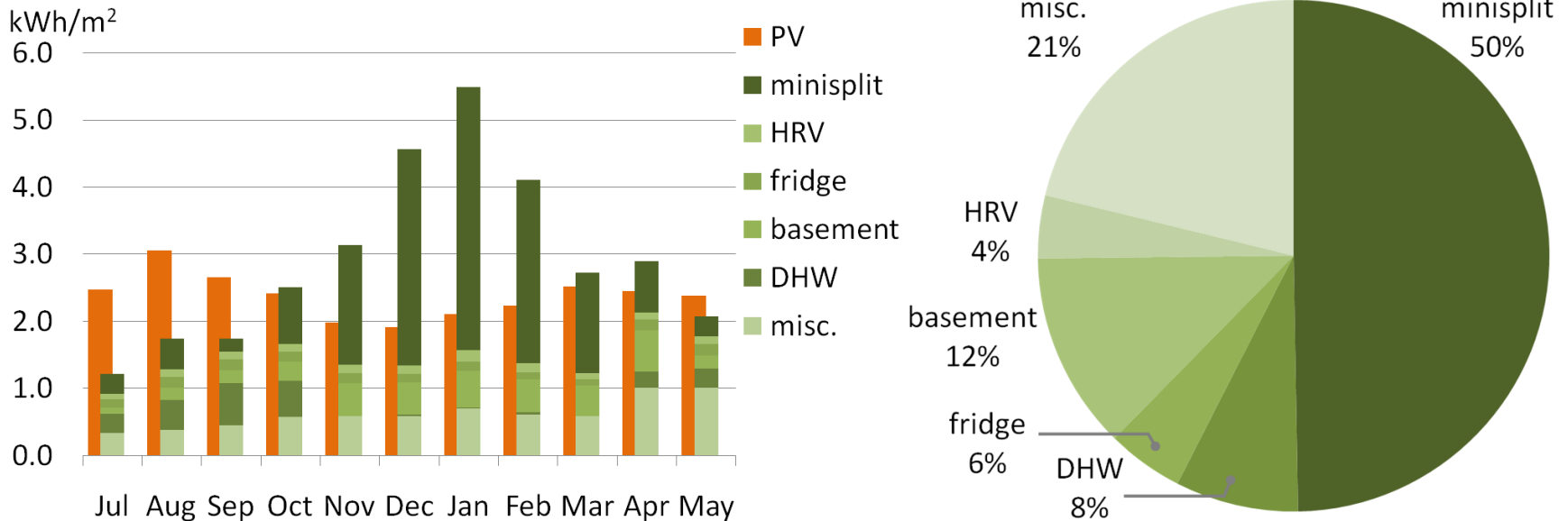
ASHRAE 90.1 for Boston: 5,641

instrumentation:

- multi-channel power meter, each breaker-circuit is measured
- temporary decentral temperature, relative humidity and CO₂ loggers

energy balance – net zero goal achieved?

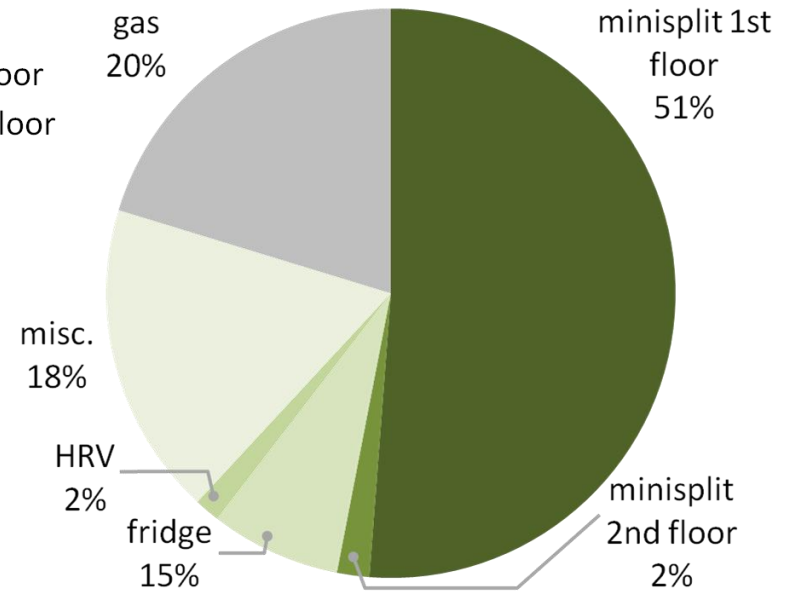
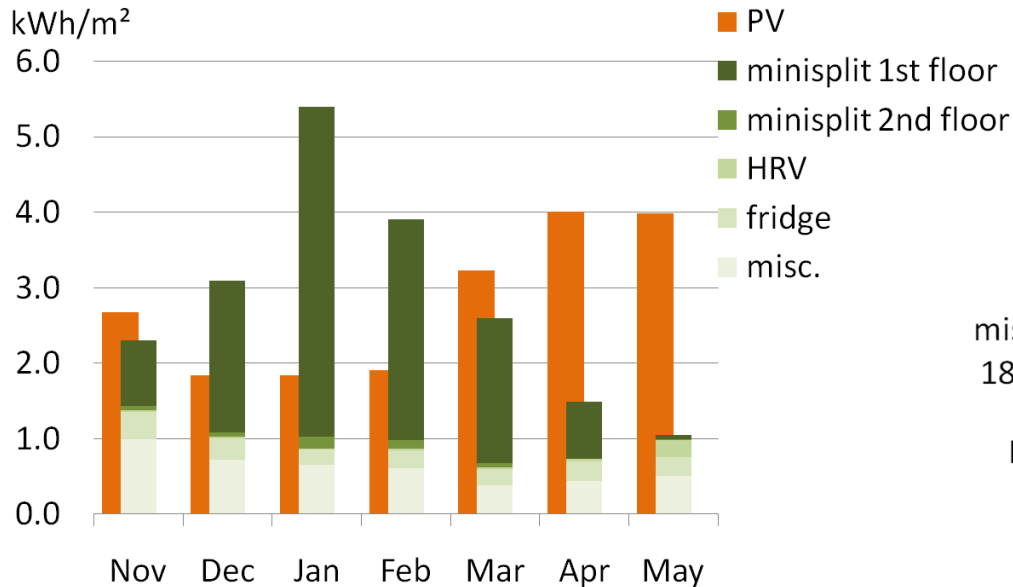
NZH in Stow – end energy consumption



- *electric* energy for space heating (Oct – Mar): **14.1 kWh/m²yr, 4.4 kBtu/ft²yr**
- energy consumption for space heating is dominating load
- DHW is „hidden“ in different circuits (direct resistance heater, heat pump plugged in basement and laundry outlet)
- energy consumption *excluding* heating/cooling/DHW/fridge is approx. 3500kWh, national average (Northeast): 6793 kWh (source: DOE, Buildings Energy Data Book 2010)

energy balance – net zero goal achieved?

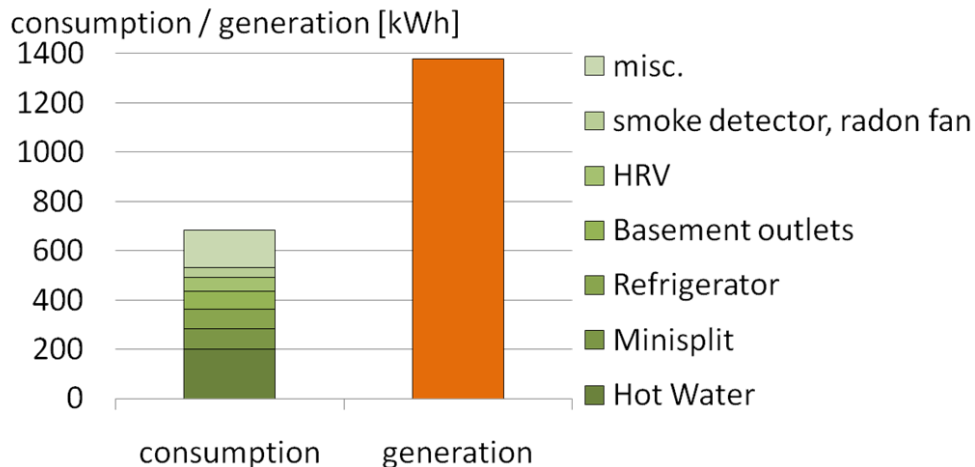
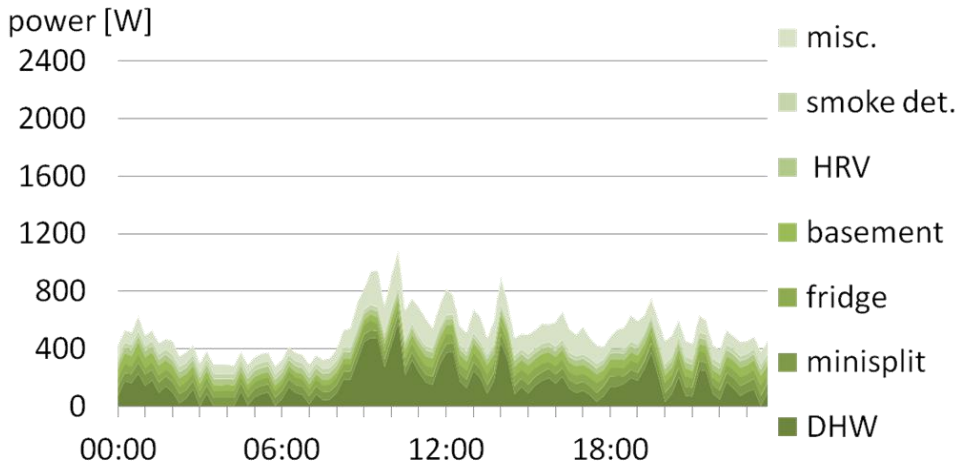
NZH in Townsend – end energy consumption



