ENERGY BALANCE OF BUILDINGS

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4BY107 – 7.5 ECTS

Today's outline

- Overview of a building in a life cycle perspective
- Energy use for operating different kinds of buildings
- Space heating
    - Key parameters influencing space heating demand of a building
- Hot water (tap water heating)
- Ventilation
- Lighting and appliances, electronics, office equipment
- Building codes and energy standards
- Role of building energy simulation
- Energy balance

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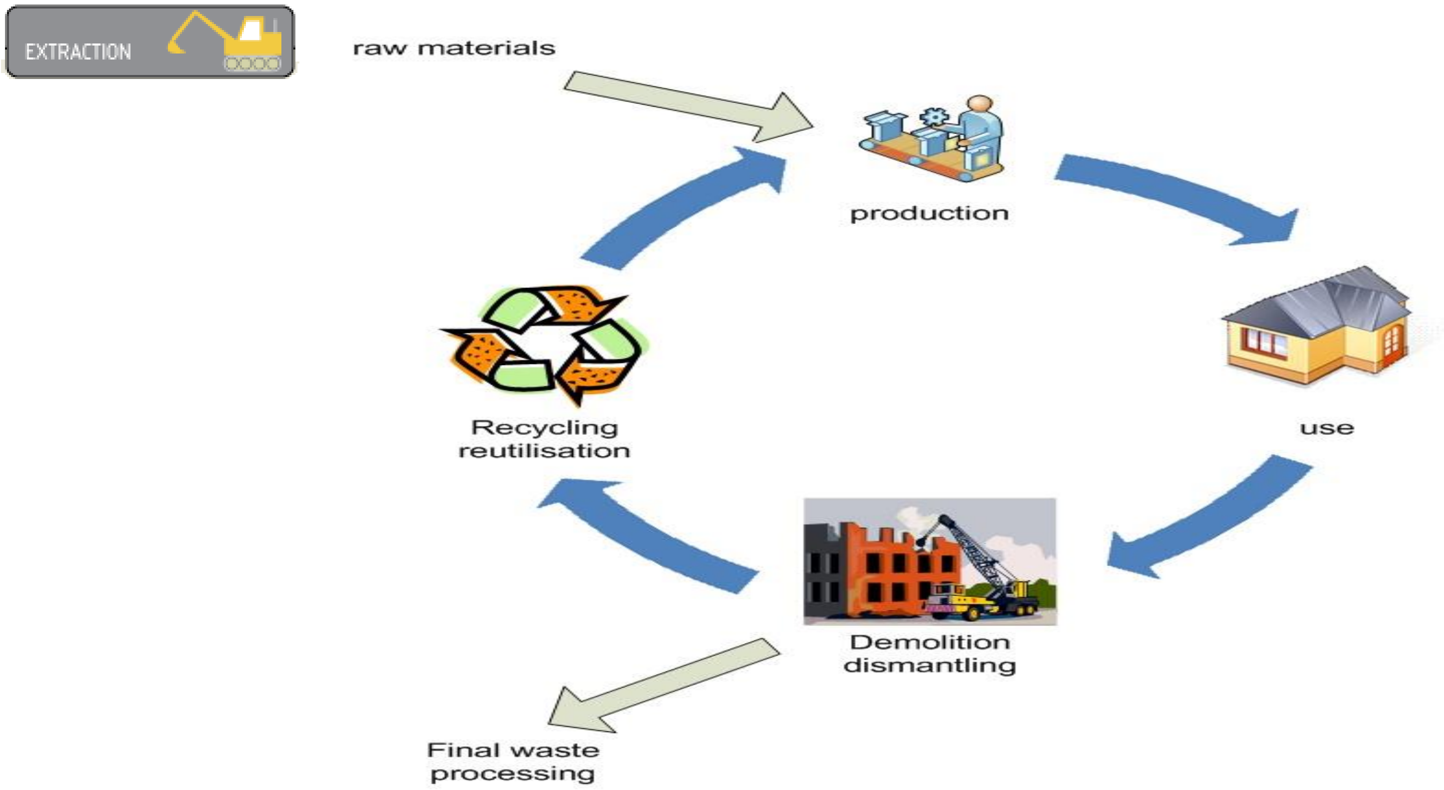
Life cycle stages of a typical building



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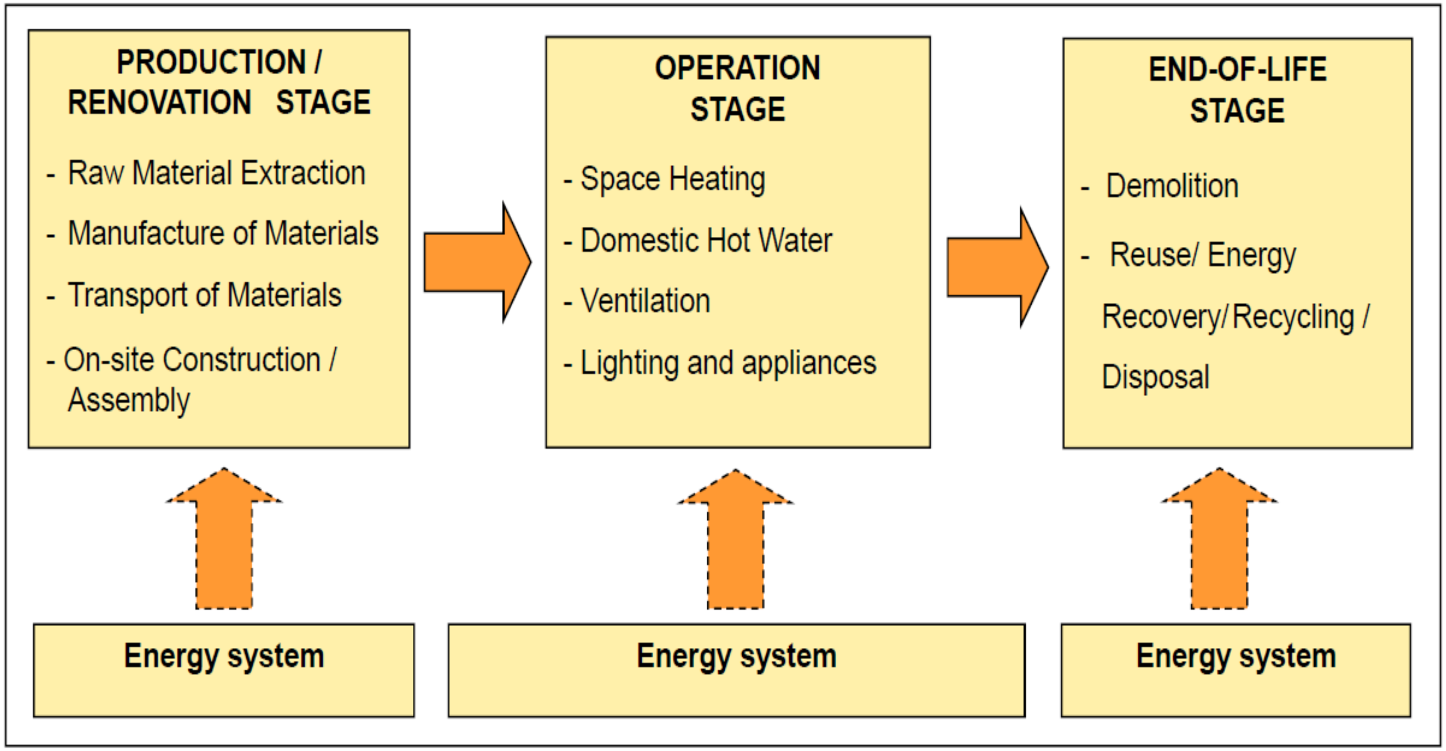
Source: Adapted from www.streamlinedesign.ca

Life cycle energy-use of a typical building



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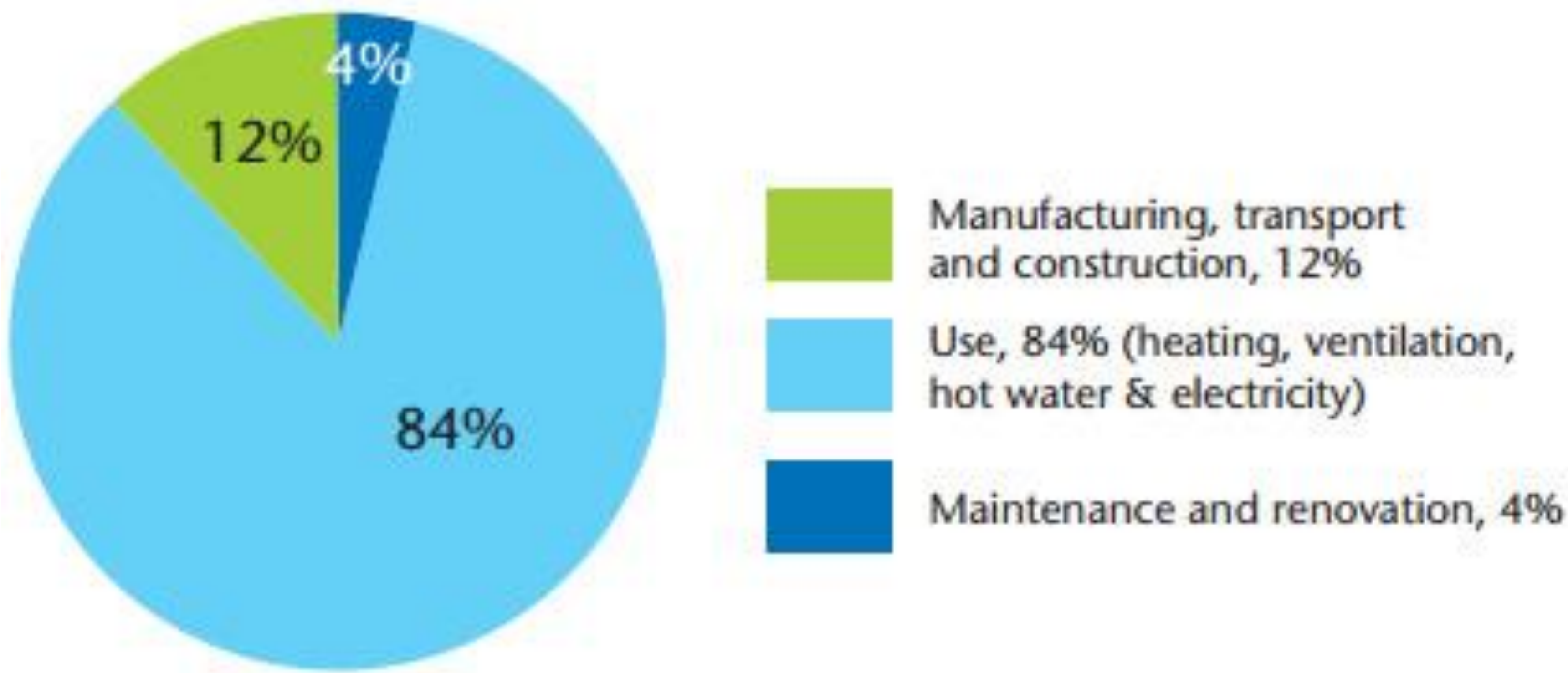
Source: Adapted from Dodoo et al.(2011) Building energy-efficiency standards in a life cycle primary energy perspective. Energy and Buildings. 43, 1589-1597.

Life cycle energy-use of a typical building



Building operation energy use - significant

Source: WBCSD (2008) Energy Efficiency in Buildings Facts & Trends. Full report

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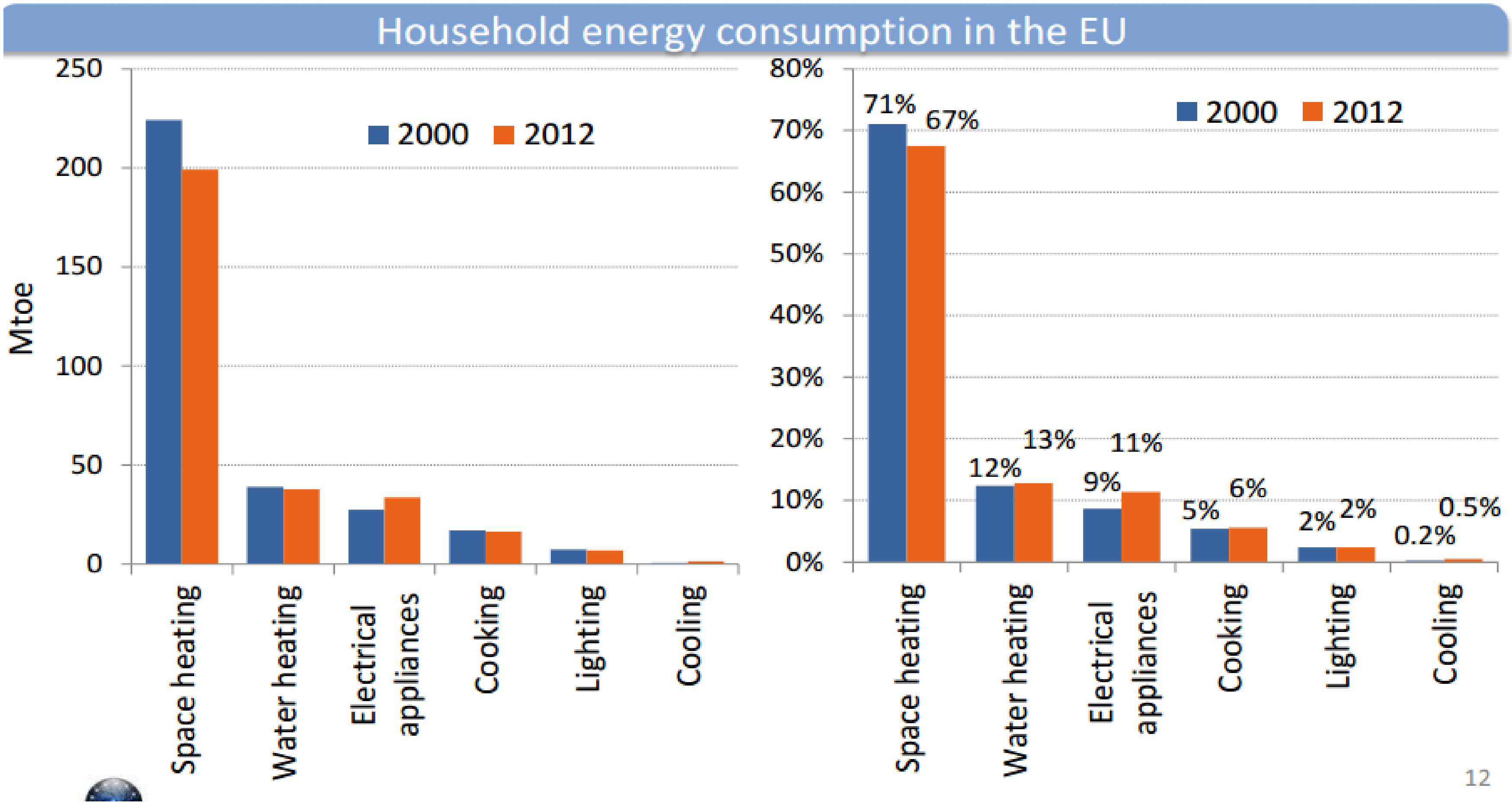
Energy use in the operation stage of a building

