Appendix A
Brief description of EnergyFlexHouse

EnergyFlexHouse®

General description

Main objective of the test facility

EnergyFlexHouse® consists of two, two-storied, single-family houses with a total heated gross area of 216 m² each. The two buildings are in principle identical, but while the one building acts as a technical laboratory (EnergyFlexLab), the other is occupied by typical families who test the energy services (EnergyFlexFamily). Each family lives in EnergyFlexFamily for 3-5 months at a time. In principle, everything can be changed in the two buildings: the thermal envelope, heating system, ventilation system, renewable energy, etc. The buildings were put into operation during the autumn of 2009.

In EnergyFlexLab, focus is on short-term tests where the interaction between installations, buildings and real weather conditions gives a unique possibility of testing components and systems under realistic conditions. In addition, EnergyFlexFamily makes it possible to test user behaviour, influence and acceptance of and interaction with the components and systems – i.e. EnergyFlexFamily is a living lab.

Institute/organisation:

DANISH TECHNOLOGICAL INSTITUTE

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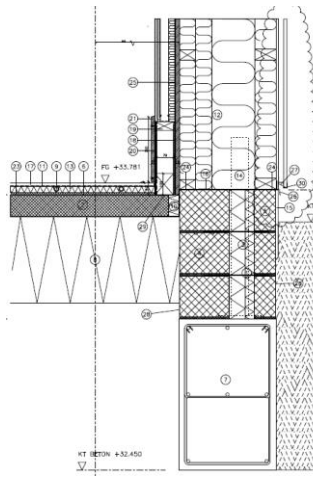
Exact location:

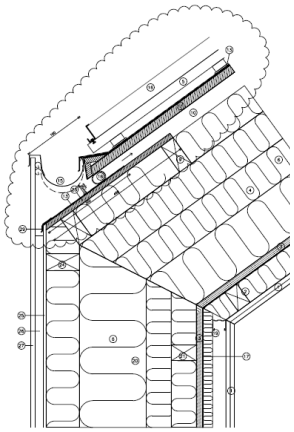
Taastrup, Denmark
55°39'N, 12°16'E

Overall layout



The foundation of EnergyFlexHouse.

EnergyFlexHouse was built to resemble an attractive, Danish, detached, single-family house, designed so most people would get the feeling: "I could live in this building".
The houses are built so they are better than the Low E class 1 defined in the former Danish Building Code from 2008, which is more or less identical to Low E class 2015 in the new Danish Building Code from 2010. The annual energy demand for space heating, ventilation, DHW and building-related electricity (not including energy for the household) amounts to less than 30 kWh/m². With the pv production, EnergyFlexFamily is energy neutral over the year including the demand for electricity of the household and an electric vehicle. The EnergyFlexFamily is a prosumer: a traditional consumer, an energy producer and energy storage when it is needed from the grid.
The houses are constructed with a core insulated wooden frame structure as shown in figure 1 and 2.



The eaves of EnergyFlexHouse.

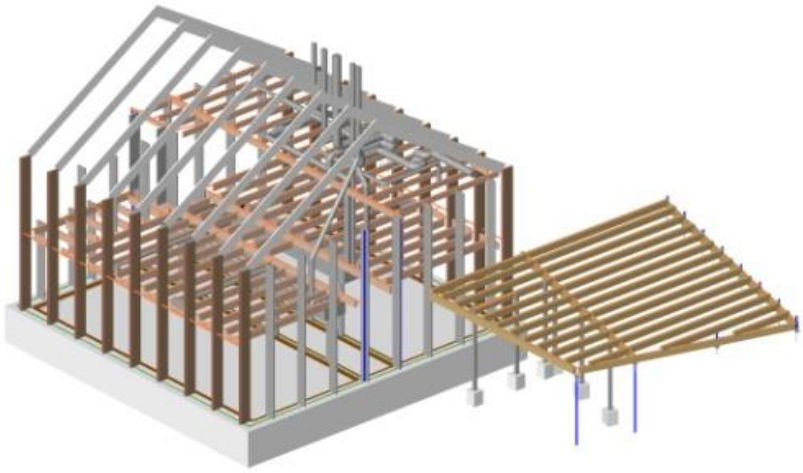
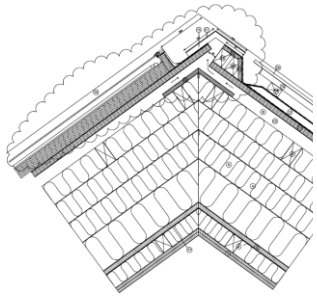


Figure1. The load-bearing wooden skeleton of EnergyFlexHouse.