- *electric* energy for space heating (Oct – Mar): **12.6 kWh/m²yr, 4.0 kBtu/ft²yr**
- separate outdoor units for ductless splits – but mainly only one unit is used
- HRV is manually switched on and off by users
- hill/trees south-west of the building shade PV during winter
- DHW by gas boiler, consumption Oct 2010 – May 2011 \cong 870 kWh

energy and comfort – summer

NZH in Stow – daily and weekly pattern

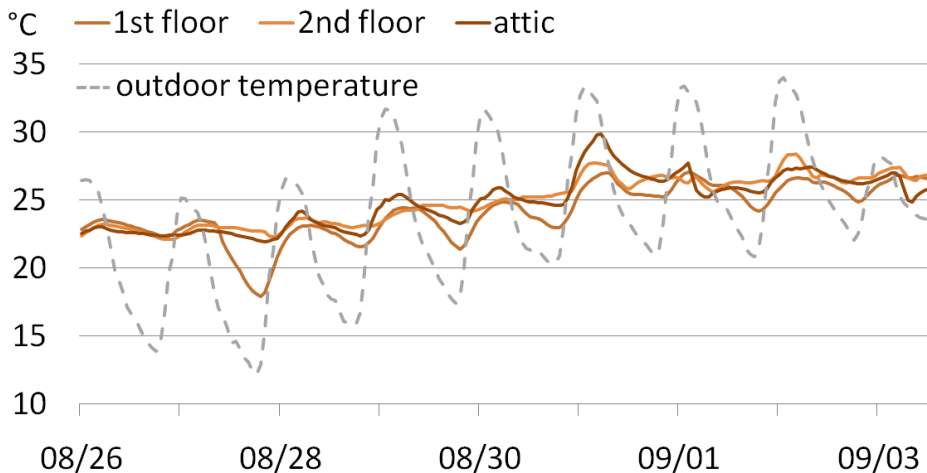
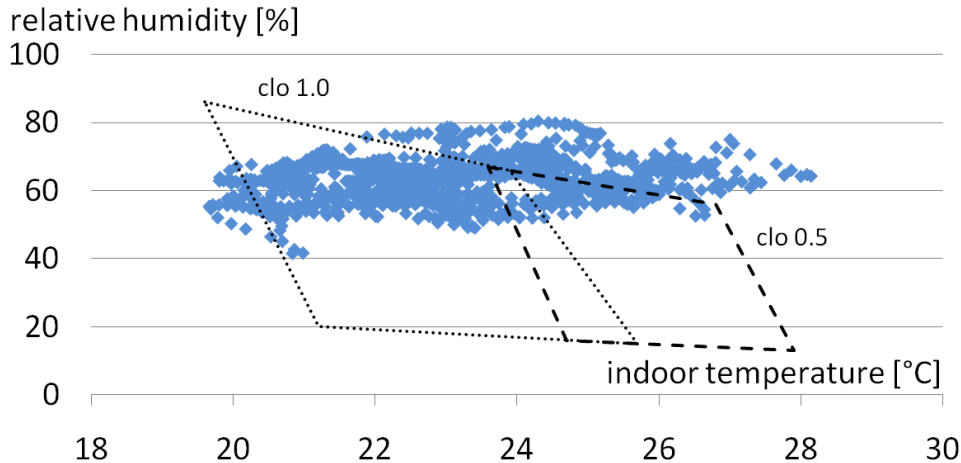


- In summer, the energy consumption is rather dominated by DHW.
- “Base load” of 300-400 W during night.
- PV generation doubles the power consumption.

circuit	average kWh/d
minisplit	3.8
DHW	3.7
fridge	1.4
basement	1.4
HRV	1.0
misc.	3.6
total	14.8

energy and comfort – summer

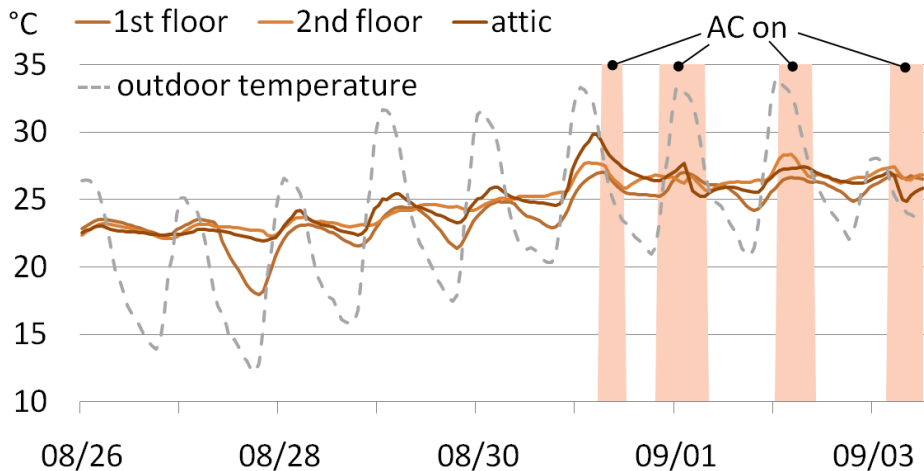
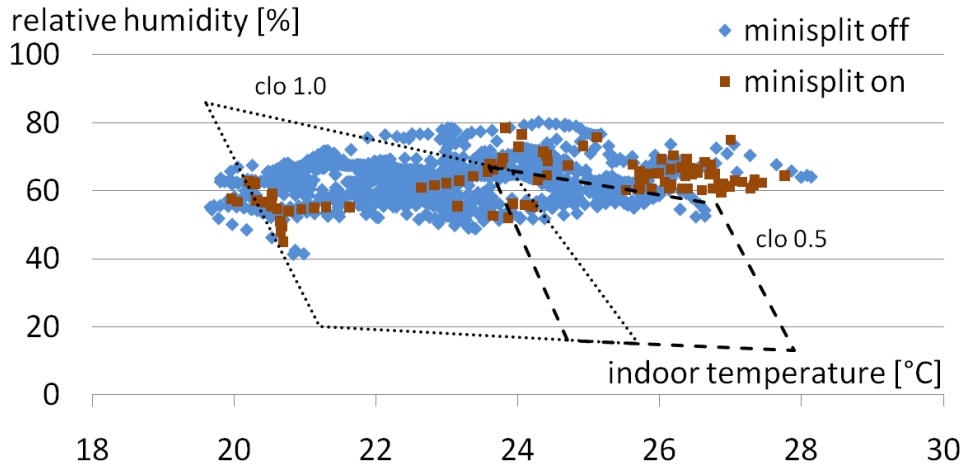
NZH in Stow – indoor thermal comfort



- Temperature and humidity are in the limits defined in ASHRAE 55 most of the time. If not, it's rather too humid than too warm.
- No distinctive temperature stratification over the 3 stories.