- Energy use for operation can be grouped into 4:
  - Space heating (Radiatorvärme)
  - Domestic hot water /tap water heating (Varmvatten)
  - Electricity for ventilation fan and pumps (ventilationsfläkt och pumpar)
  - Electricity household and facility (Hushållsel och Fastighetsel)

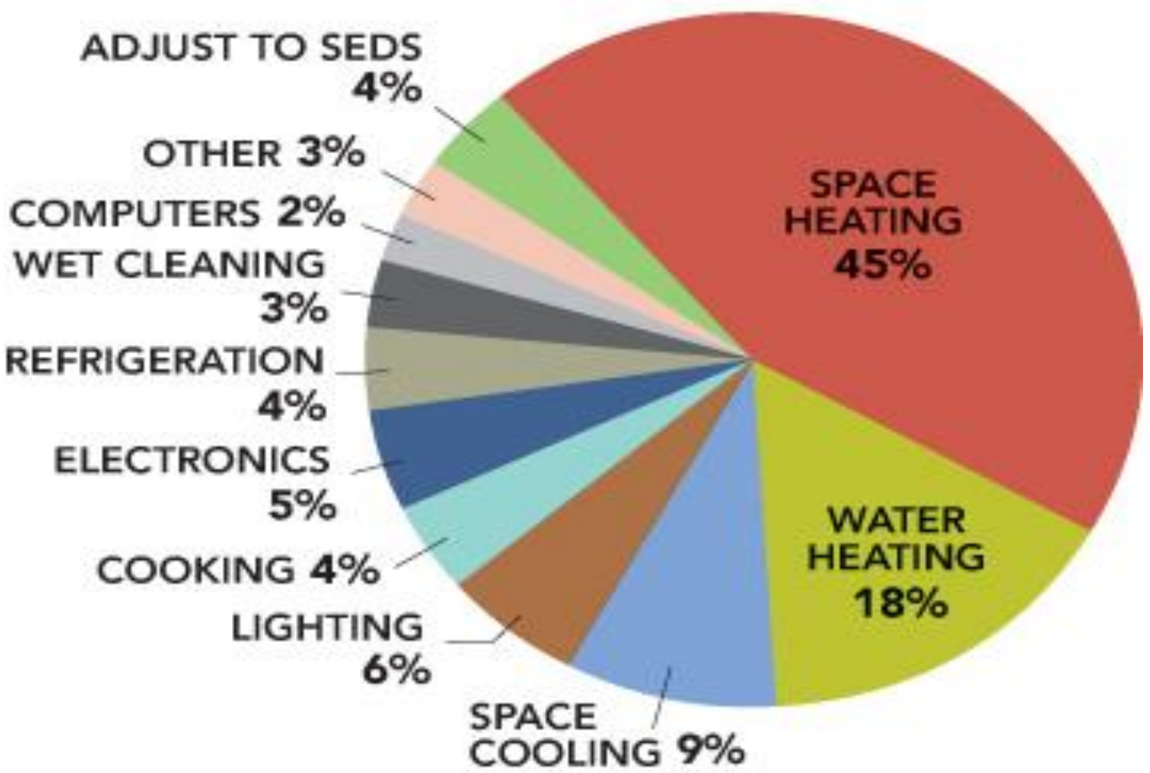
Building operation energy use breakdown



Source: Lapillonne et. Al 2014. Energy Efficiency Trends for households in the EU

Building operation energy use breakdown

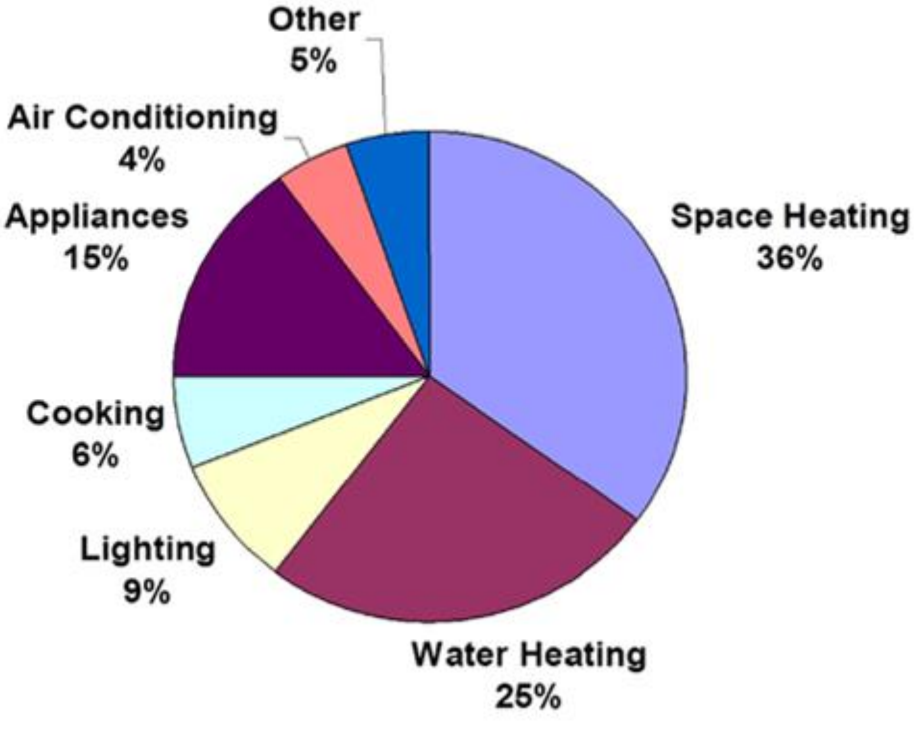
Operation energy use for residential buildings in US (2009)



Source: http://buildingsdatabook.eren.doe.gov/ChapterIntro2.aspx

Building operation energy use breakdown

Operation energy use for residential buildings in China (2005)



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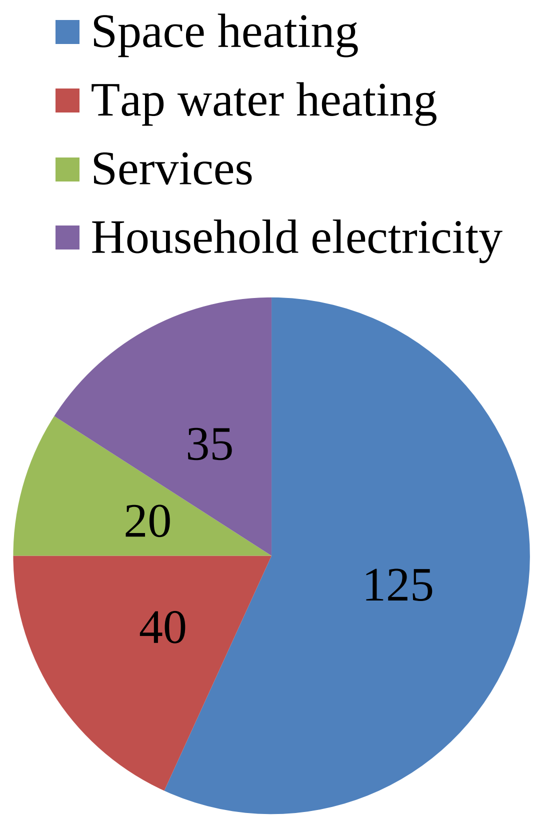
Source: IEA 2013

Final operation energy use for a typical miljonprogrammet building built in 1960s / 1970s



Final operation energy use (kWh/m²)

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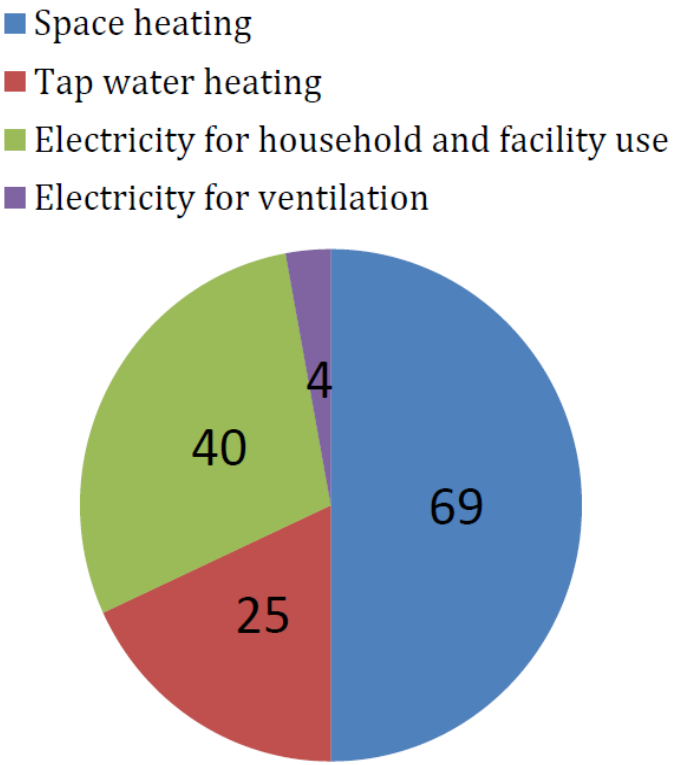
Final operation energy use for a recent building built in the 1990s



Final operation energy use (kWh/m²)

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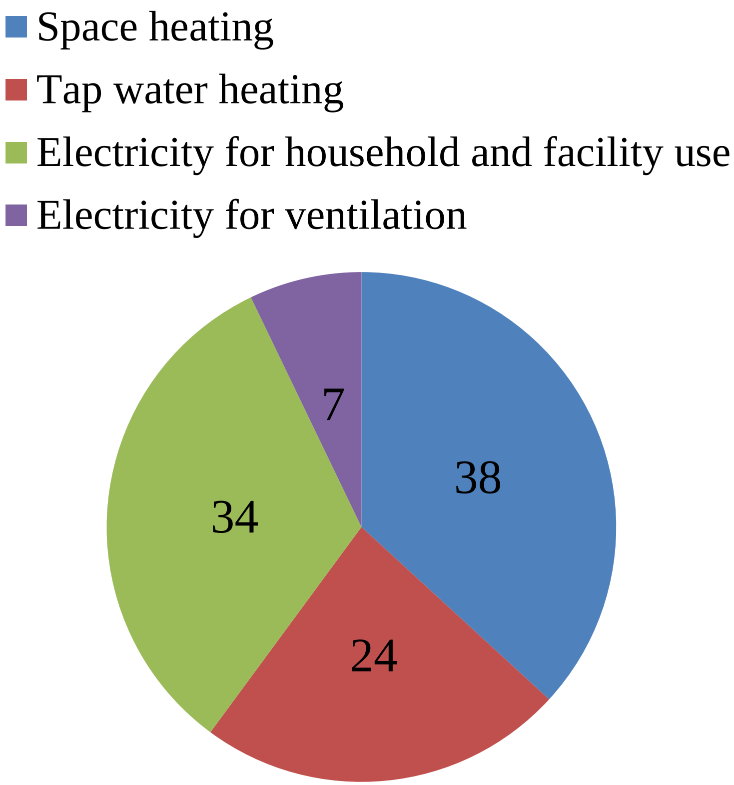
Final operation energy use for a typical new building completed in 2014



Final operation energy use (kWh/m²)

