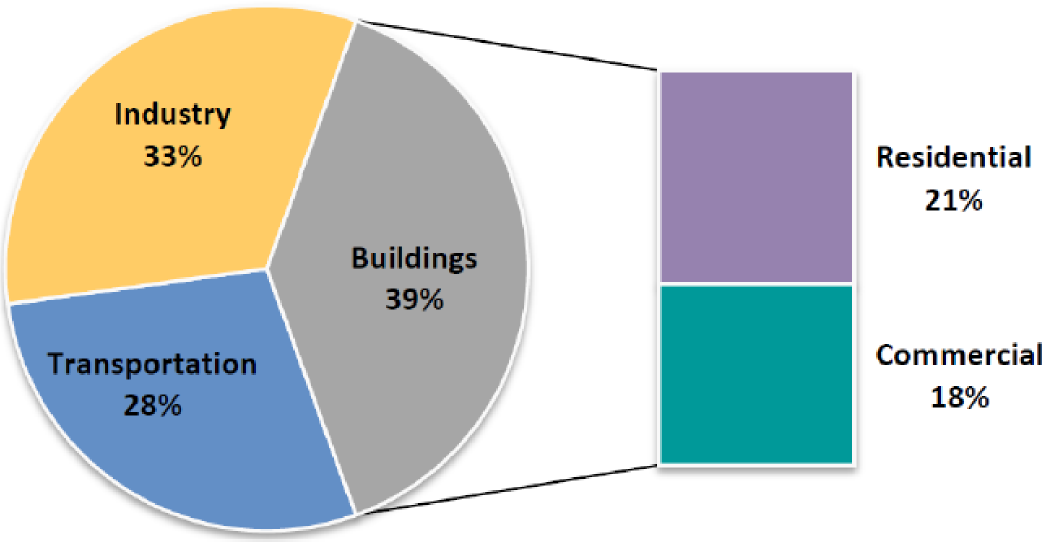
7S815 – Design of sustainable energy systems for the built environment – List of questions ’12-‘13

Energy resources, building and climate

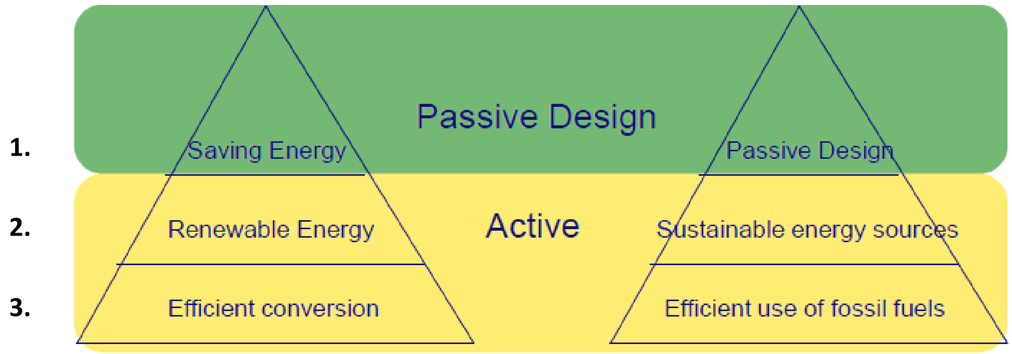
1. **What share do buildings have in the national energy budgets of industrialized countries?**
   Residential mainly for heating (32%). Commercial mainly for lights (28%) and heating and cooling (together 29%).



2. **Which issues put pressure on the building related energy use in the (near) future?**
   - The built environment has a large share in energy use and this use is relatively easy to reduce.
   - Climate issues.
   - Energy sources are at their production peak (see question 4 on Hubbert curves).

3. What signifies the Trias Energetica and how does it relate to basic strategies of building design? Give of each strategy a concrete example.

Trias Energetica is a way of dealing with energy. It is a simple and logical concept that helps to achieve energy savings, reduce the dependence on fossil fuels, and save the environment. Incorporating passive and active systems to achieve each one of these elements is the way in which building design can be related to the Trias Energetica.