energy and comfort – summer

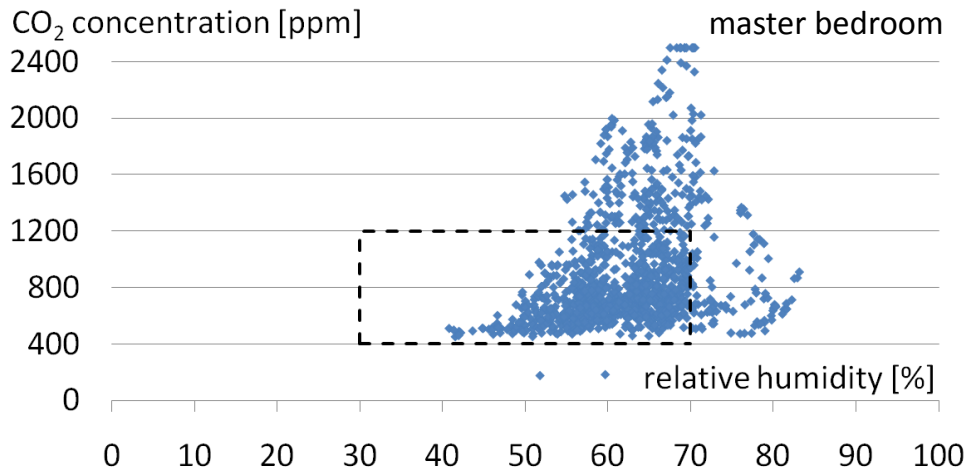
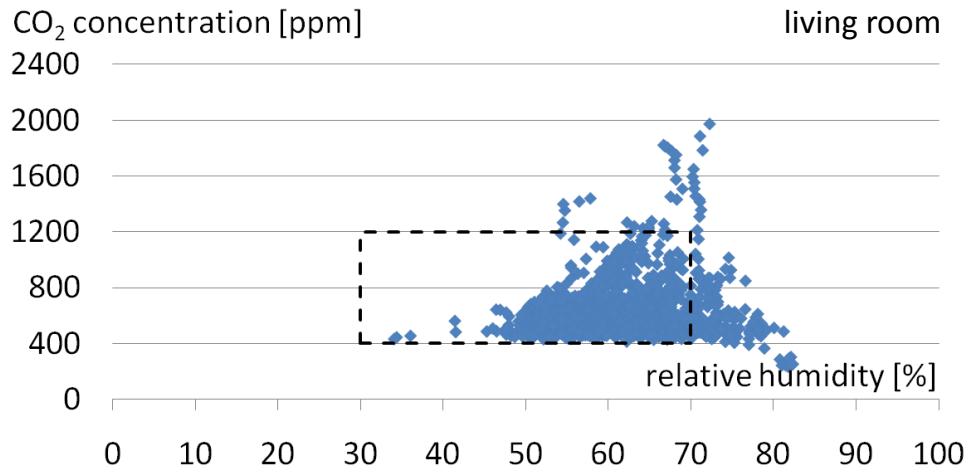
NZH in Stow – indoor thermal comfort



- Temperature and humidity are in the limits defined in ASHRAE 55 most of the time. If not, it's rather too humid than too warm.
- No distinctive temperature stratification over the 3 stories.
- AC is mostly used, when temperatures don't drop under 20°C (68°F) over night.

energy and comfort – summer

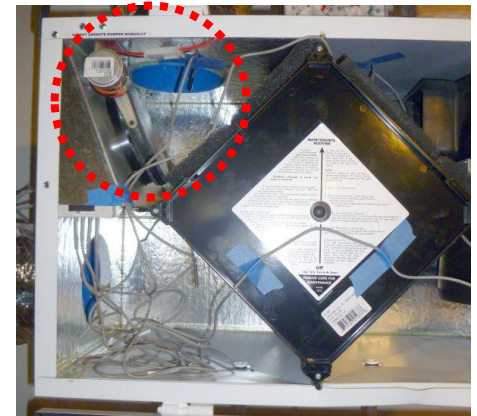
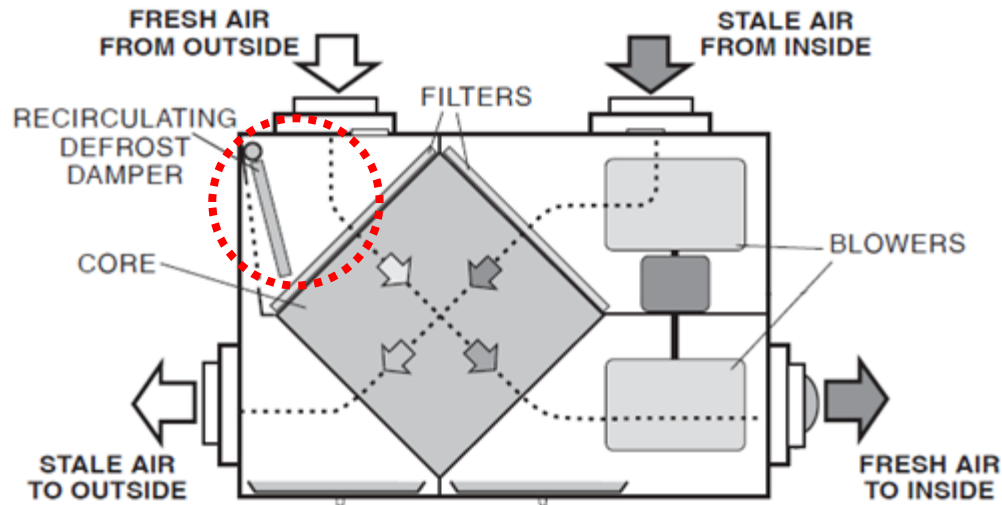
NZH in Stow – indoor air quality



- ASHARE 62.1 limits (CO₂ 700ppm over outdoor conditions) exceeded significantly, especially in the master bedroom.
- Reason is fault in ventilation unit.

energy and comfort – winter

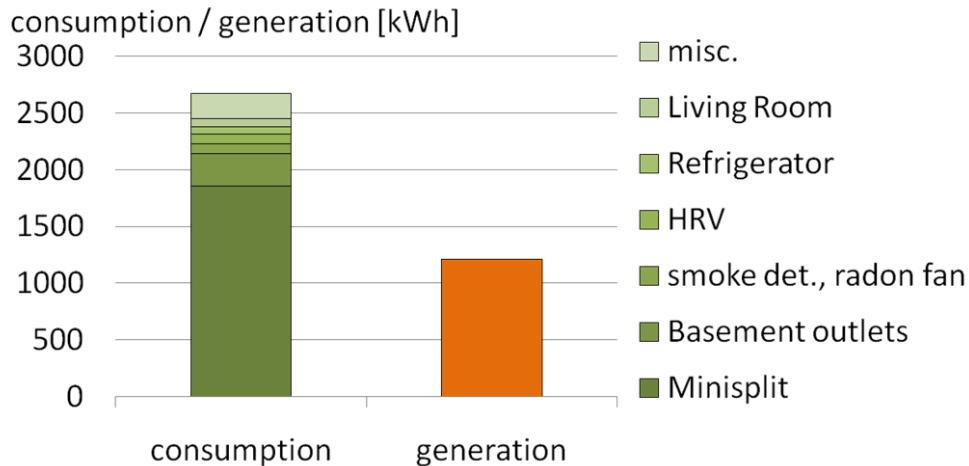
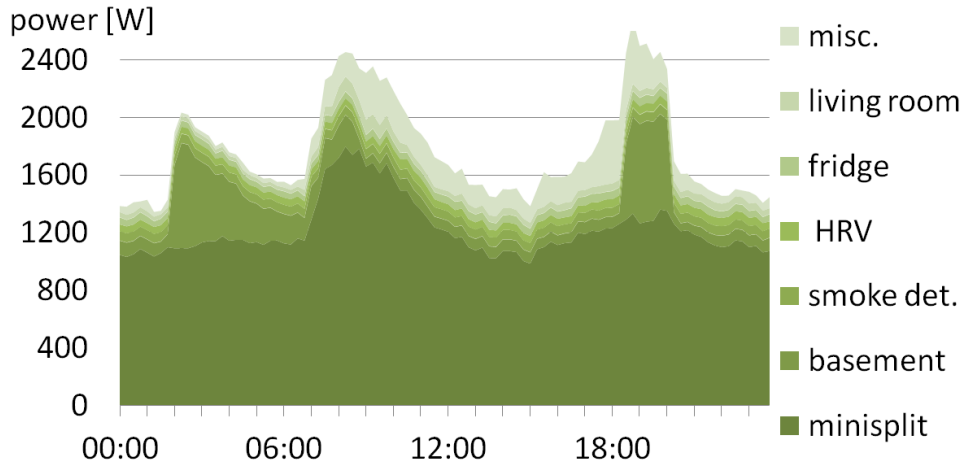
malfunction in ventilation unit controls