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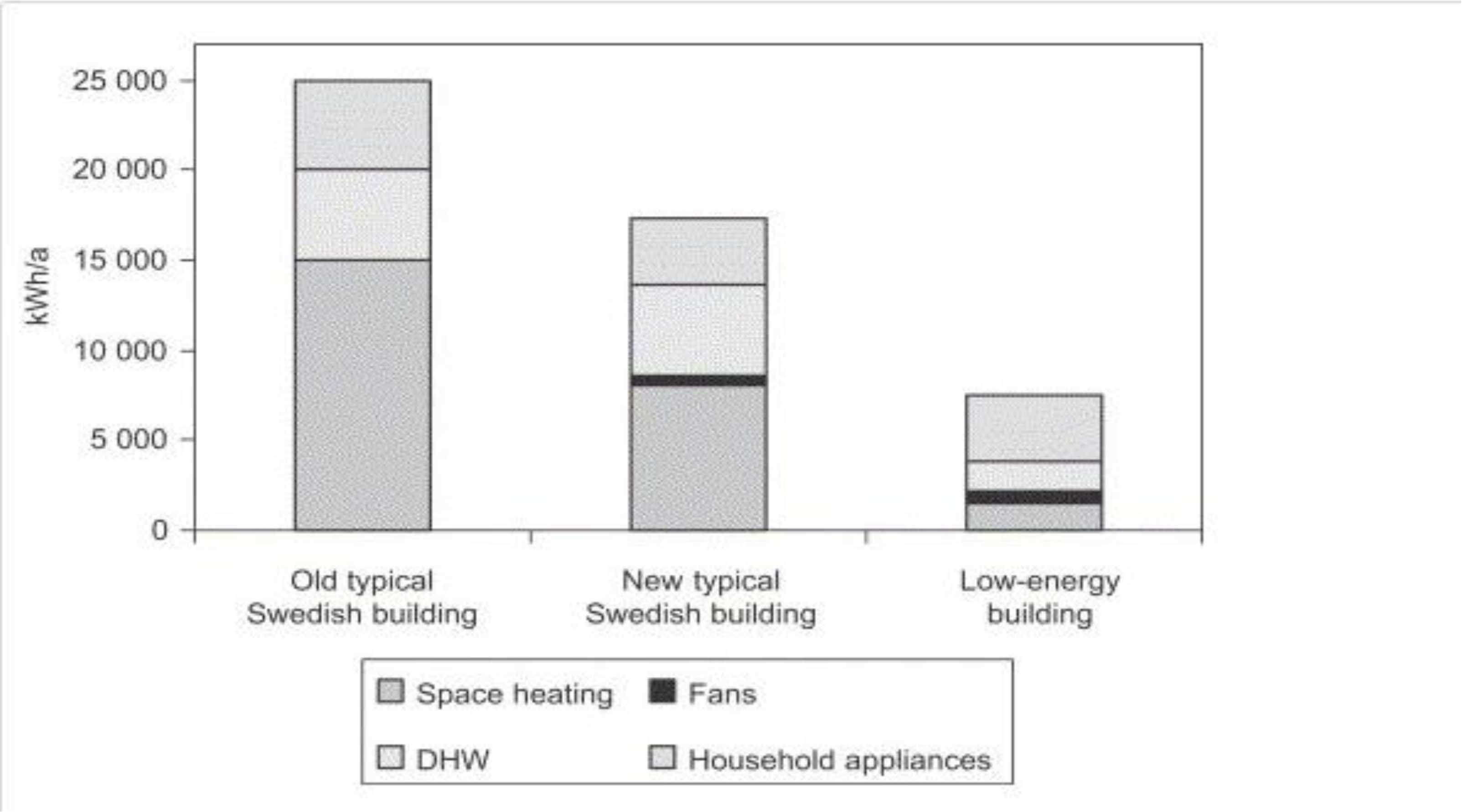
Final operation energy use for typical old and new Swedish building compared to a low-energy building



Source: Karlsson and Moshfegh (2007) A comprehensive investigation of a low-energy building in Sweden. Renewable Energy Volume 32, Issue 11 2007 1830 - 1841

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Important notes

- A building has different life cycle stages
- Operation (use) stage account for the biggest energy use in the life cycle of a typical building
- Space heating account for the largest share of the operation energy use in today's buildings

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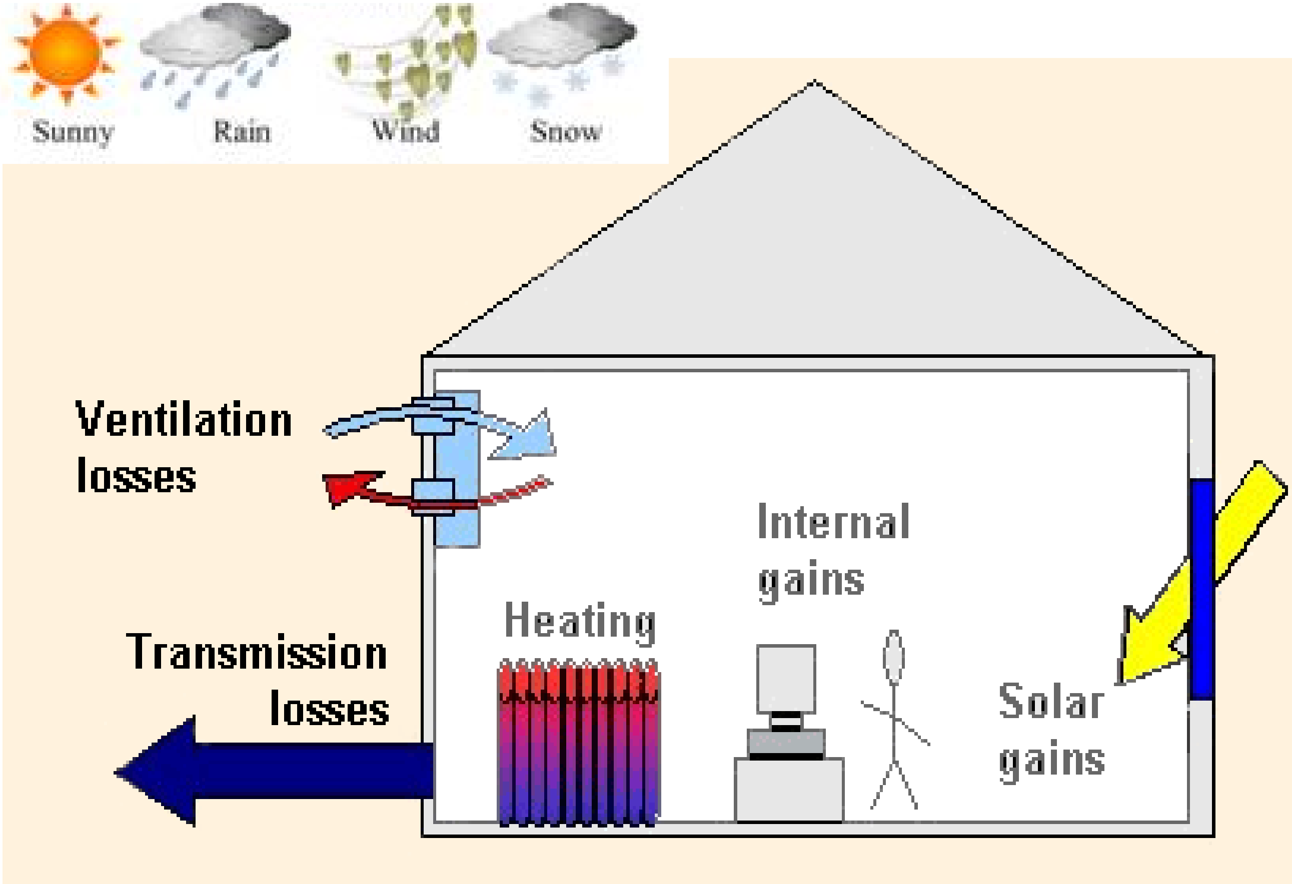
Energy balance of the building as a system



Source: Adapted from http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/3.htm

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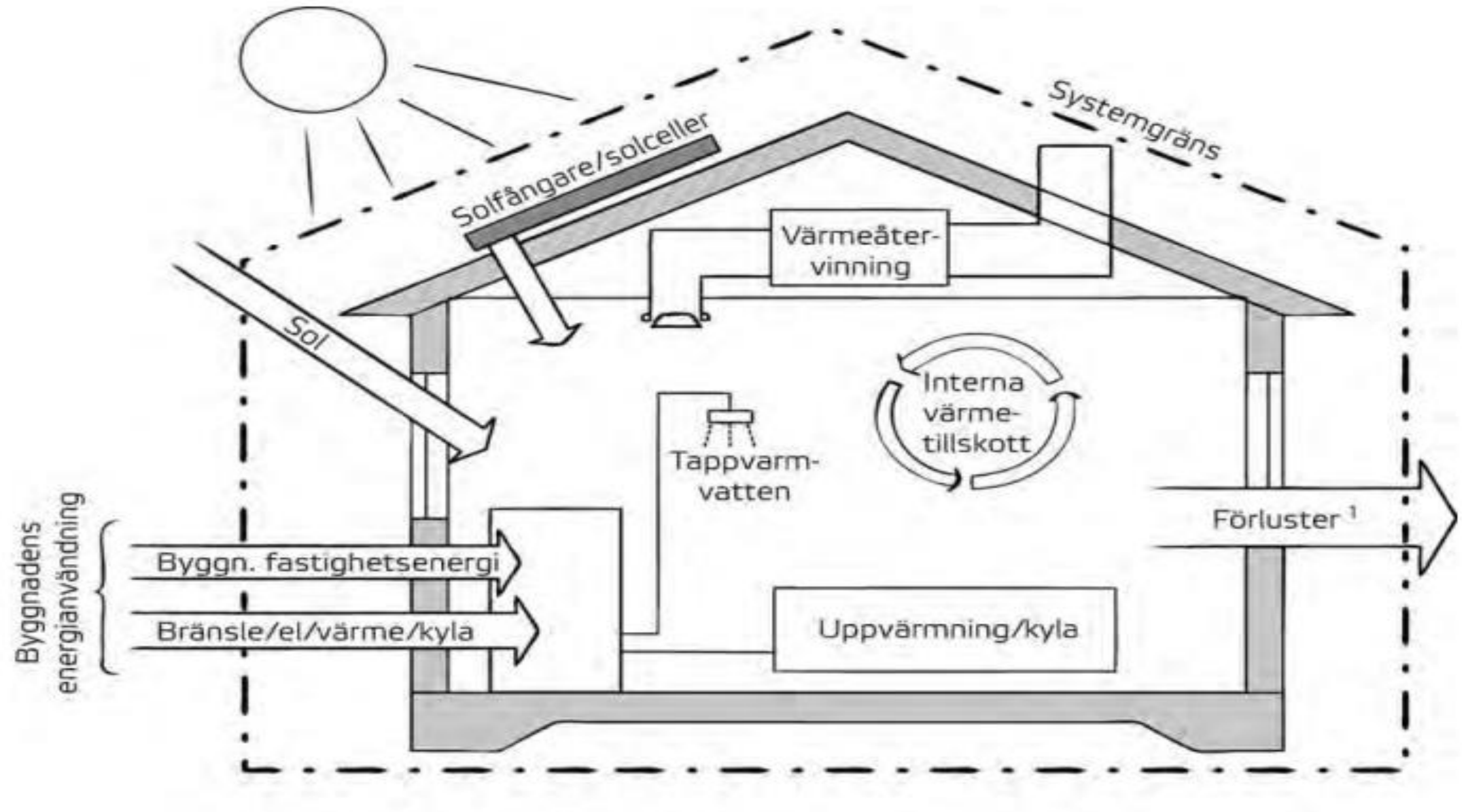
Energy balance of the building as a system



1) Transmissionsförluster, luftläckning, ventilationsförluster och dylikt.

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Source: Boverket (2011)

Energy (heat) losses/ emitted in a building "system"

- Transmission losses
  - Losses due to heat flows through the building envelope systems (wall, roof, floor, foundation, windows, doors, etc.) from inside to outside.
- Ventilation losses
  - Heat losses when there is exchange of inside and outdoor air, to bring fresh air.
- Leakage losses
  - Heat losses through infiltration and exfiltration
- Sewage losses
  - Heat losses as warm goes down the drain

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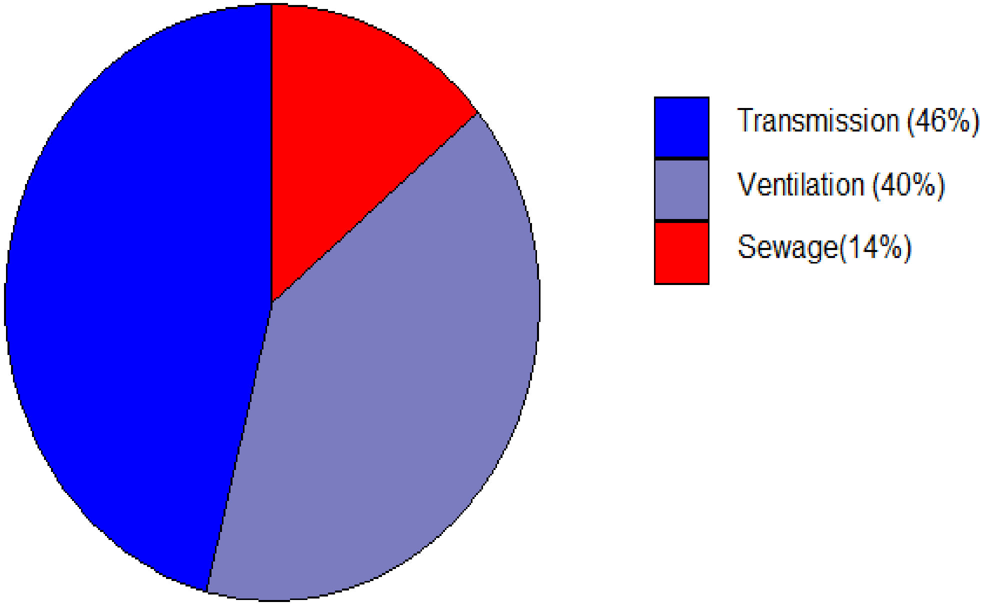
Example of relative distribution of heat losses in Wälluden built in the 1990s in Växjö