The ridge of EnergFlexHouse.

The insulation of the walls and roof is divided into several layers, which can be stripped off to resemble the insulation level at different periods. The labels in figure 2 are:

- red arrow: the demand of the Danish Building code from 1977
- green arrow: the demand of the Danish Building code from 1995
- blue arrow: thickness in order to reach the Low E class 1 in the Danish Building code from 2008

By adjusting the thickness of the insulation and replacing the Low E windows, it is also possible to test energy saving solutions for renovation purposes.

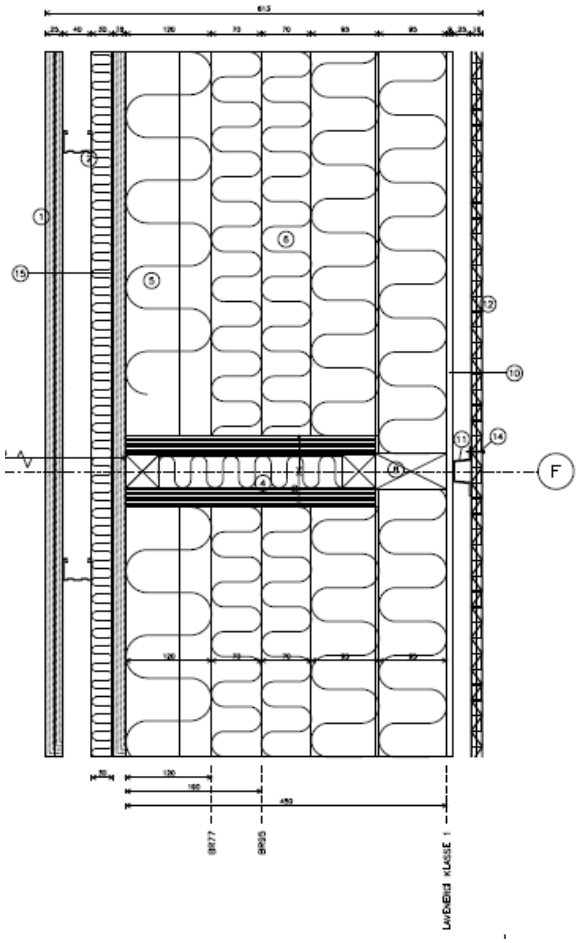
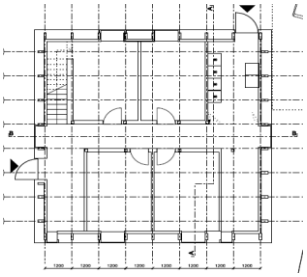
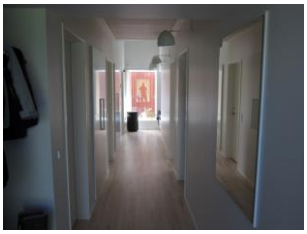


Figure 2. Horizontal cross section of an EnergyFlexHouse wall.

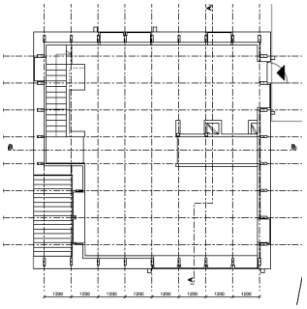
North





The floor plan and picture of the ground floor of EnergyFlexHouse.

North



The floor plan and picture of the 1st floor of EnergyFlexHouse.

The U-values of the original design of EnergyFlexHouse are:

External walls:	0.08 W/m²K
Roof:	0.09 W/m²K
Ground floor slap:	0.105 W/m²K
Windows in external walls:	0.73-0.9 W/m²K
Skylights:	1.4 W/m²K

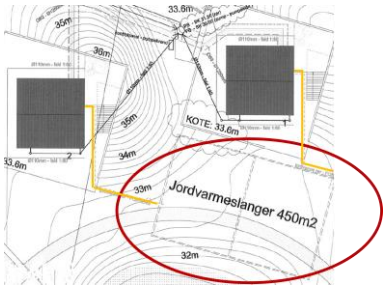
The layout of the two houses is similar to the layout of many Danish single-family houses (although reversed concerning the use of the two floors):

- Ground floor: 4 rooms and 2 bathrooms
- 1st floor: combined kitchen and living room

At the ground floor of EnergyFlexLab, the floor plan allows for side-by-side testing: two rooms facing south are identical and two rooms facing north are identical.