- Damper that seals fresh air inlet and opens bypass to re-circulate the air was constantly in “frost protection” mode.
- error is remedied
- but internal leakages are likely.

energy and comfort – winter

NZH in Stow – daily and weekly pattern

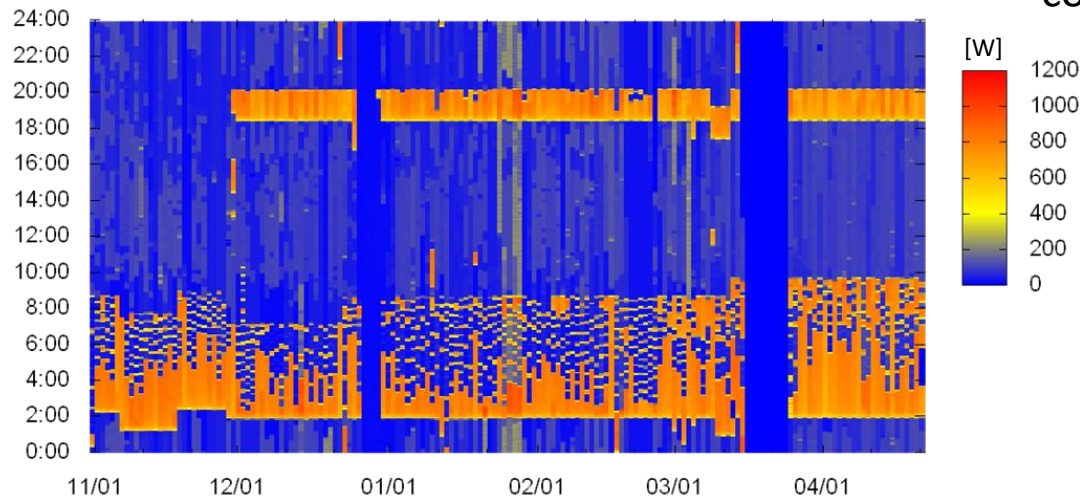
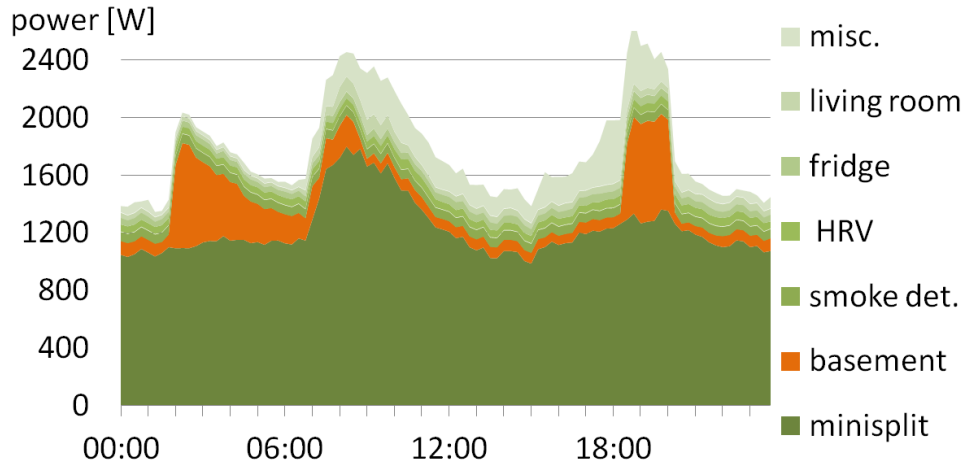


- Average load pattern during heating season (Dec 2010, Jan, Feb 2011).
- Space heating is dominating load.
- During winter time PV covers only a third of the energy consumption.

circuit	average kWh/d
minisplit	30.3
basement outlet	4.6
smoke det.	1.5
HRV	1.3
fridge	1.2
misc.	4.5
total	43.4

energy and comfort – winter

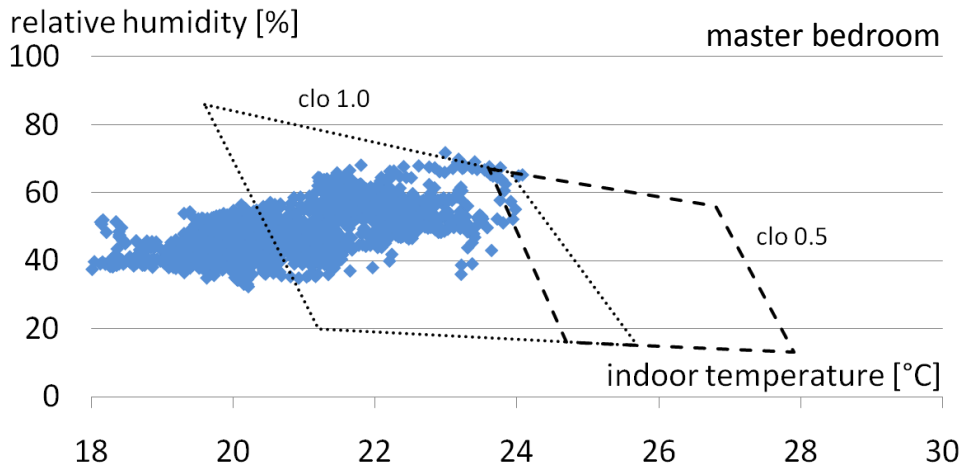
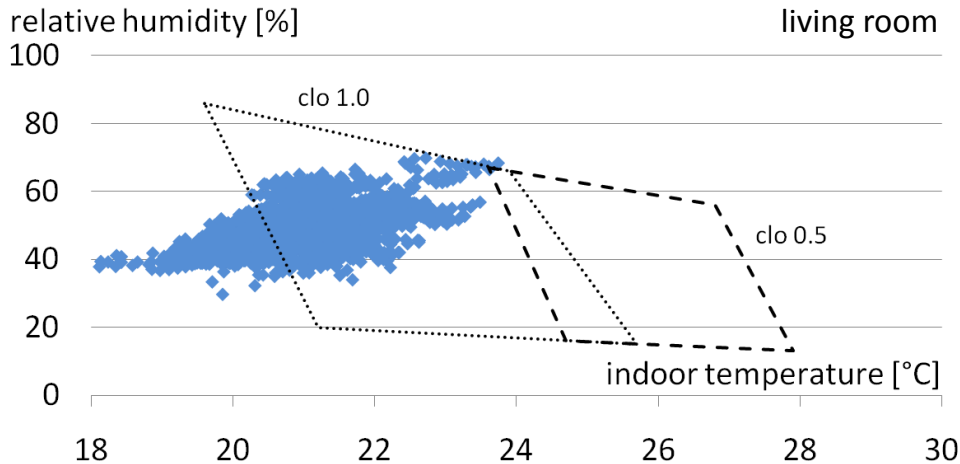
NZH in Stow – daily and weekly pattern



- Average load pattern during heating season (Dec 2010, Jan, Feb 2011).
- Water heating is switched to a heat pump, which was plugged in the “basement outlets” circuit, controlled by a timer.