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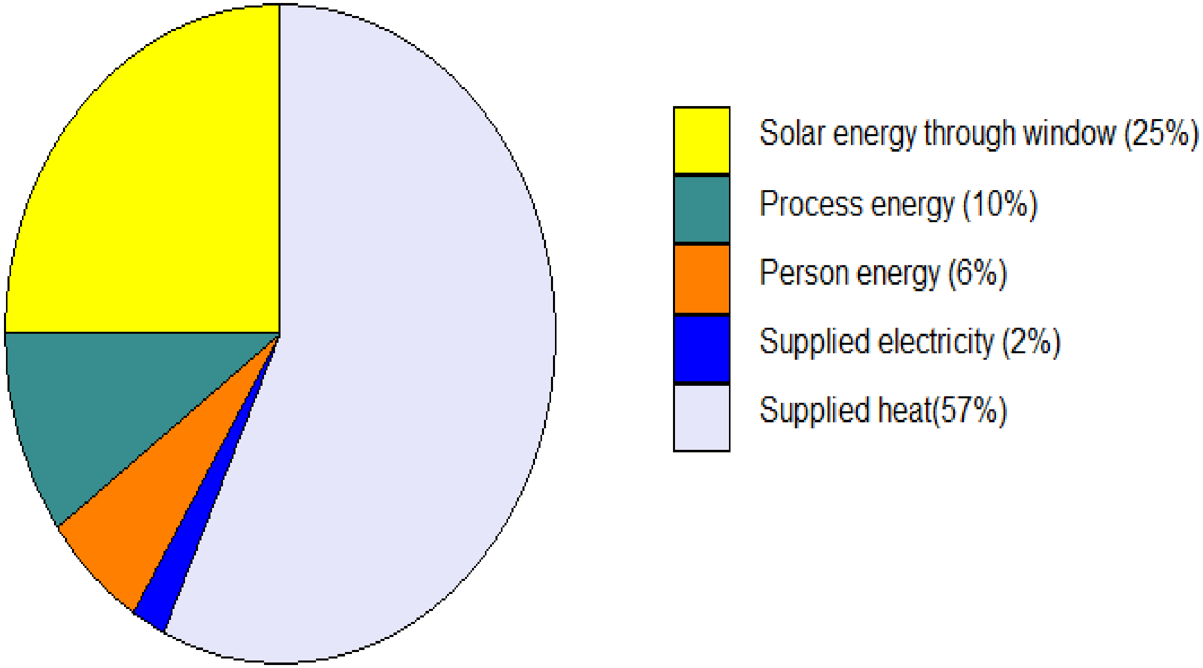
Energy (heat) gain / supply in a building “system”

- Solar gains
  - Solar irradiations e.g. through windows and other transparent elements.
- Persons gains
  - Heat from persons (metabolism)
- Warm water
  - Heat released into a building from the use of warm water
- Process gains
  - Heat from lighting and electric appliances
- Heating system
  - Heat supplied by active heating system to maintain the desired room temperature

Example of relative distribution of heat losses in Wälluden built in the 1990s in Växjö



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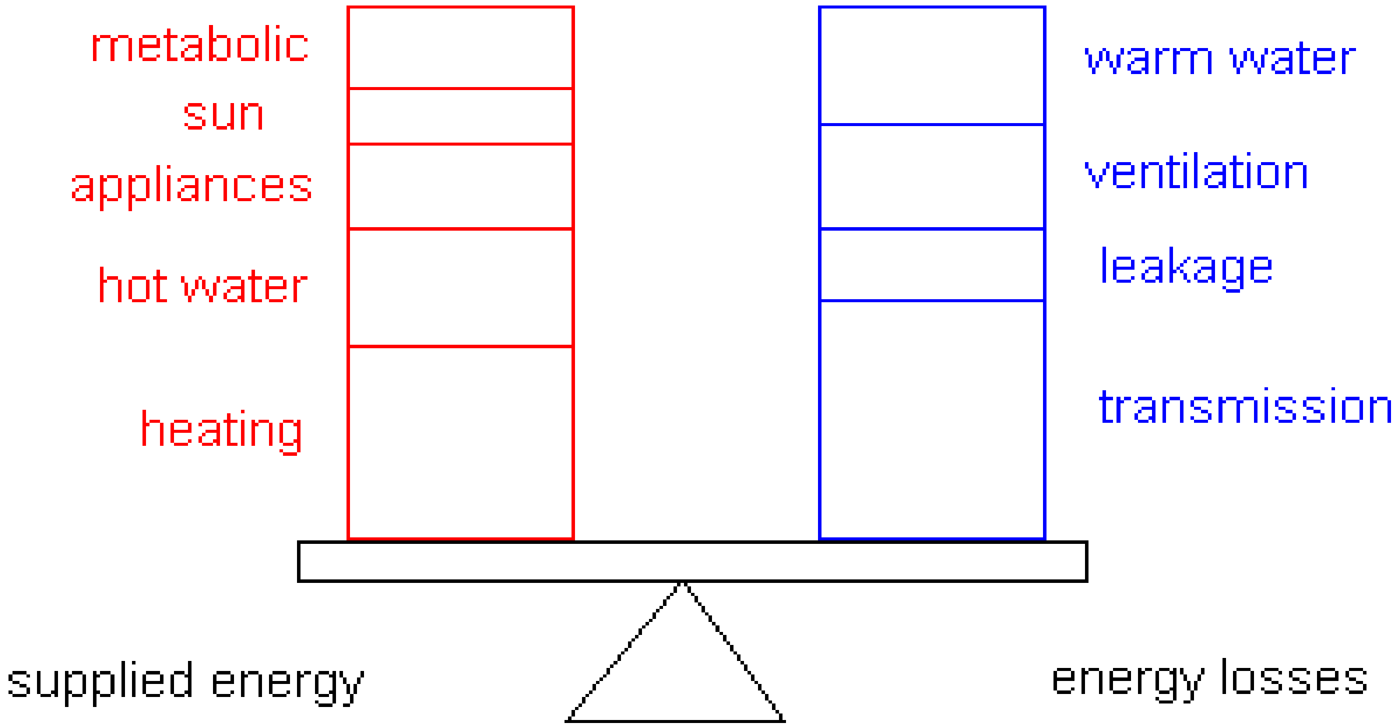
Definition of energy balance of a building

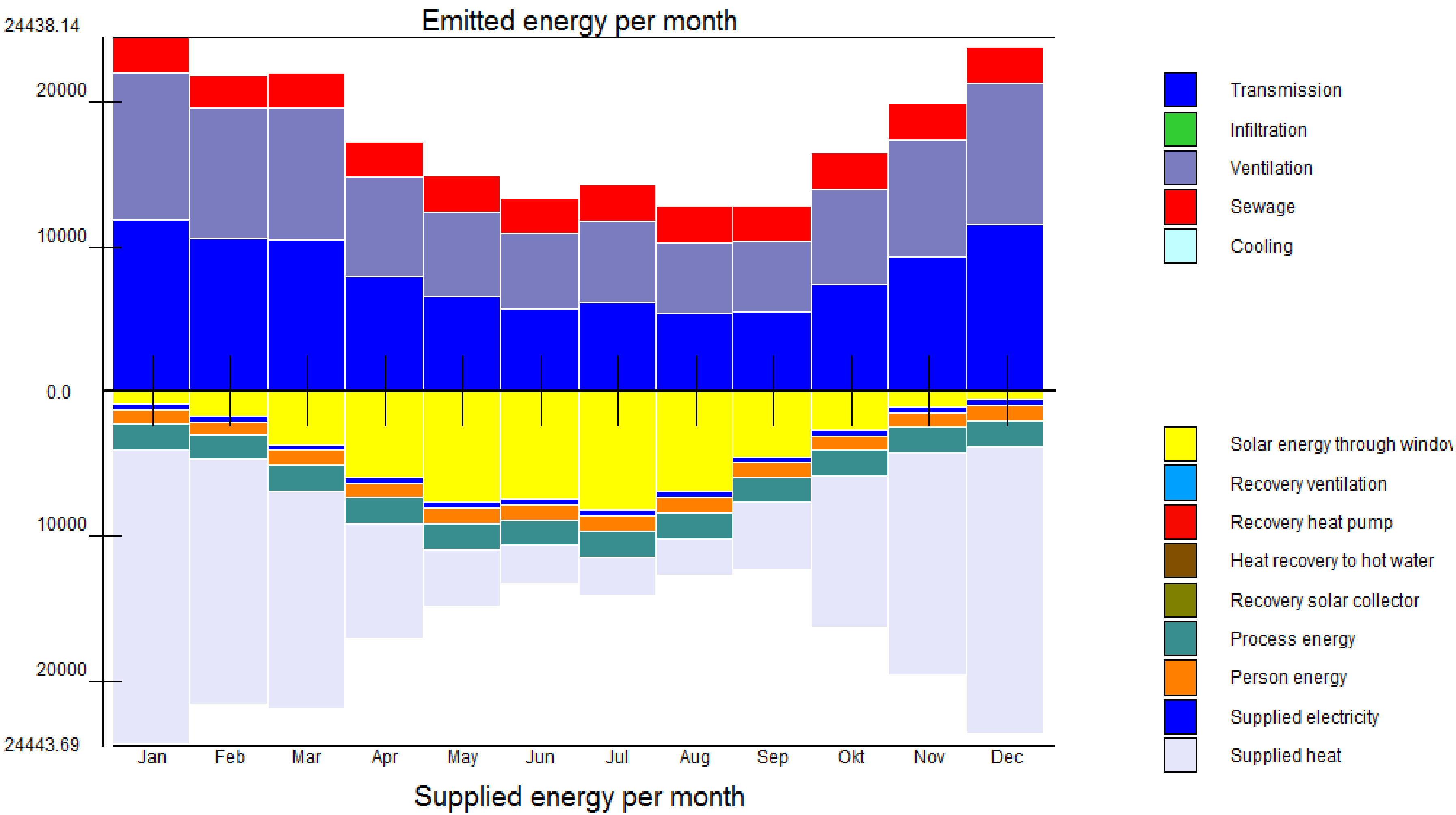
- Systematic accounting of all energy flows (including all heat gains and losses) in a building “system”.

Statement of conservation /flow of energy in a 'system'

Energy gains / supplied = Energy losses / emitted



Energy balance for the Wälluden building (values in kWh)



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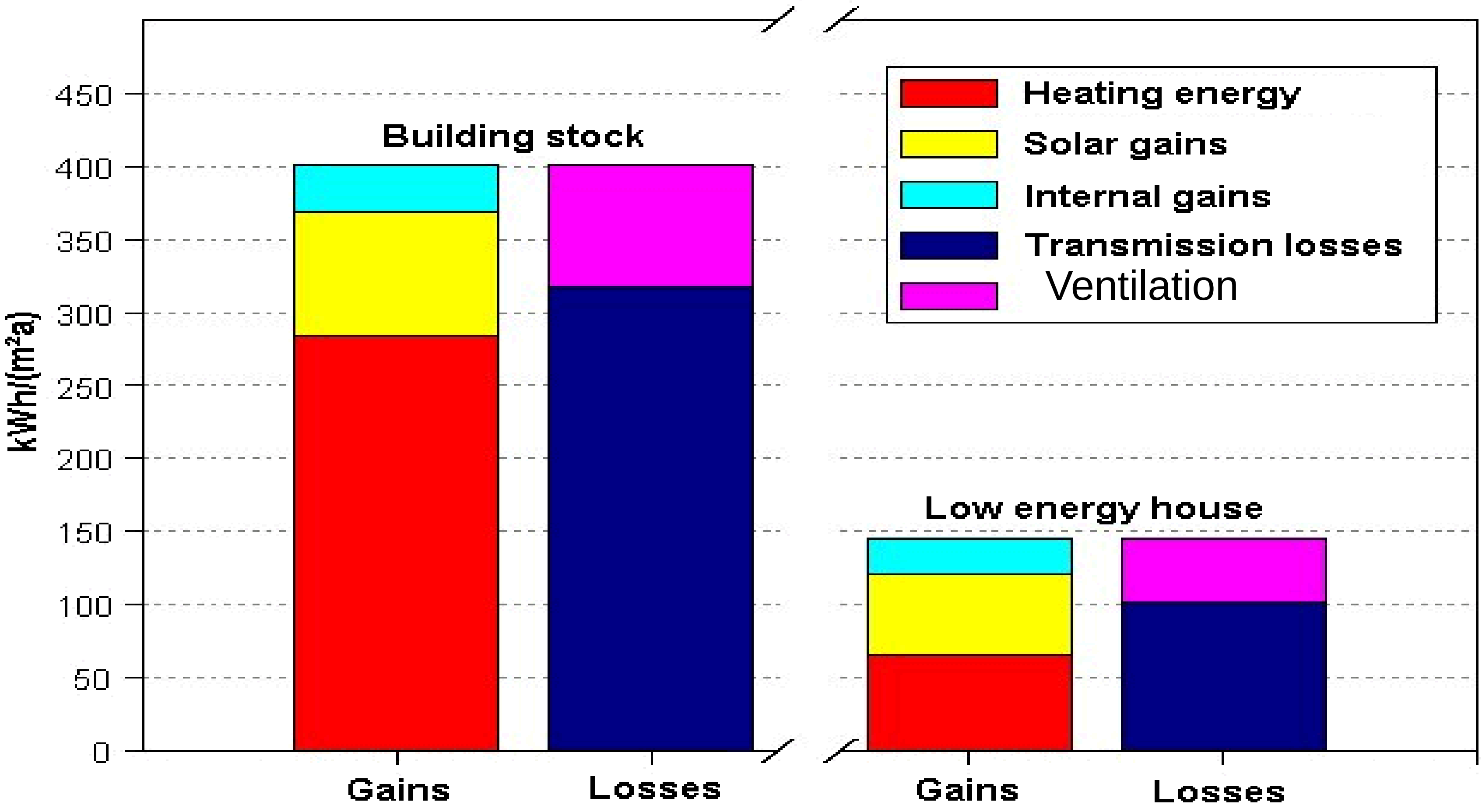
Energy balance for a conventional and low-energy building