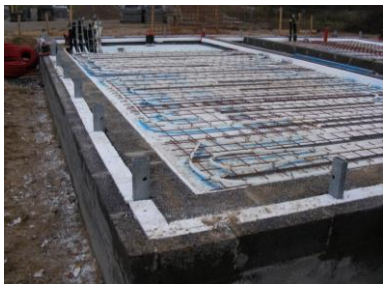
Both buildings are equipped with pv and solar collectors as seen in figure 3.

District heating for EnergyFlexHouse.



Area with ground source heat exchangers for the ground coupled heat pumps in EnergyFlexHouse.

Sun screening of the windows facing south on EnergyFlexHouse.



Floor heating in the ground floor during construction of EnergyFlex-House.

Figure 3: The solar collectors and pv panels of the two EnergyFlexHouses. Approximately 20 m²pv is needed for the electric vehicle.

Inside boundary conditions

Different possibilities are available for creating the desired indoor climate in EnergyFlexHouse:

- Heating: boilers – gas, oil, pellets, ..
  heat pumps: ground couples, air to water, air to air
  district heating
  solar heating
- Ventilation: mechanical: with passive heat exchanger and/or air to air heat recovery heat pump
  natural ventilation
  hybrid ventilation
- Solar radiation: sun screening
- Cooling: so far no cooling system has been installed, but it may be later if required by tests
- Heat distribution system: floor heating, radiators (either by the window or at the back wall) or via the ventilation systems

The internal conditions in EnergyFlexLab may be adjusted in order to reach the conditions required by a test. In EnergyFlexHouse, the conditions are the normal comfort conditions in a house, expected by the families who live there.

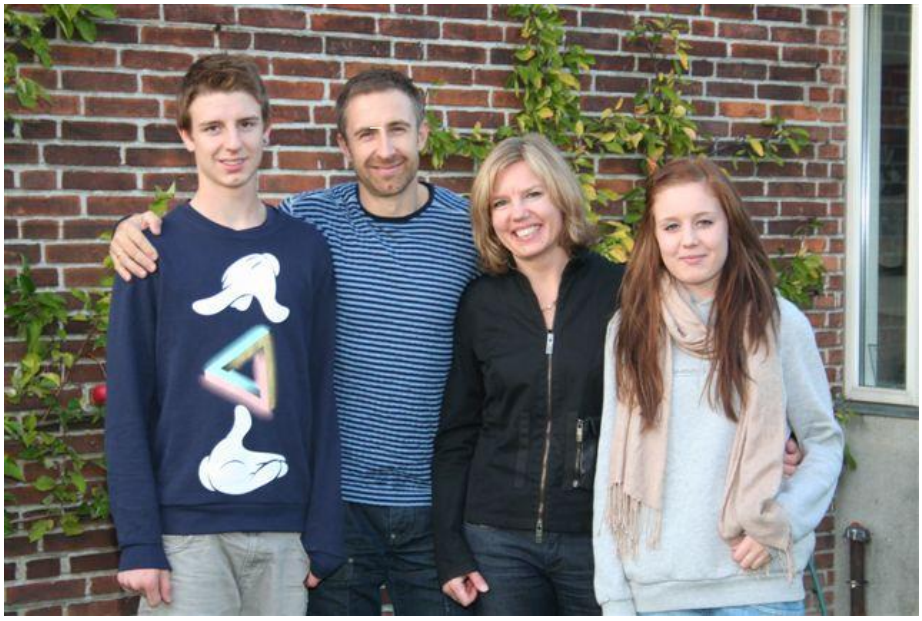


Figure 4. The first family in EnergyFlexFamily.

Outside boundary conditions

The outside conditions are the actual weather conditions on Zealand, Denmark where EnergyFlexHouse is situated.