energy and comfort – winter

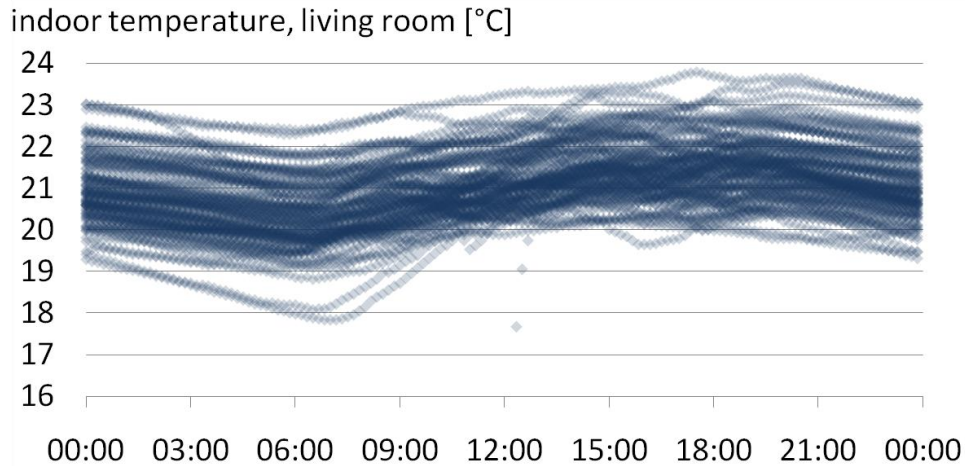
ASHRAE 55 - NZH in Stow



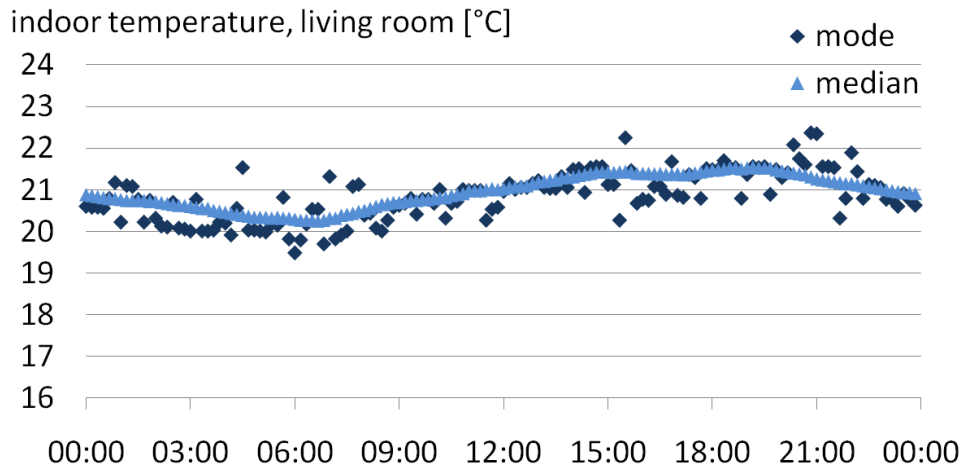
- Measurement period:
01/25 – 04/10/2011
- Indoor thermal comfort most of the time within good comfort conditions (assuming clothing rate clo 1.0)

energy and comfort – winter

Stow

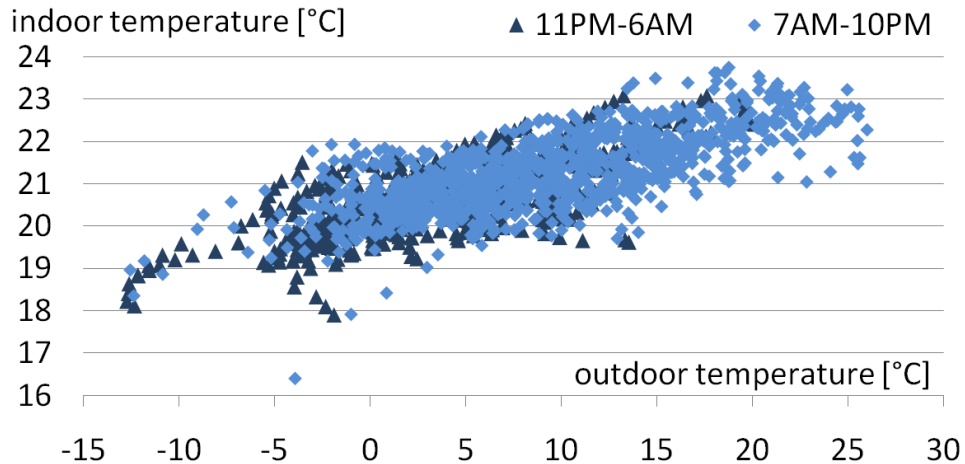


- Indoor temperature very stable.
- Fluctuations typically not more than 2K over a day

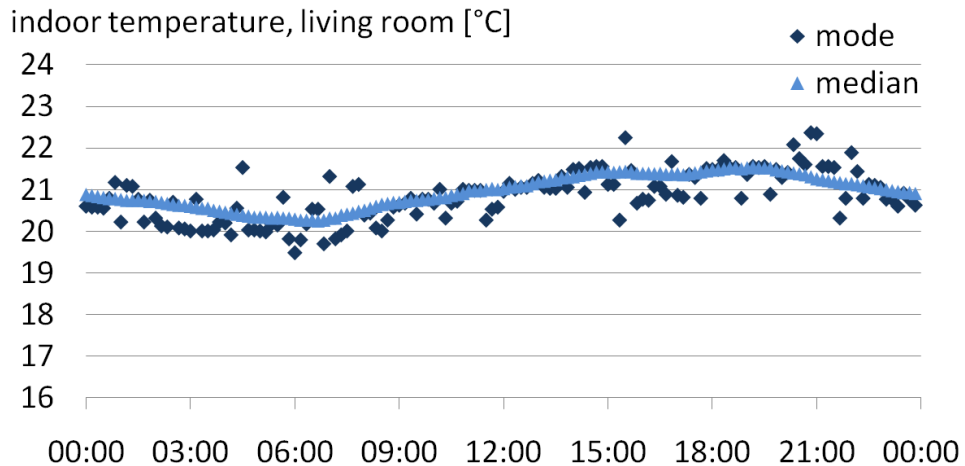


energy and comfort – winter

Stow

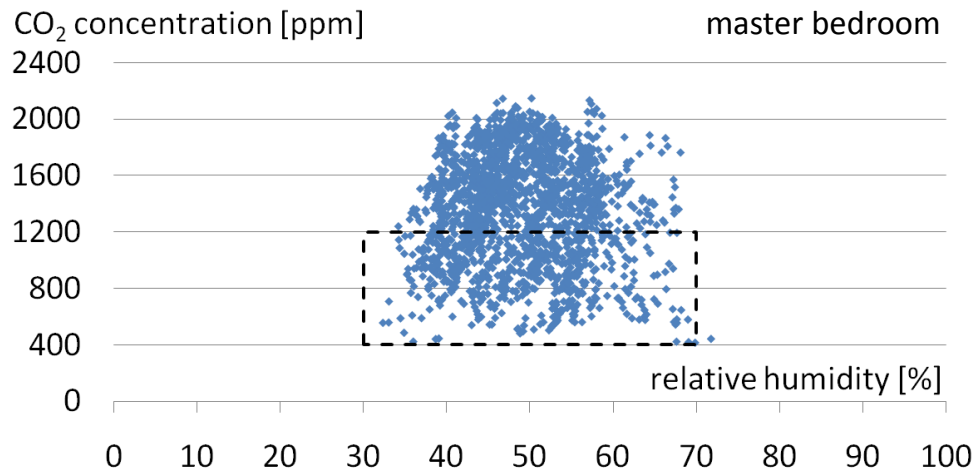
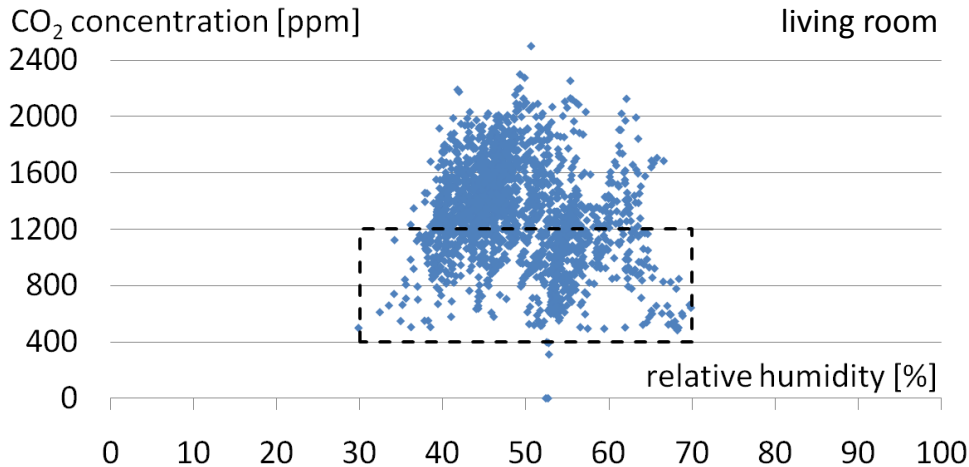