Source: http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/3.htm

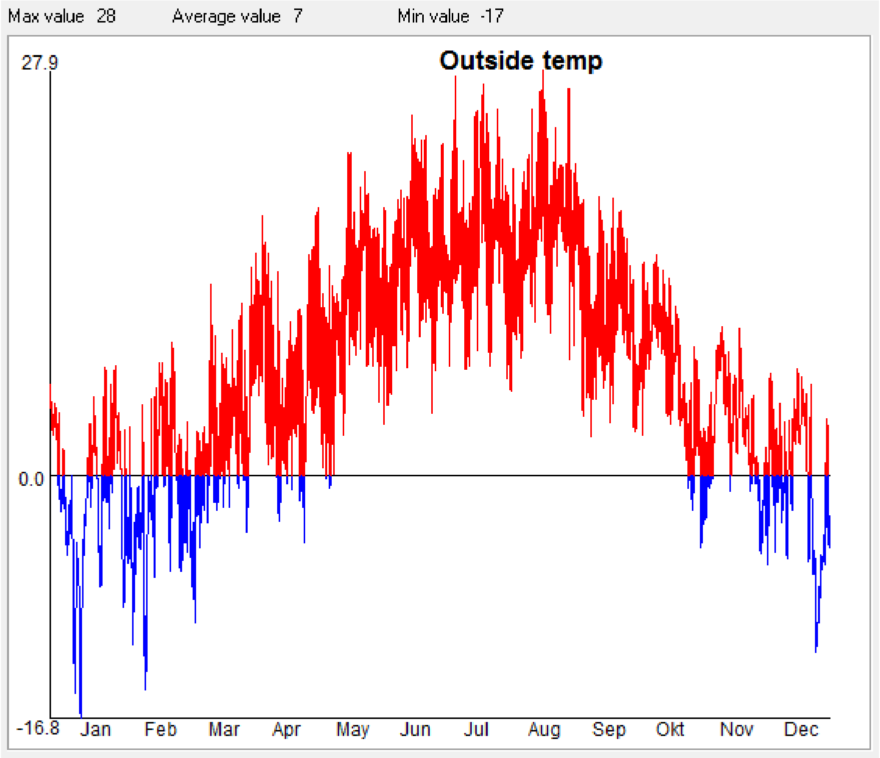
Importance of energy balance analysis of buildings

- To establish all the energy that can enter or leave a building
- To calculate the heating (or cooling) demand of a building
- To size and design heating (or cooling) systems in a building

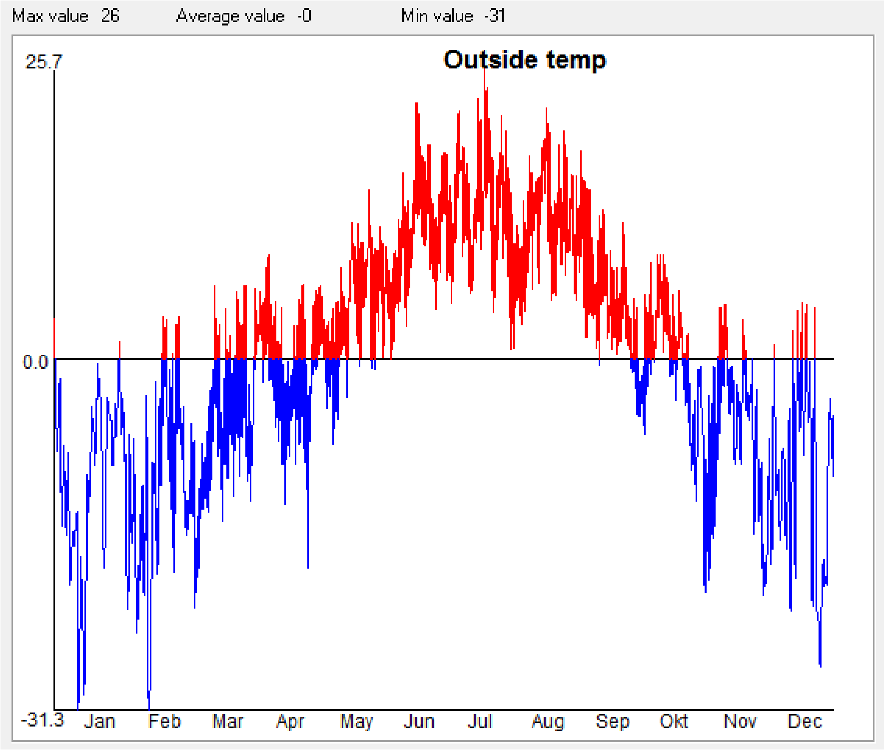
Key factors which influence a building's (space) heating demand

- Outdoor climate
- Orientation
- Opening (window / door) size and type
- Size and shape
- Heat gains
- Appliances
- Insulation
- Infiltration / Airtightness
- Air change rate (ventilation)
- Indoor temperature
- Thermal mass of material

Outdoor climate elements – outside temperature



Outisde temperature for Växjö
Average data from 1996-2005



Outisde temperature for Kiruna
Average data from 1996-2005

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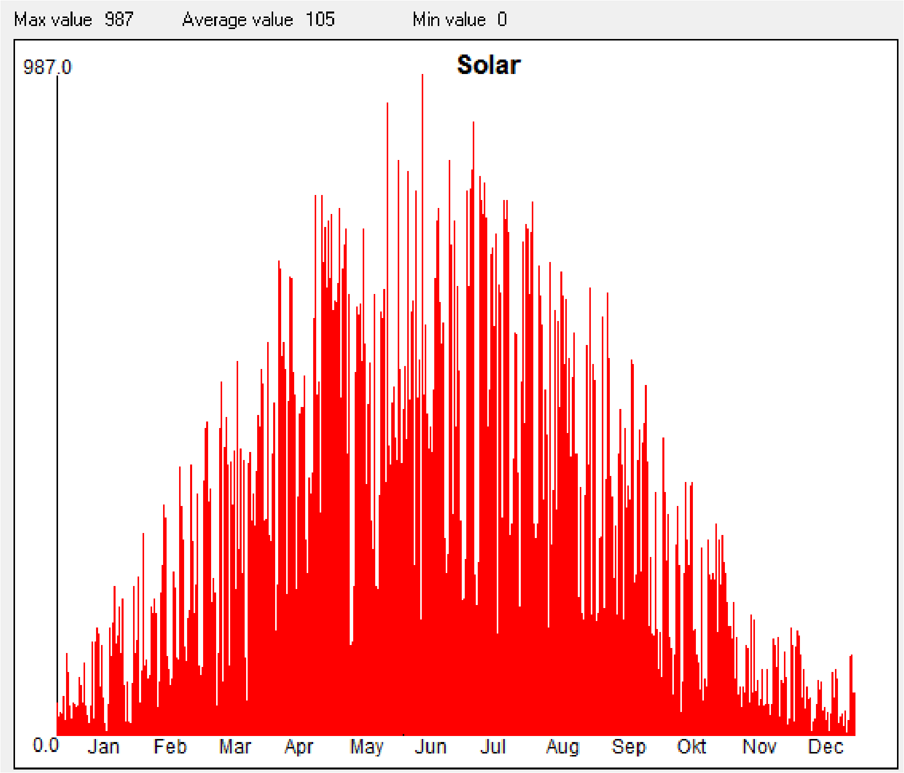
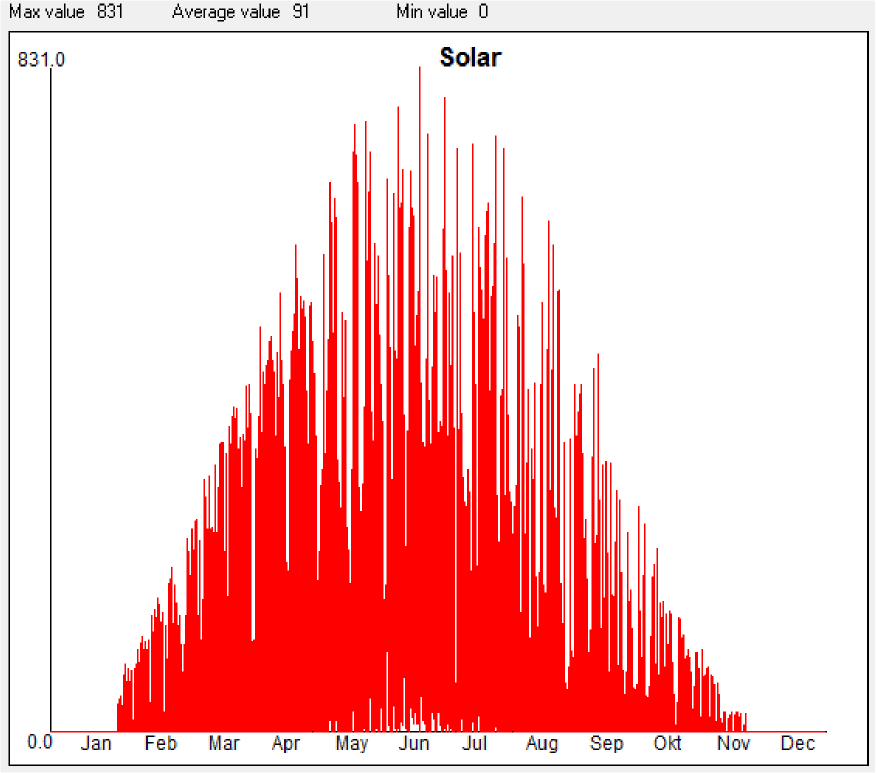
Outdoor climate elements – solar irradiation



Solar radiation for Växjö
Average data from 1996-2005



Solar radiation for Kiruna
Average data from 1996-2005

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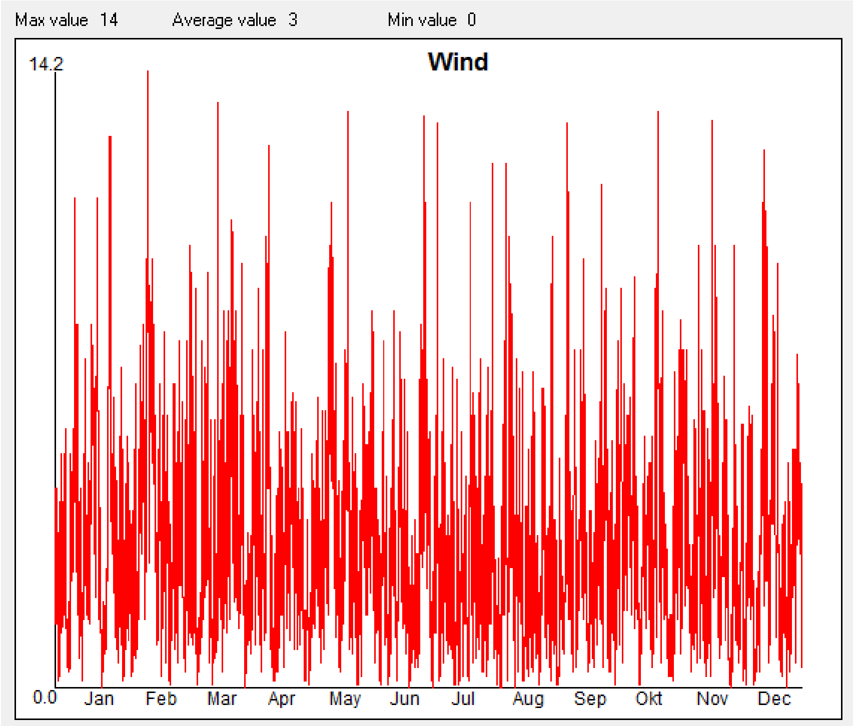
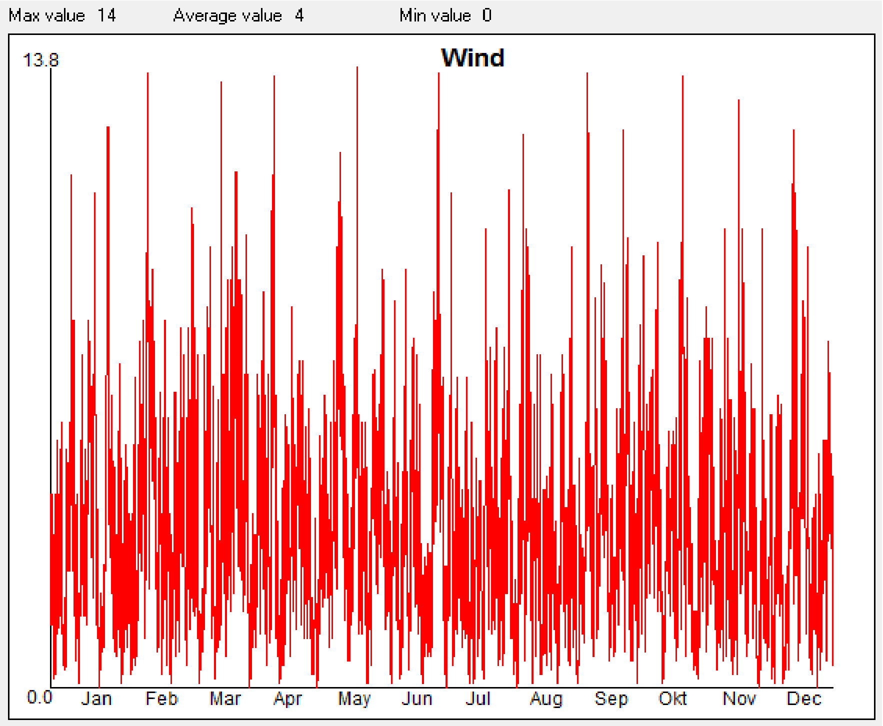
Outdoor climate elements – wind