In order to monitor the microclimate around the two houses, several sensors are applied:

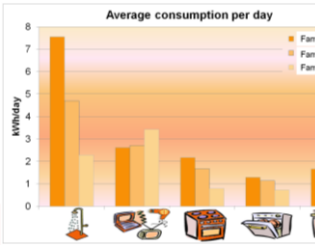
- Weather station at 10 m: ambient temperature, wind speed, wind direction, rain, humidity, barometric pressure
- Solar radiation: global and diffuse horizontal
  total on south, west and east of the houses
  on the south facing roof of the houses
- Ambient temperature: at the south, west, east and north of the houses
- Long wave radiation: horizontal

Special limitations / possibilities

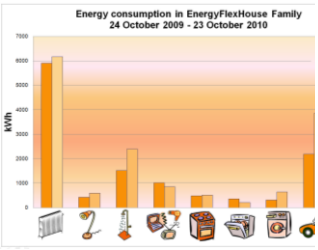
The houses are designed to limit constraints as much as possible: meaning that everything in principle can be changed.

The limitations are the size and orientation of the houses and the specific conditions created by the Danish weather.

For envelope components, the size limit is determined by the distance between the wooden, load-bearing skeleton. That distance is 1.2 m.



Mean daily energy demand of three different families distributed on different services.



Energy demand distributed on services during the first year with three families in EnergyFlexFamily.

Combined global and diffuse radiation pyrgeometer

Pyranometers and pyrgeometer at the roof of EnergyFlexLab.

Pyranometer and temperature sensor at the south wall of EnergyFlexLab.

Data analysis

Data acquisition system

The basic layout of the data acquisition system is shown in figure 5 and 6. Figure 5 shows the data acquisition system in EnergyFlexLab, while figure 6 shows the data administration. The data acquisition system in EnergyFlexFamily is similar to figure 5, but in order not to disturb the families the room sensors are wireless. In addition, the electricity demand on all plugs**,** ceiling points and of the white goods in EnergyFlexHouse is measured individually and the opening of doors and windows is logged.

Heat meters at EnergyFlexLab.

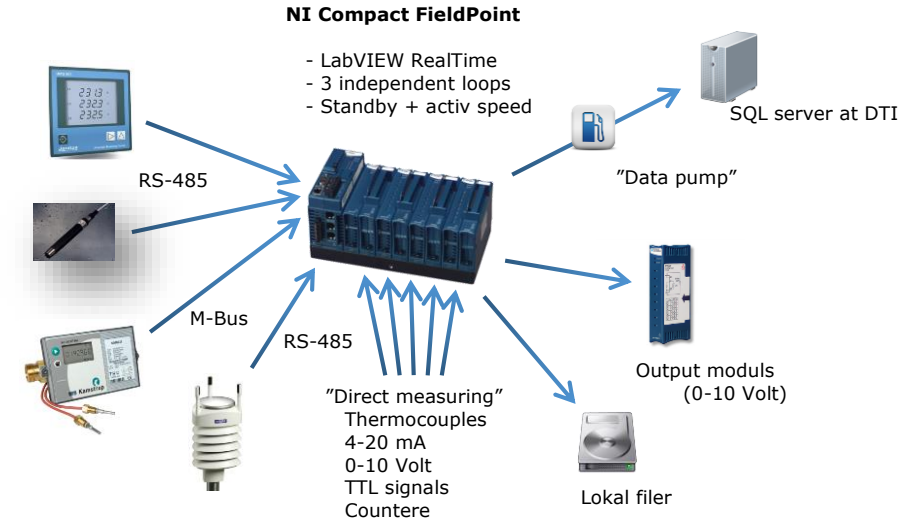
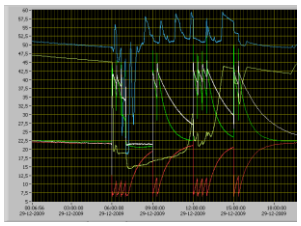


Figure 5. The data acquisition system in EnergyFlexLab.



Cold and hot water temperature and temperatures in the DHW tank.