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energy and comfort – winter

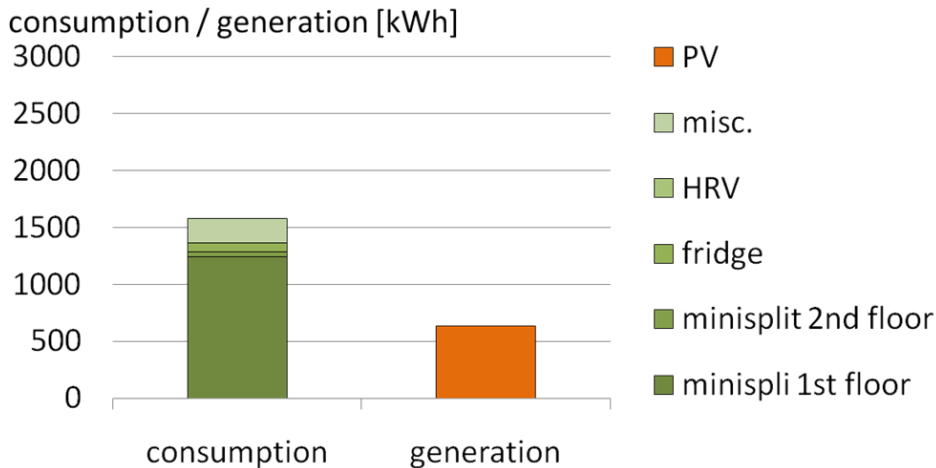
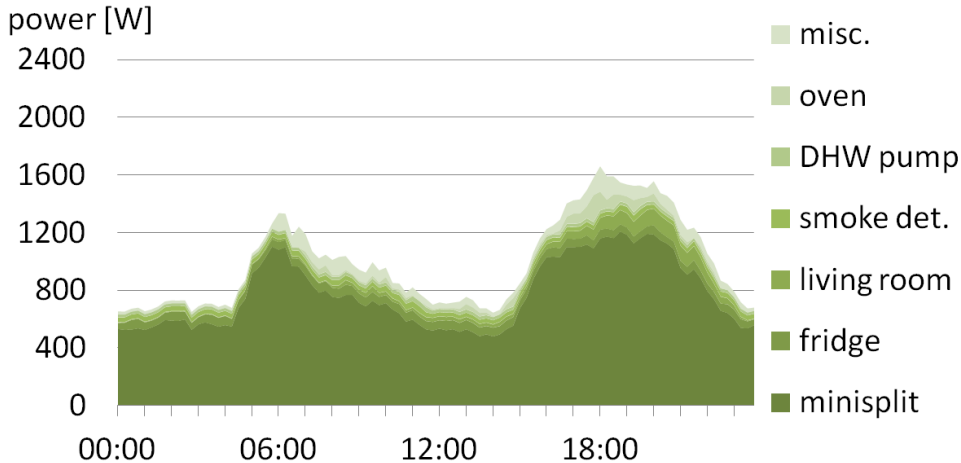
NZH in Stow



- CO₂ concentration unusual high
- But during the measurement most of the time untypical high occupation density (8 people present): far beyond the design parameters of the ventilation system.
- Internal leakages in the ventilation system likely (but not quantified).

energy and comfort – winter

NZH in Townsend – daily and weekly pattern

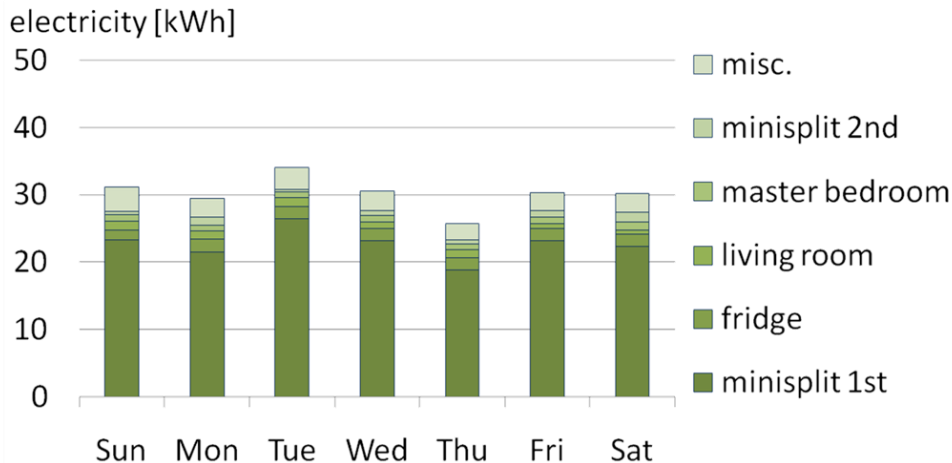
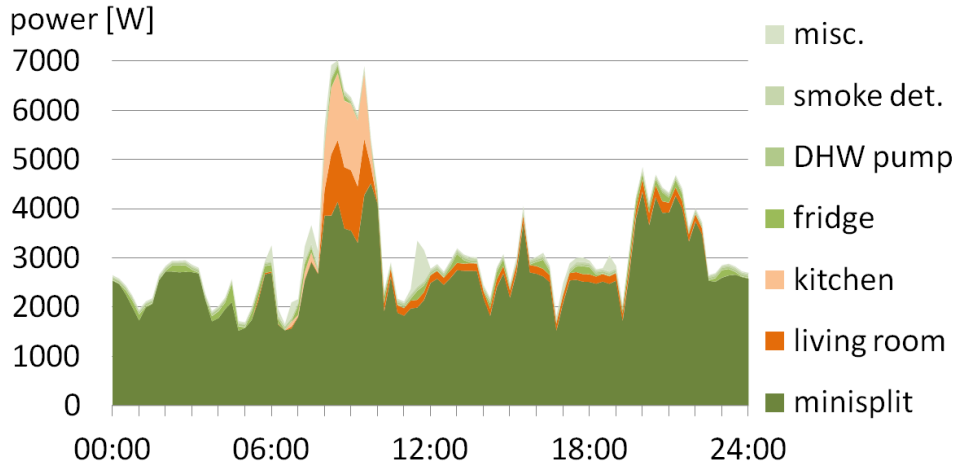


- Average load pattern during heating season (Dec 2010, Jan, Feb 2011).
- Water heating is *not* included.
- Space heating by far biggest load.
- Over a three months period, the fridge has a higher *average* load than any other appliance.

circuit	average kWh/d
minisplit 1 st floor	22.7
fridge	1.8
living room	1.0
master bedroom	1.0
minisplit 2 nd floor	0.8
misc.	2.9
total	30.2

energy and comfort – winter

NZH in Townsend – daily and weekly pattern

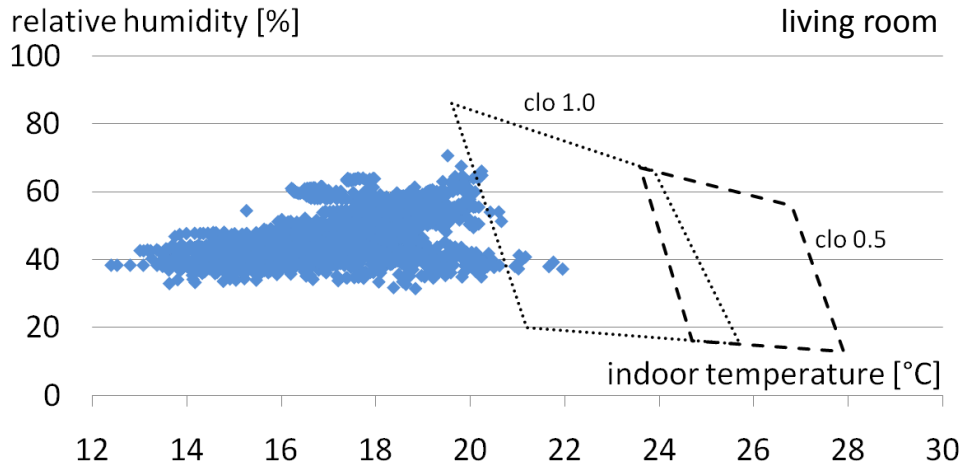


- Example for one day:
Monday, 01/24/2011: day with the highest energy consumption in the “living room” circuit.
- Average ambient temperature:
-17.1°C (1.3°F)

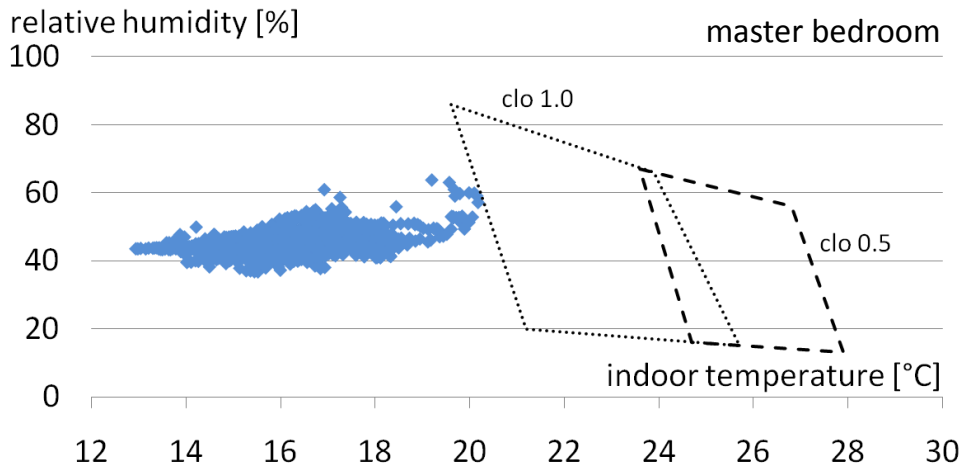
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energy and comfort – winter