Wind velocity for Växjö
Average data from 1996-2005

Wind velocity for Kiruna
Average data from 1996-2005

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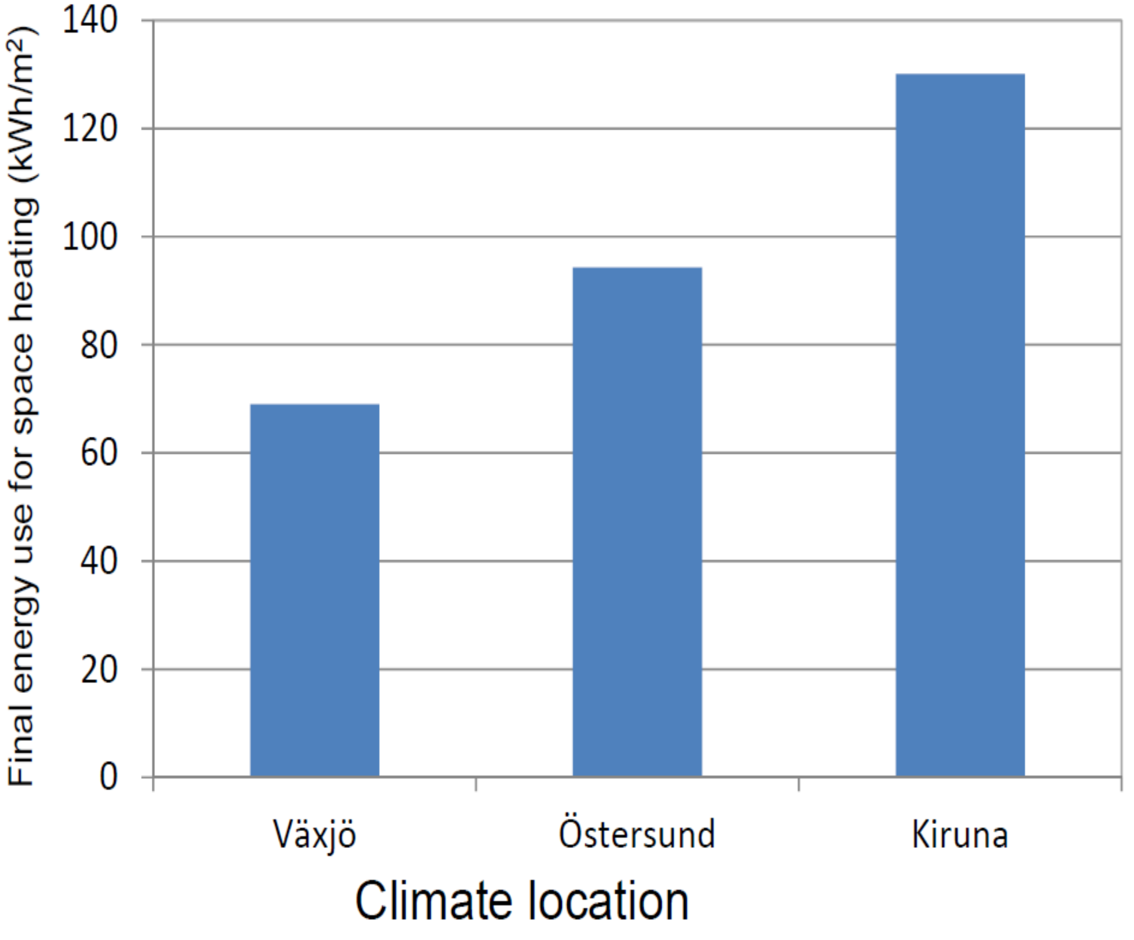
Effect of outdoor climate on space heating demand for Wälluden



Location	Relative location	Average temperature
Växjö	South	6.5 °C
Östersund	Middle	2.5 °C
Kiruna	North	-1.2 °C

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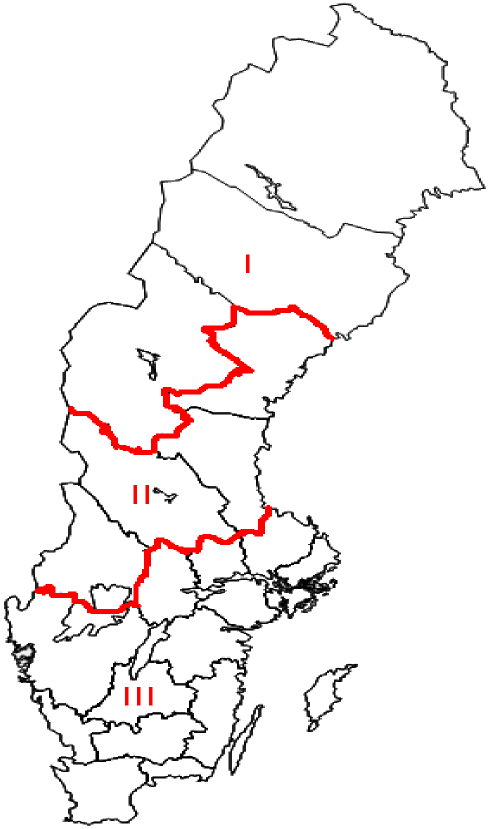
Building specific energy use* limits for BBR 2012 and passivhus criteria Energy balance of buildings

Description	Electric heated			Non-electric heated		
Climate zone	I	II	III	I	II	III
BBR 2012	95	75	55	130	110	90
Passive criteria	29	27	25	58	54	50



* Comprises purchased energy for space and water heating, and electricity for fans and pumps but excludes electricity for household use.

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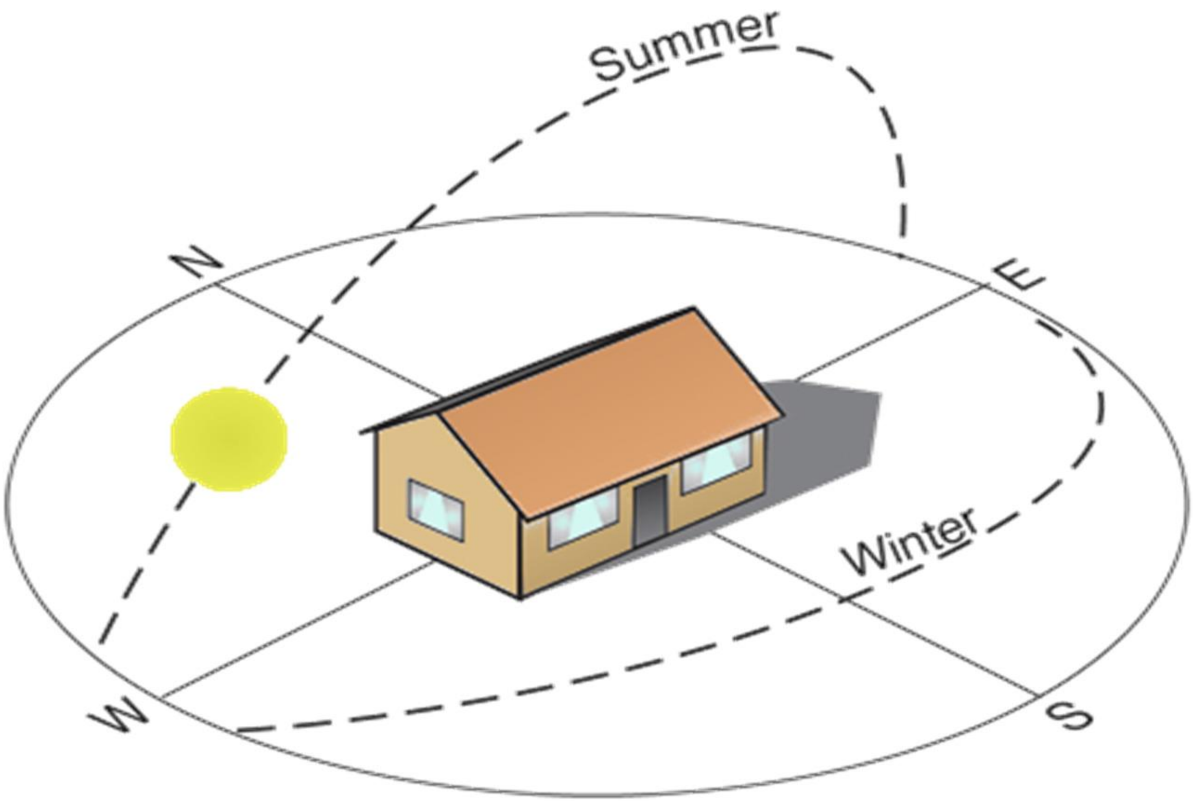
Source: http://www.boverket.se and http://www.passivhuscentrum.se

Effects of orientation



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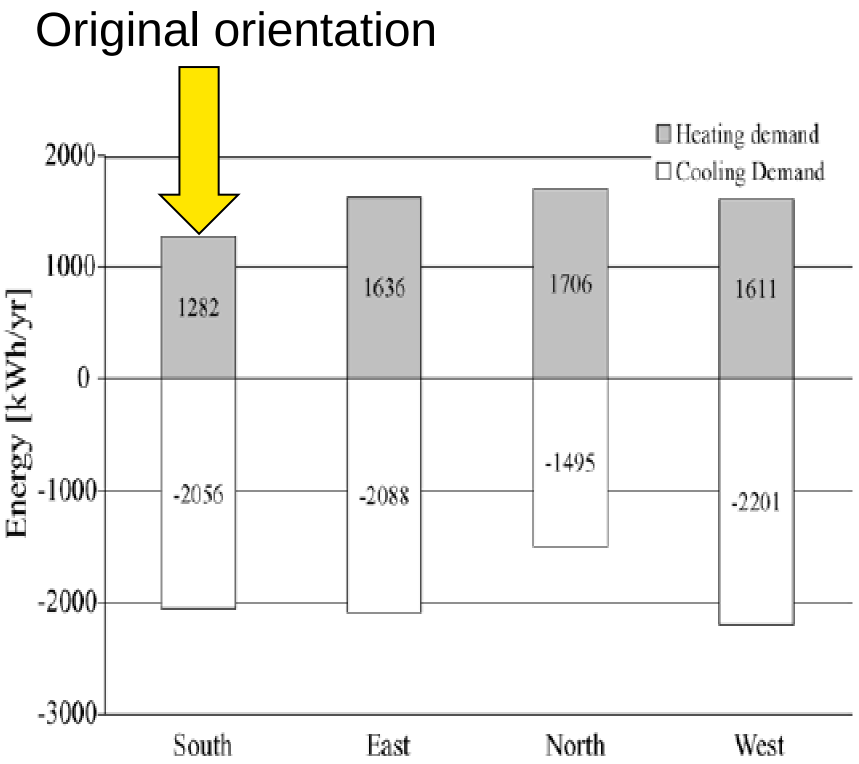
Source: http://www.nachi.org

Effects of orientation

- Space heating and cooling demands for different orientations



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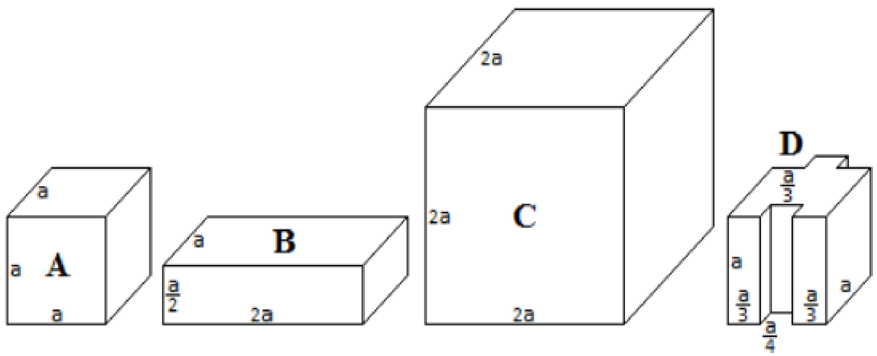
Source: Persson et al. (2006). Influence of window size on the energy balance of low energy houses. Energy and Building, 38. p.181-188

Effects of building shape and form

- Shape factor = $\frac{\text{Building thermal envelope area}}{\text{Building volume}}$



	A	B	C	D
Volume	a^3	a^3	$8a^3$	a^3
Thermal envelpe	$6a^2$	$7a^2$	$24a^2$	$7a^2$
Shape factor	6/a	7/a	3/a	7/a