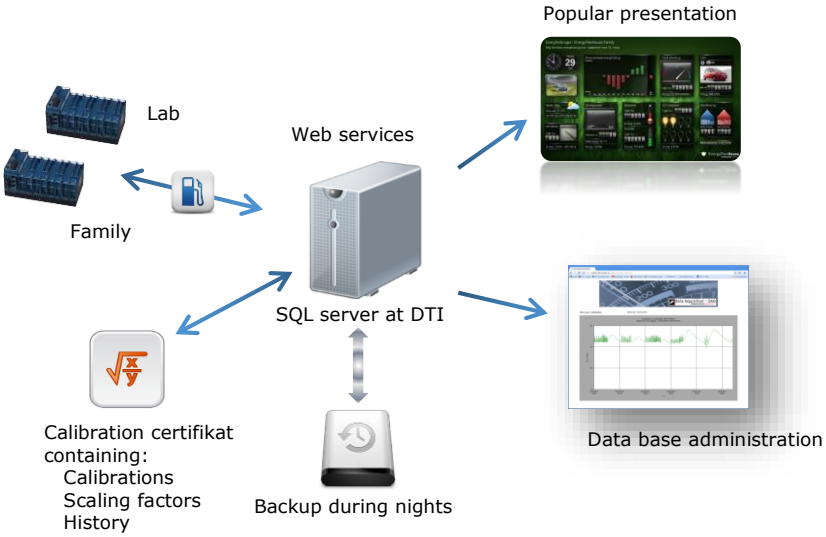


Figure 6. Data administration.

At the beginning of 2011, up to 700 measuring points were included in the EnergyFlexHouse data acquisition system. The data acquisition system is scalable so new sensors may be added.

In addition to the weather sensors, the basic sensor set consists of:

- air temperature sensors
- surface temperature sensors
- temperature sensors embedded in the constructions
- temperature sensors in the installations
- air humidity sensors – both in rooms and ventilation systems
- CO_2 sensors - both in rooms and ventilation systems
- heat flux sensors
- air speed sensors - both in rooms and in ventilations systems
- lux sensors
- contacts on windows and doors
- heat flow meters
- electricity meters
- multi amperimeters

Air, globe and surface temperature sensors, humidity sensors, lux sensor and heat flux sensor in one side-by-side room in EnergyFlexLab.

Embedded temperature sensors in the floor of one of the side-by-side test rooms in EnergyFlexLab before concrete was poured in.

Link to the popular presentation: http://datalog.energyflexhouse.dk/pview/index_en.html

Accuracy and logging resolution

All sensors and meters have been calibrated and the documentation is available on file - as shown in the left bottom corner of figure 6.

Analysis of the data

There is no standard procedure for analysis of the measured data from EnergyFlexHouse as many very different tests and experiments may be carried out. However, one standard analysis is carried out on data from EnergyFlexFamily: a rolling annual energy balance including a popular presentation as seen in figure 6 and 7.

Figure 8. Popular presentation of the energy balance in EnergyFlexFamily.

Examples of previous studies

Several studies have been, are being conducted or are scheduled to be carried out in EnergyFlexHouse – e.g.:

EnergyFlexFamily:

- The possibility of obtaining energy neutrality on an annual basis is being investigated with real families living in the building
- The user acceptance of different energy efficient lighting systems
- Optimized control of the installations (heating, ventilation and solar screening) in order to optimize the indoor climate while minimizing the energy demand
- Utilization of the electricity demand of households as regulation power for the grid
- Development of a micro ground coupled heat pump for single family low energy houses
- Electric vehicles in combination with energy neutral homes

Optimized control of e.g. solar screening in order to decrease overheating.

EnergyFlexLab:

- Heating (both space heating and DHW) via low temperature district heating
- PCM (phase change materials) in the floor slap for increasing the thermal storage capacity of the constructions
- Low energy windows with less dew on the outside
- Energy efficient DHW installations
- Demand controlled ventilation. Natural ventilation during the summer
- Optimization of the forward temperature to floor heating in order to increase the COP of a heat pump
- Optimization of the combination of savings and renewable energy sources on site in order to reach energy neutrality

Electric vehicle used by the families in EnergyFlexFamily.

Maintenance / collaboration

Personnel involved

The buildings are operated and maintained by the employees of the Energy and Climate Division at Danish Technological Institute.

International collaboration

No formal international collabortion has yet been established, but promissing contact with e.g. UC Berkeley, Lawrence Berkeley National Lab, Standford, ITRI (Taiwan) and Research Centre for Zero Emmission Buildings, Norway, is ongoing.

Danish Tecnological Institute is looking for international collaboration and project opportunities utilizing EnergyFlexHouse as part of the Danish contribution.