ASHRAE 55 - NZH in Townsend

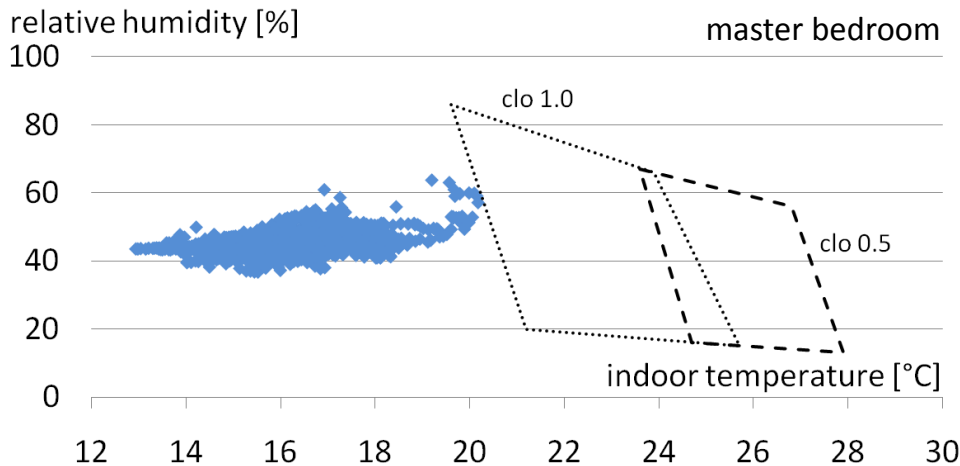
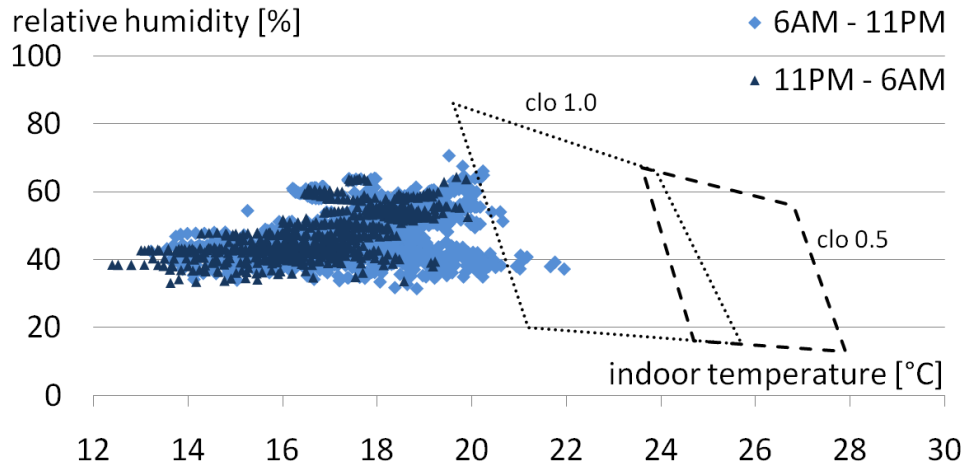


- The measured values for temperature are outside of comfortable conditions (assuming a clothing rate of 1.0).



energy and comfort – winter

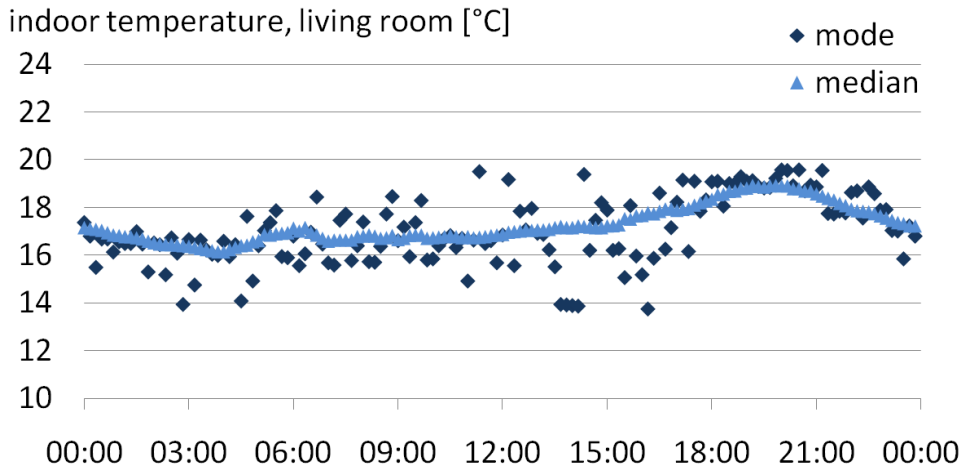
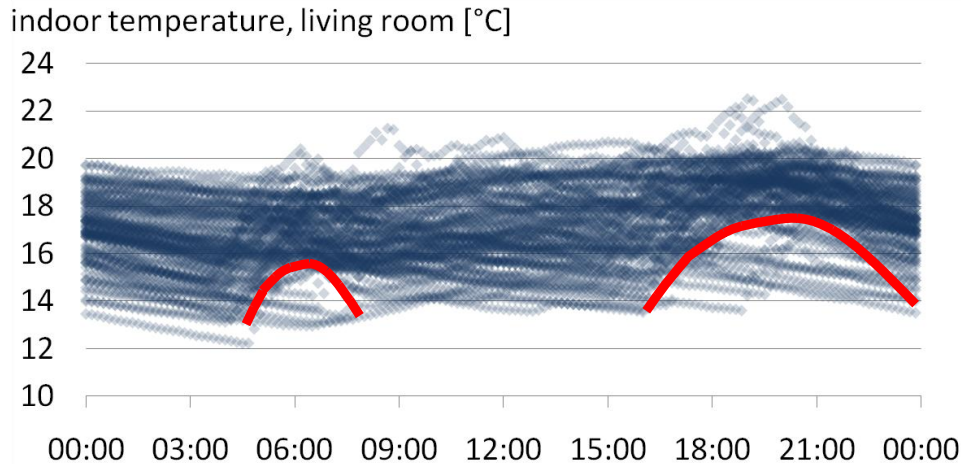
ASHRAE 55 - NZH in Townsend



- The measured values for temperature are outside of comfortable conditions (assuming a clothing rate of clo 1.0).
- Nevertheless occupants accept lower temperatures (space heating system is not at its limit).

energy and comfort – winter

Townsend

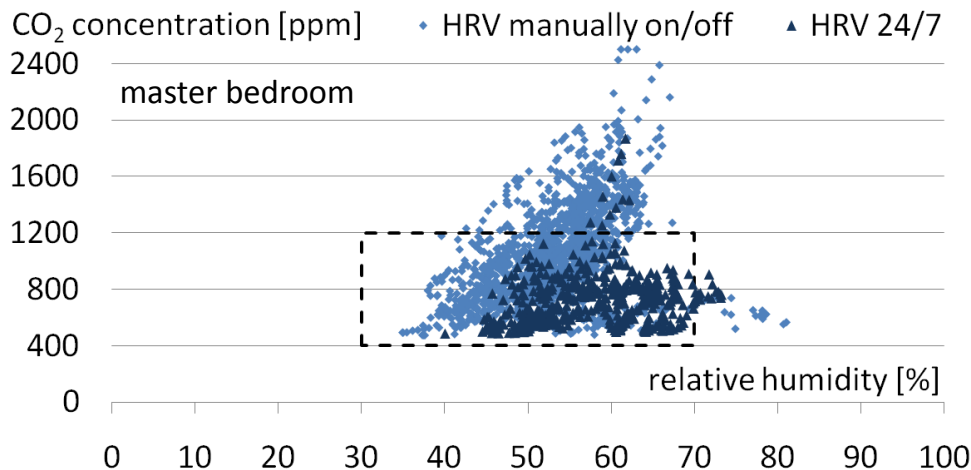
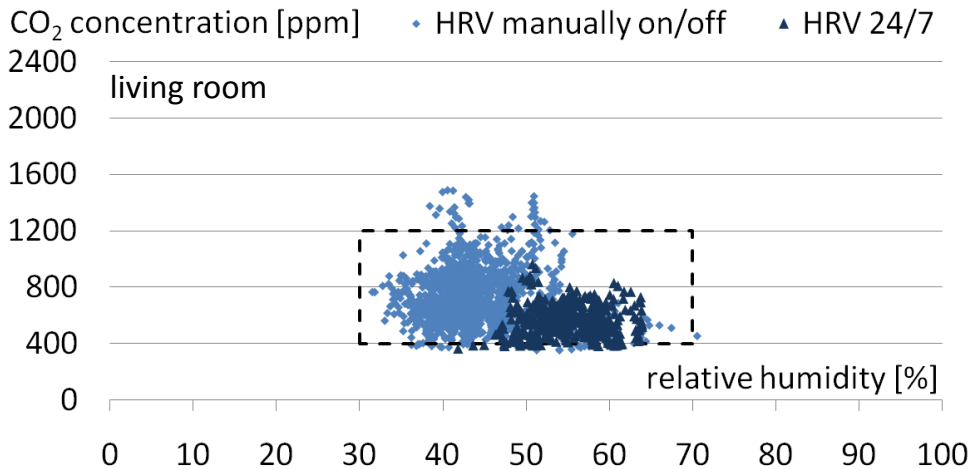