- Reflects a building's compactness

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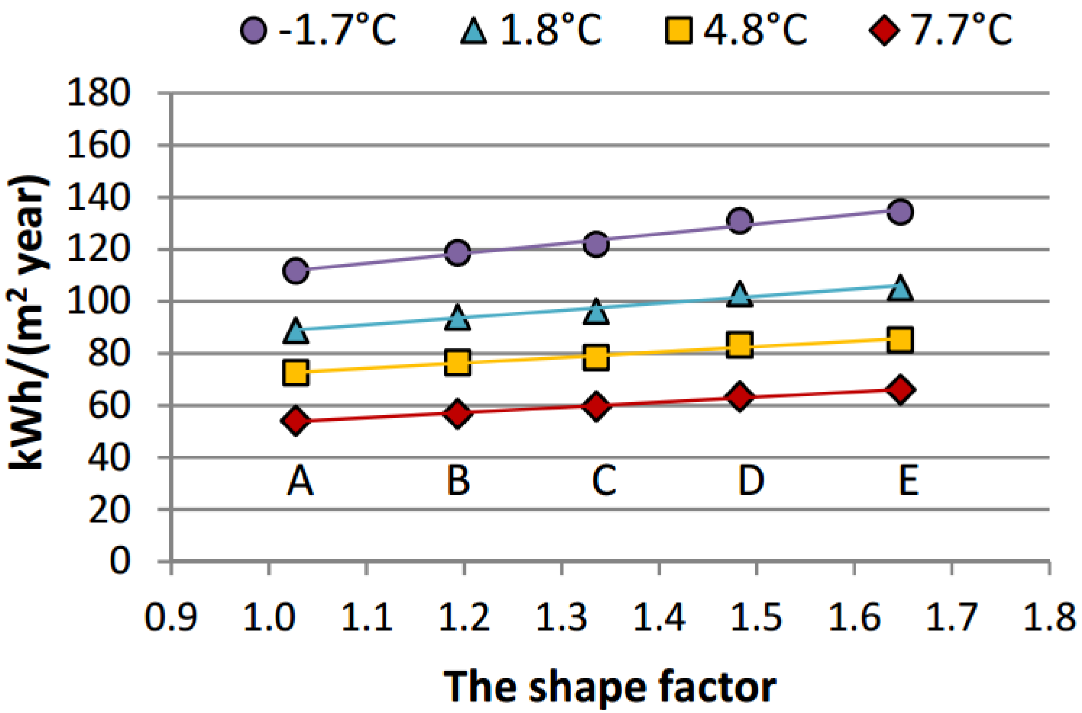
Source: Danielski et al. (2012). The impact of the shape factor on final energy demand in residential buildings in nordic climates: (WREF 2012)

Effects of shape factor under different outdoor temperature



- In colder climates the correlation between final energy use and shape factor is strong

Source: Danielski et al. (2012). The impact of the shape factor on final energy demand in residential buildings in nordic climates: (WREF 2012)

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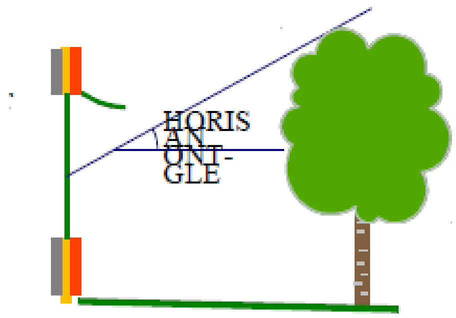
Heat gains

- Solar heat gains depend on:
  – Geographical latitude
  – Local cloud condition
  – Season of the year
  – Angle between the sun and building surfaces
  – Shading or shelter by near-by objects



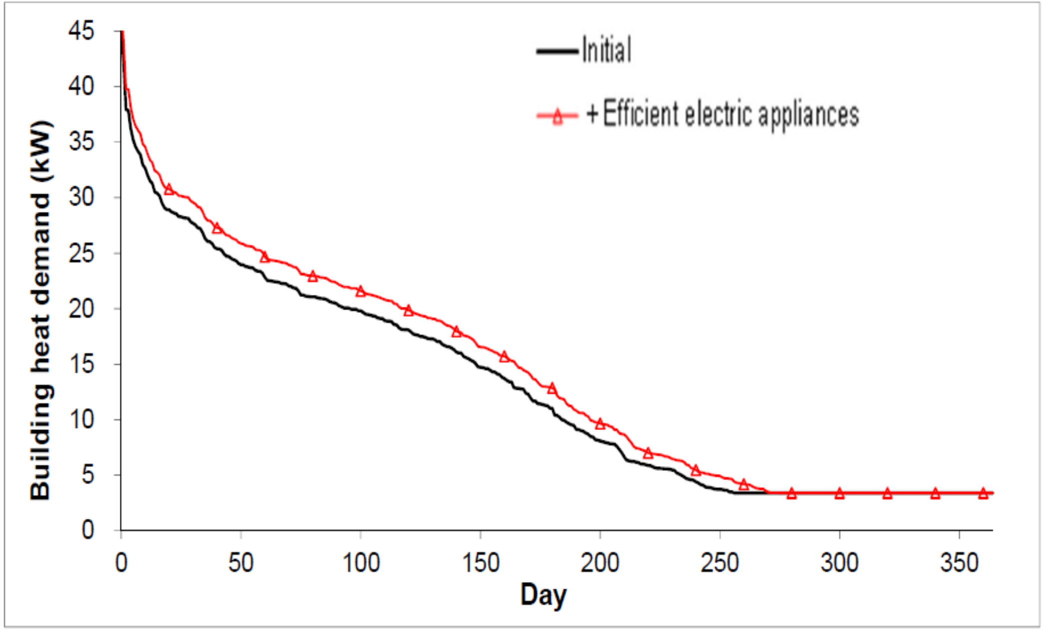
Heat gains

- Person (metabolism) heat gains depend on:
  - Number of persons in a building
    - One person give about 1,2 kWh/day
    - If a family of 4 - heat gain is 4,8 kWh/day
  - Occupancy pattern and use of building
    - Residential building?
    - School?
    - Offices?

Heat gains

- Lighting and appliances heat gains depends on:
  - Energy efficiency level of equipment
    - Inefficient equipment release more heat to surroundings
    - Efficient equipment gives less heat

Example effects of heat gains on annual heating demand Wälludden with 'standard' or 'efficient' appliances



Energy use (kWh/m2)	Space heating	Tap water heating	Ventilation electricity	Household/ facility electricity	Total	Savings
Building with 'standard' appliances	68.7	25.0	4.0	45.0	142.7	-
Building with 'efficient' appliances	77.8	25.0	4.0	25.1	131.9	10.8

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Effects of insulation on space heating demand

- Reflects in the thermal transmittance (U-value)
  - Genomsnittlig värmegenom- gångskoefficient
- Insulation levels for different building parts or whole buildings are usually specified in codes
- BBR 2012 specifies an average U-value (0.4 W/m2 K) for residential buildings

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Effects of insulation on space heating demand

Typical U-values for different building envelope elements

Envelope element	U-value (W/(m2•K)
• Foundation	0,20 - 0,30
• Walls	0,20 – 0,25
• Attic	0,18
• Roof	0,10 - 0,15
• Windows	1,2 – 1,7
• Doors	1,0

Effects of insulation on space heating demand

U-values over time

Building year	Walls	Attic
1940 or prior	0.5	0.33
1941-1960	0.52	0.31
1961-1975	0.37	0.24
1976-1988	0.25	0.18

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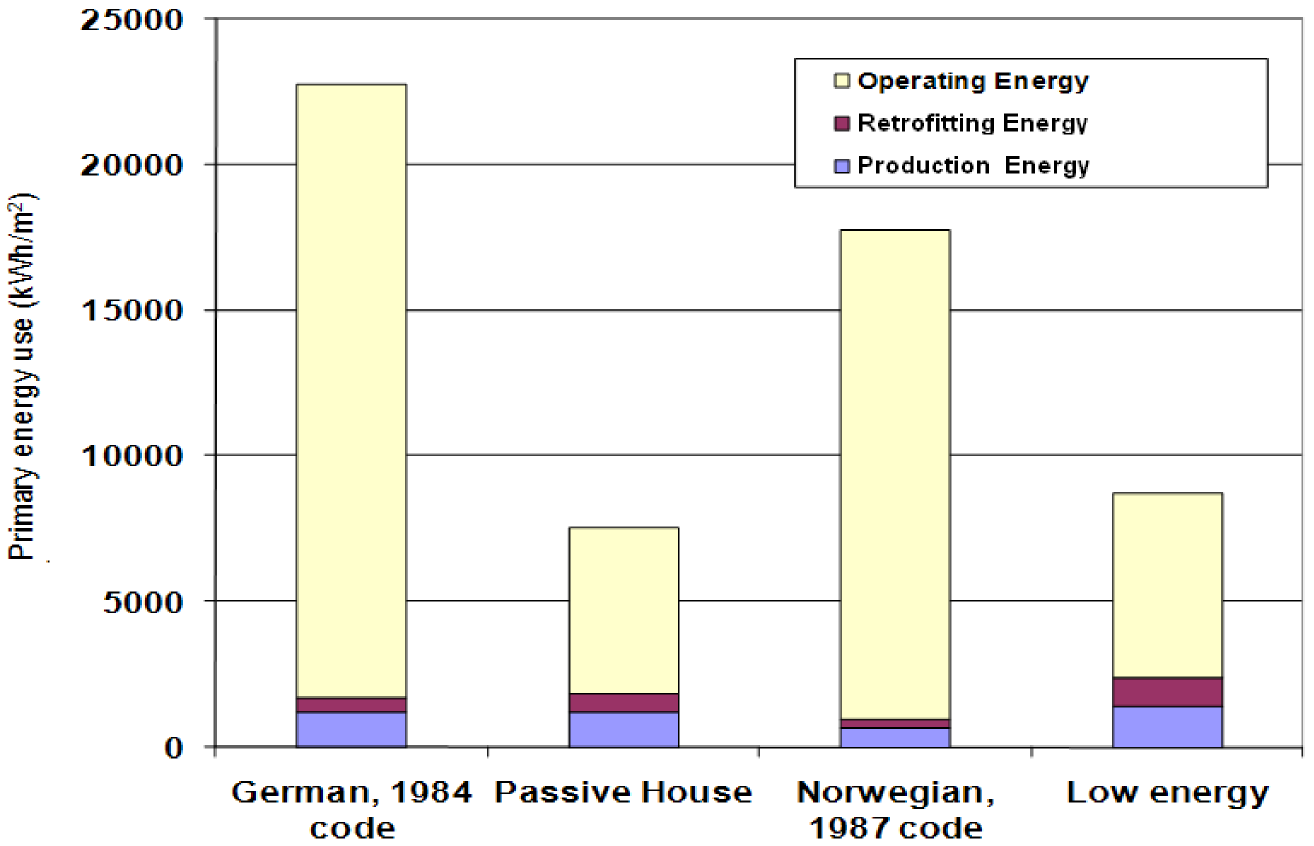
Effects of insulation on space heating demand

- Impact of insulation based on different codes and standards



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Infiltration / Airtightness (Lufttäta)

- Airtightness
- No airtightness values specified in BBR 2012
- Commonly used values today:
  - Standard residential buildings: 0,5-0,8 liter/(s • m² of envelope)
  - Passive houses: 0,1-0,3 liter/(s • m² of envelope)

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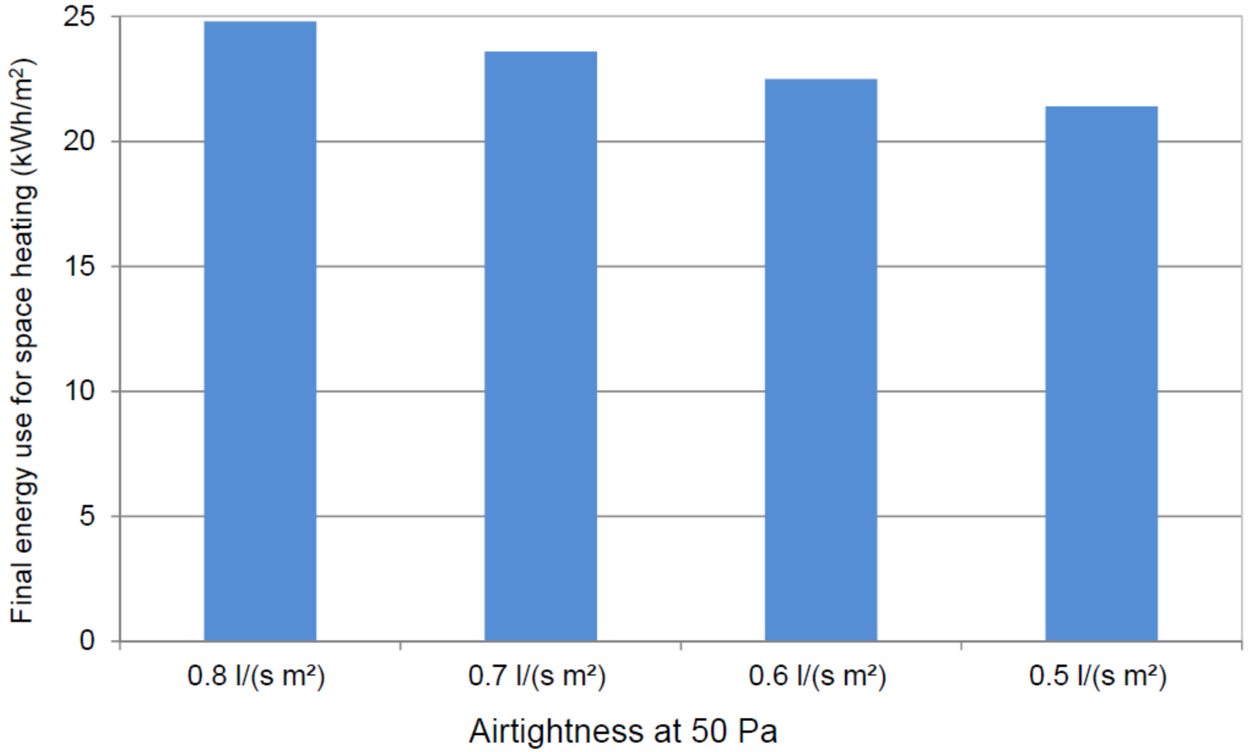
Infiltration / Airtightness (Lufttäta)