Link to other devices

The two EnergyFlexHouses are part of the overall test possibilities at Danish Technological Institute as illustrated in figure 8.

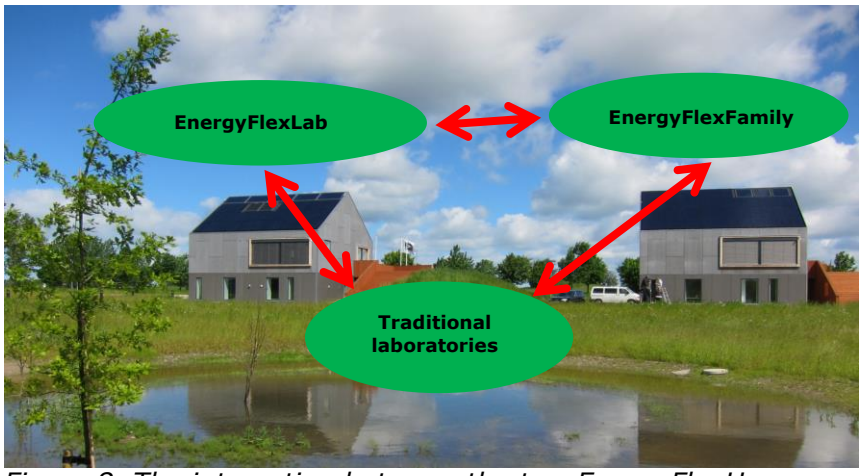


Figure 8. The interaction between the two EnergyFlexHouses and the traditional laboratories at Danish Technological Institute.

The traditional laboratories at Danish Technological Institute offer detailed component tests of: insulation materials, windows, ventilation systems, heat pumps, district heating units, circulation pumps, radiators, cooling systems, white goods, pv systems, consumer electronics, etc.

A logical test setup is:

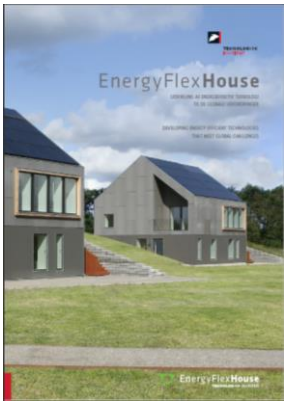
- test and optimization of individual components in laboratory
- test of the interaction between components and building under real weather conditions: EnergyFlexLab
- test of the interaction between components, building and users under every-day conditions including user acceptance: EnergyFlexFamily (living lab)

Test of building components in hot box.

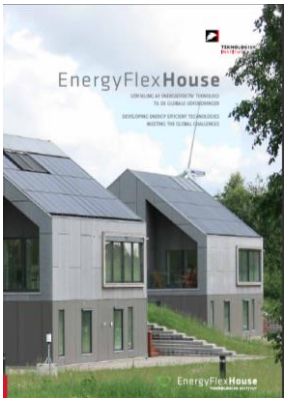
Test of circulation pumps.

Test of heat pumps.

Test of pv systems.



www.dti.dk/_root/media/36141_EFH%20publikation%20final%20low.pdf



www.dti.dk/inspiration/25348

Relevant literature

General literature about the test facility:

EnergyFlexHouse – Developing energy efficient technologies that meet global challenges:

www.dti.dk/_root/media/36141_EFH%20publikation%20final%20low.pdf

www.dti.dk/inspiration/25348

Homepage of EnergyFlexHouse: http://www.dti.dk/inspiration/25348

Literature on previous measuring campaigns:

Christensen, A.H. et al, 2012. Intelligent energy services in low-energy homes based on user-driven innovation (in Danish). Danish Technological Institute, Energy and Climate Division.

Tahersima, F., 2012. An Integrated Control System for Heating and Indoor Climate Applications. PhD thesis. Aalborg University.

Iqbal, A., 2014. Calculation methods for natural ventilation through centre pivot roof windows. PhD thesis. Danish Building Research Institute, Aalborg University.

Christiansen, C.H. et al, 2014. InnoBYG: Installation packages for single-family houses – solar heating, heating and ventilation systems (in Danish). Danish Technological Institute, Energy and Climate Division.

Jensen, S.Ø., 2015. Natural ventilation in single family houses during the summer. Danish Technological Institute, Energy and Climate Division.