- Indoor temperature is significant lower than in Stow, but stable.

- Influence of space heating (and occupants) is obvious at 6:00PM and partly at 6:00AM.

energy and comfort – winter

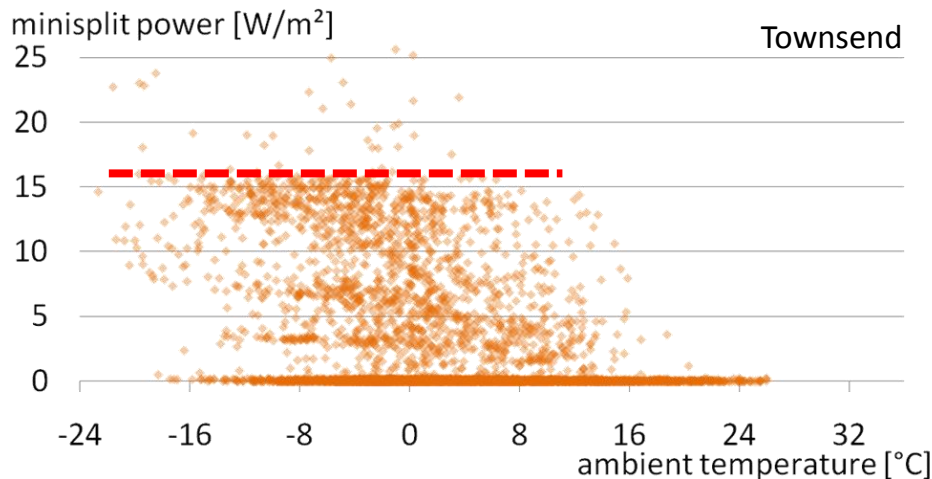
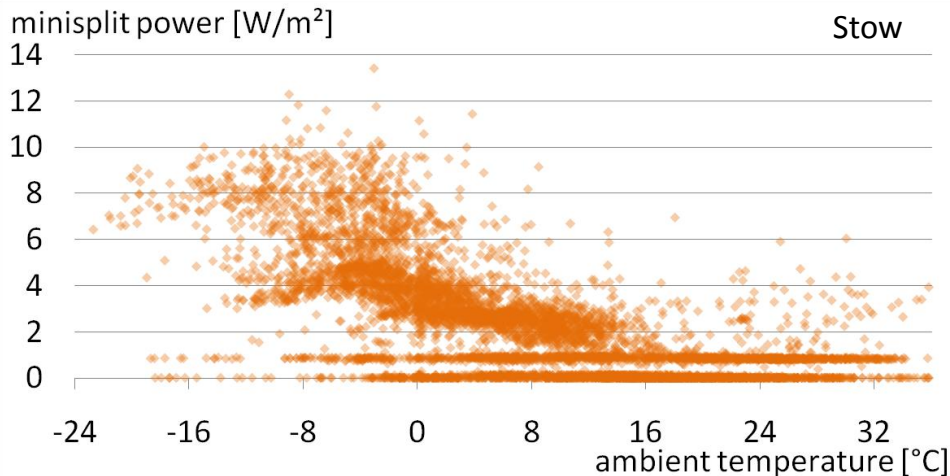
NZH in Townsend



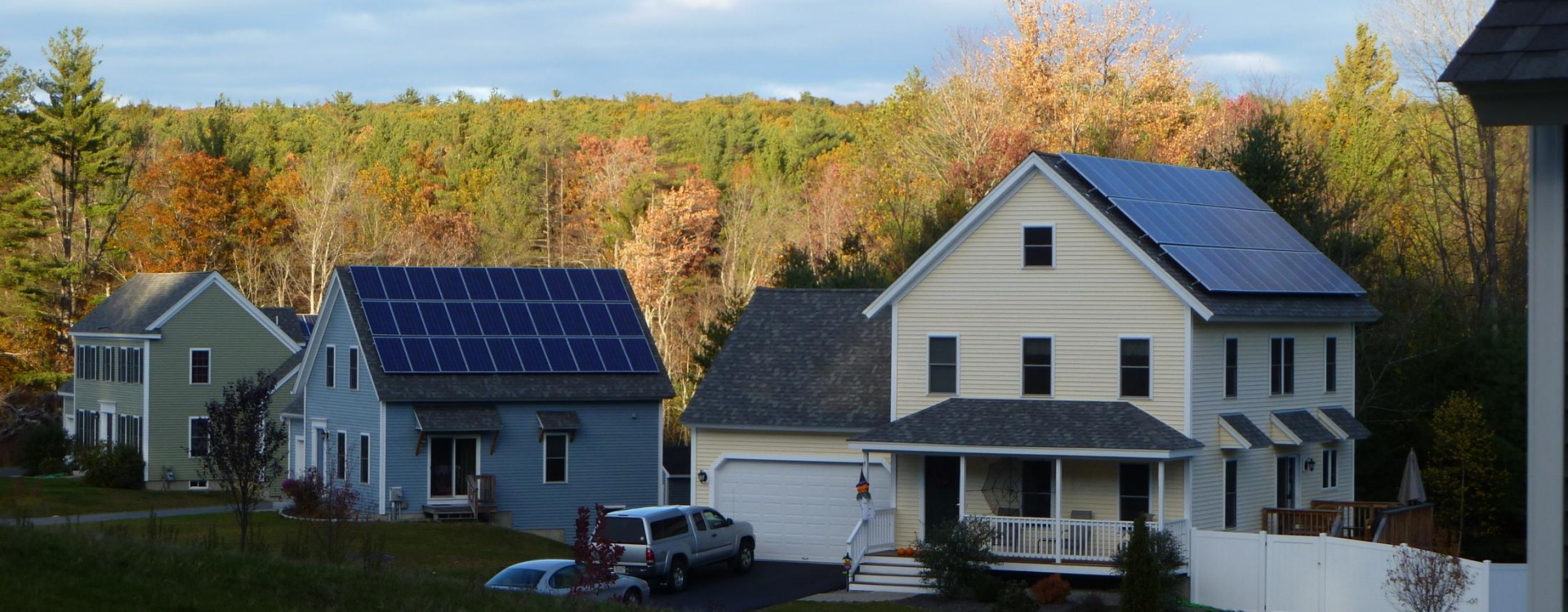
- CO₂ concentration in the living room is acceptable even with manually switched mechanical ventilation.
- In the bedroom concentrations are too high.
- After switching the HRV to 24/7 operation, CO₂ levels are significantly reduced.

energy and comfort – winter

comparison of ductless split loads



- Correlation of ambient temperatures and loads from the ductless split (hourly mean values) systems show a more reasonable temperature – heat-loss correlation in Stow.
- Coldest Days are not the days with the highest loads.
- In Townsend the available power seems to be limited – because the second unit (on the second floor) is hardly used.



- Energy for space heating remains dominating load, followed by DHW.
- In a good insulated envelope single point heat source can be used without comfort problems.
- NZEHs are likely occupied by “aware” users
- Mechanical ventilation is crucial in airtight buildings, but available solutions need improvements.
- Standby losses can sum up to a significant energy consumption.

thank you!

www.cse.fraunhofer.org

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