- Example of effects of different airtightness on space heating demand of Wälludden with ventilation heat recovery



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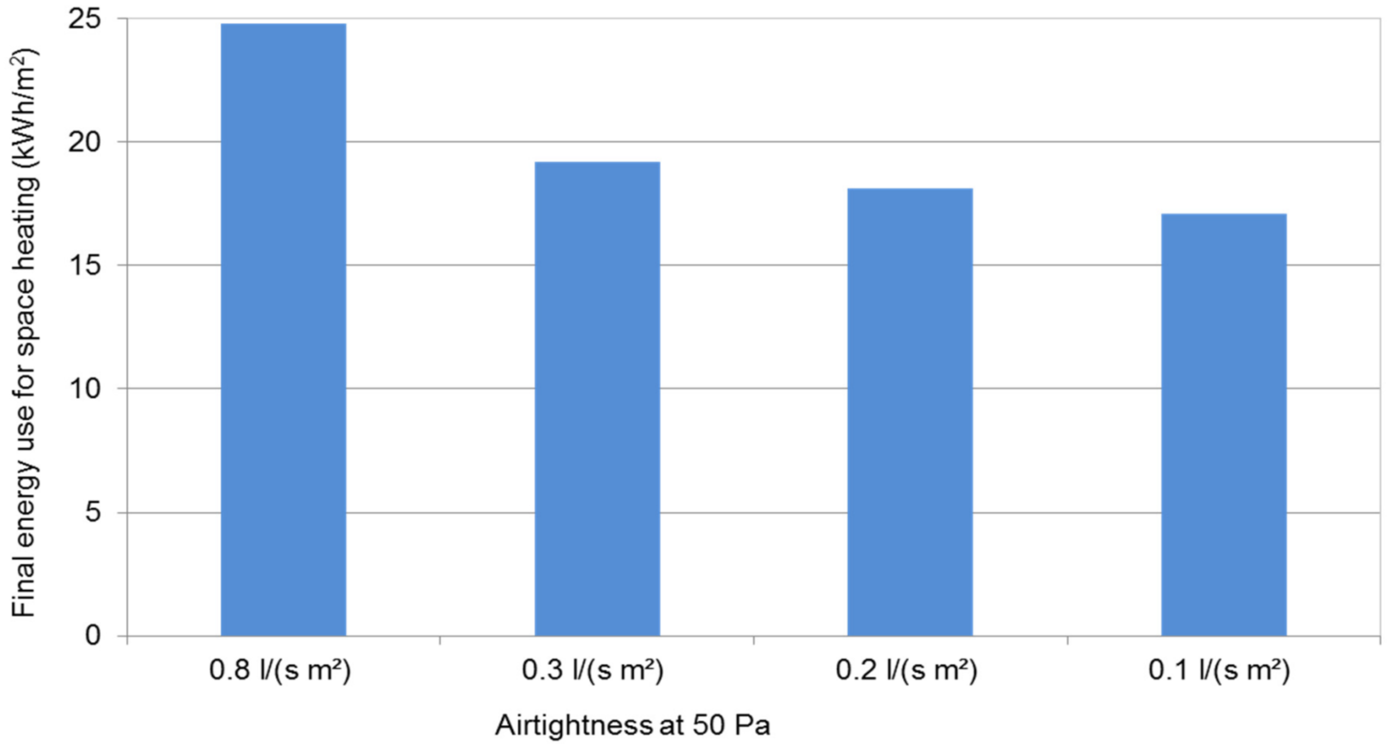
Infiltration / Airtightness (Lufttäta)

- Example of effects of different airtightness on space heating demand of Wälludden with ventilation heat recovery



Infiltration / Airtightness (Lufttäta)

- Why airtightness?
  - Reduce energy losses
  - Avoiding moisture condensation problems
  - Necessary for controlled ventilation
  - Allow heat exchangers to recover heat

Air change rate (ventilation)

- Air change necessary in a building
  - To bring fresh air and to remove contaminants
- How much air should we change?
  - Depends on functional requirement of building
  - Controlled by building code
    - BBR specify minimum supply change rate 0.35 $l/m^2\,s$

Indoor temperature

- Air temperature: minimum of 18° C

- Typical temperatures in different zones of a building

  - Common area 18° C

  - Living area 20 - 22° C

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Indoor temperature

- Variations in indoor temperature over time

1880	16-18° C
1950	Houses:19.8° C Apartments: 20.7° C
1990	Houses: 20.9° C Apartments: 22.2° C

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Thermal mass

- Thermal mass is a the heat storage capacity of a material
- Effective thermal mass can absorb and store large amounts of heat, to level out temperature variations
- Thermal mass may affect space heating demand
  - Space heating savings from thermal mass is small for Nordic climate

Reading assignments and literature

- Gustavsson, L., Dodoo, A., Truong, N.L., Danielski, I. (2011). Primary energy implications of end-use energy efficiency measures in district heated buildings. Energy and Buildings. 43, 38-48.
- Dodoo A., Gustavsson L. and Sathre, R., (2010). Life cycle primary energy implication of retrofitting a wood-framed apartment building to passive house standard. Resources, Conservation and Recycling, 54(12): 1152-1160.
- Boverkets Byggregler, Boverkets Författningssamling, The national Boardof Housing, Building and planning, Karlskrona, available at http://www.boverket.se
- Kravspecifikation för nollenergihus, passivhus och minienergihus, Bostäder,FEBY 12 available at http://www.passivhuscentrum.se/sites/default/files/kravspecifikation feby12 - bostader sept.pdf
- Clarke, J. (2001). Energy Simulation in Building Design. 2nd Edition, Butterworth-Heinemann, Oxford.

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Energy balance of buildings

Objectives of the assignment in module 1

- Understanding of the impact of building features and various parameters on the building's energy use
- Creating and evaluating building models in the VIP+ simulation software
- Analysis of VIP+ model results and various energy efficiency measures for buildings.

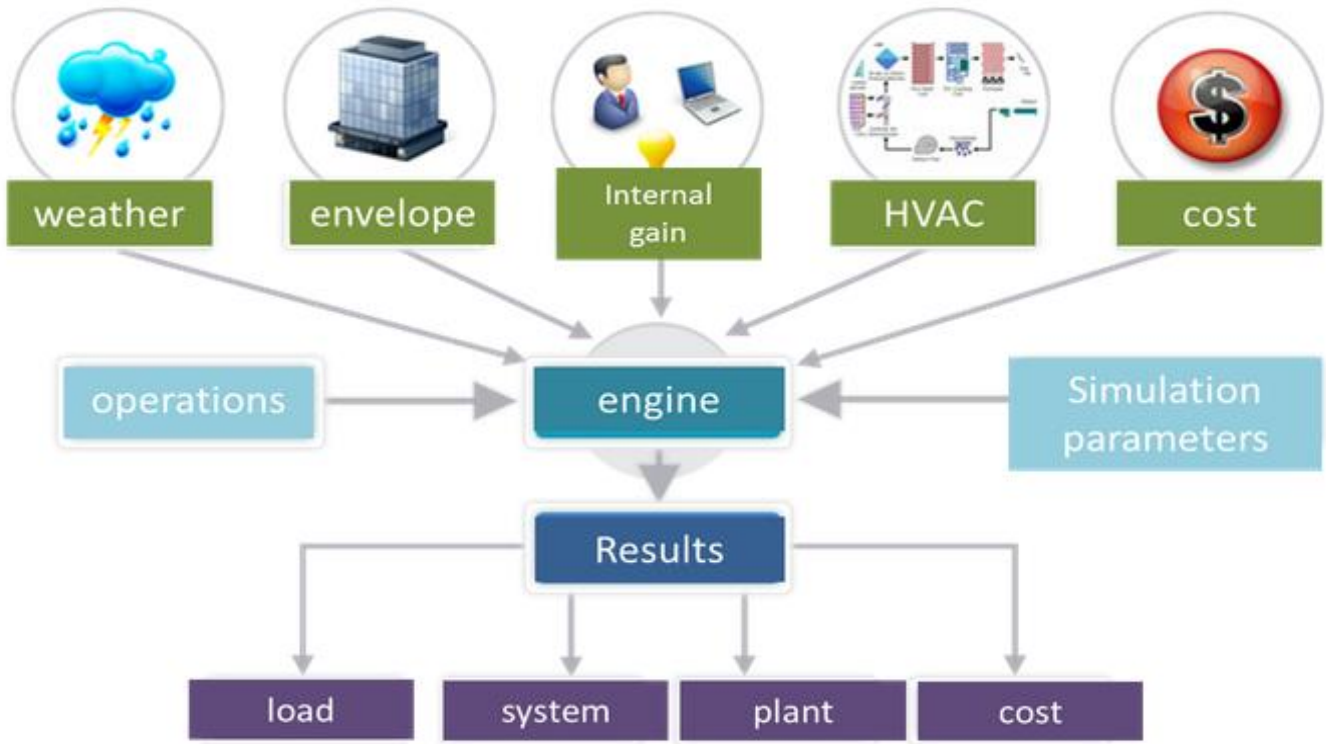
Energy balance of buildings

Two main methods / ways for building energy modelling:

1. Simplified method
   - uses integrated weather representations e.g. degree days or degree hours
   - uses integrated totals of interior loads
   - Because of this energy prediction is not very accurate
   - Fast/quick approach to have an overview of building energy performance

2. Detailed method
   - performs a whole-building heat loss/heat gain calculation every hour of the year
   - accounts for exact sun angles, cloud cover, wind, temperature, and humidity on an hourly basis
   - accounts for effects of thermal time lag and thermal storage in the building's interior

Building energy simulation



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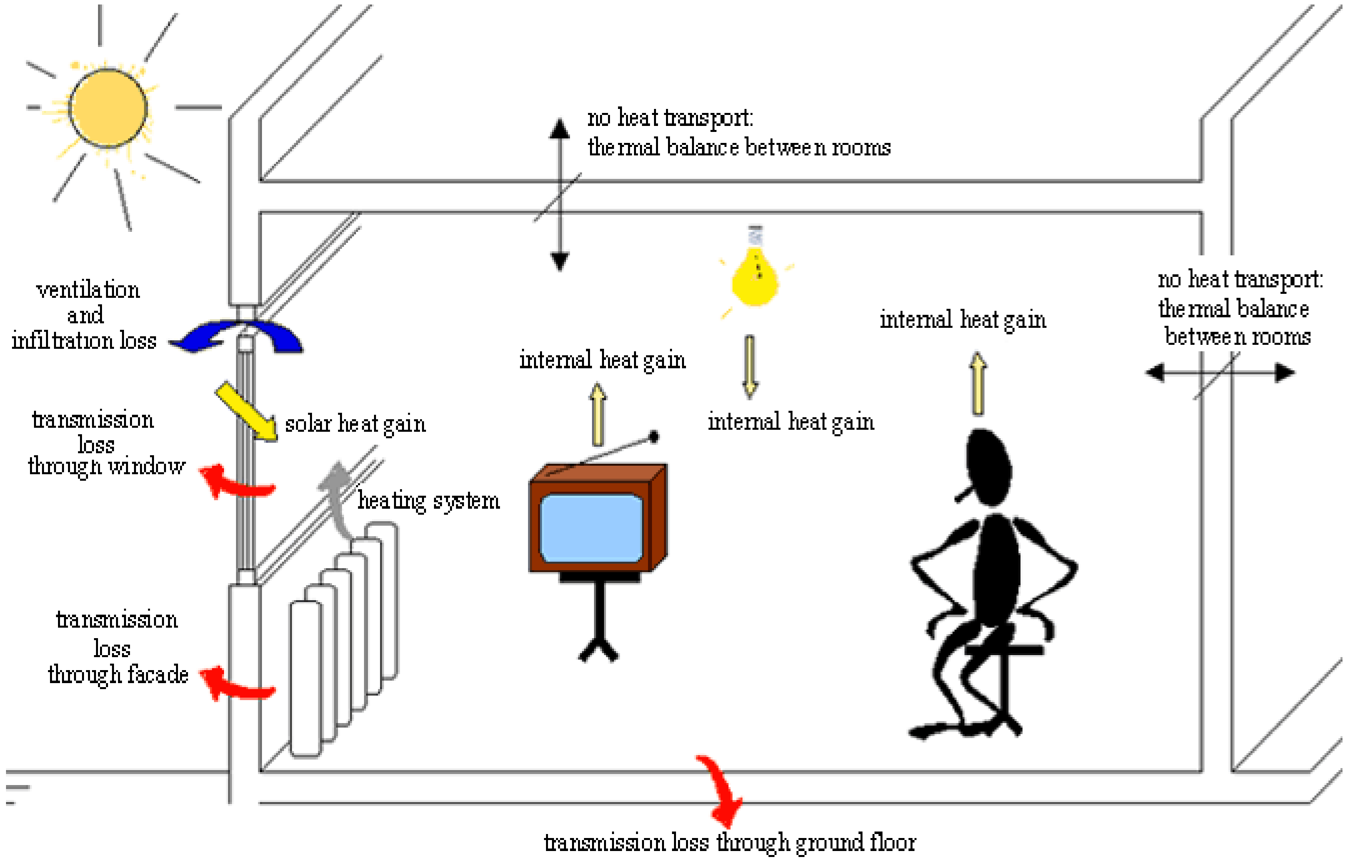
Source: http://www.sustainablesv.org

Energy balance of buildings



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