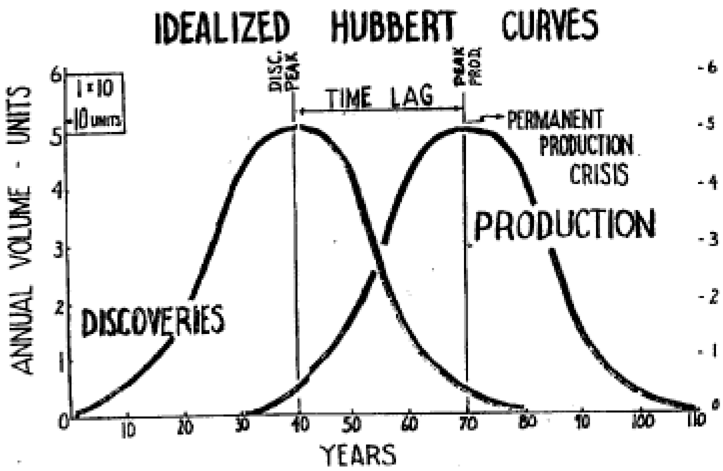


Examples are:

1. Reduction of demand:
   - Air tightness
   - Insulation
   - Ventilation with heat recovery
   - External shading
   - Domestic hot water
   - Electricity use for household appliances towards 2000 kWh/year in 2050
2. Employ renewable energy source:
   - Solar thermal (space heating and DHW)
   - Geothermal (HP)
   - Electric: PV and small-scale wind
   - Hybrid: PVT, heat-driven µ-ORC
3. Efficicent/clean fossil energy
   - Stirling µ-CHP (Combined Heat and Power)
   - Fuel cells
   - District heating (residual heat)
   - HR

4. Discuss the 'peak' problem as identified by Hubbert. What other peaks can be identified as well and what does this mean for sustainable solutions to the energy problem.

Peak oil is the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline. According to Hubbert, the production curve has the same shape as the discoveries curve which it follows with a time lag peculiar to the region. Hubbert predicted the time lag for the US was 30 to 40 years. See graph below. Campbell, Hubbert and others predicted oil production will peak between 2000 and 2010. Gas production in the Netherlands peaked around 1998 (although predictions from earlier years showed the peak would be much earlier). Other resources which follow the Hubbert curve are materials, copper for example.



5. **Discuss climate considerations on passive building design and on active building design.**

Climate issues to be considered on building design are:

	Passive	Active
Air temperature	-	-
Relative humidity	-	-
Wind speed/direction	- Use outside air to cool - Passive ventilation	- Wind turbines
Solar radiation (direct/diffuse)	- Optimize solar exposure for heating - Minimize undesired heat flows through façade ((natural) shading) - Reduce internal loads for artificial light	- Optimize solar exposure for PV cells or solar collectors
Urban heat island effects		- Availability of waste heat from utilities

And concerning these issues the following points are important:

	Passive	Active
Average	-	-
Daily variation	- Apply thermal mass to reduce amplitude of temperature swing	- Transfer coolness of the night to the day (thermal wheel/thermal mass/PCM’s)
Seasonal variation	-	- Store excess energy (acquifer, TCM, PCM, water storage vessel)

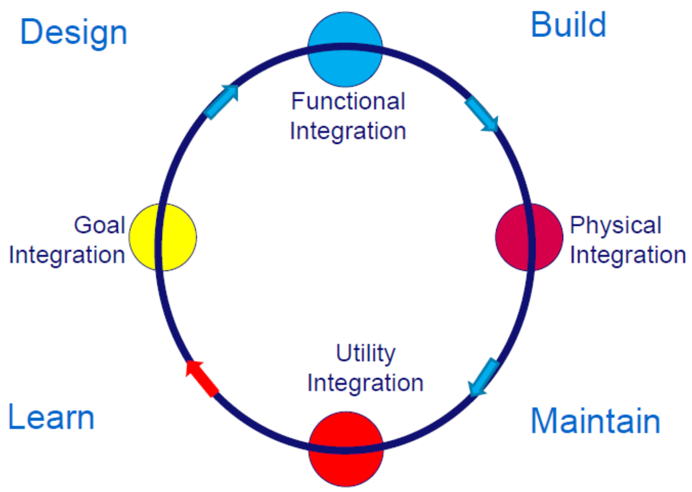
Integral design

6. **What is integrated design of buildings and what types of integration do you distinguish? Provide a concrete example of each type of integration.**

Integrated design is a collaborative design methodology emphasizing knowledge integration in the development of a design. The complexity of the design of a building is caused by the large number of disciplines that should contribute together to achieve the main objectives (design goals). The multidisciplinary nature of the objectives is fairly complicated in itself and requires special effort from the design and construction team to achieve the optimum and often unique solution. In an integrated design of buildings, one should give attention to (1) a systematic and structured design, (2) an attitude of equity among the members of the team and (3) an effective framework for communication between team members. We distinguish 4 different types of integration:

1. *Goal integration* (values: why?)
   Everybody together at the same time towards a common goal.
   - Check feasibility of value drivers
   - Develop ideas
   - Find a balance between the value drivers
   - Example: for the users of the building, the comfort is very important, which means an air-conditioning system is required which costs a lot of energy. It is possible that the ecologist will not agree because of environmental reasons, the building owner because of installation and energy costs.
2. *Functional integration* (concept: what?)
   Concepts determines costs. Installation + construction + façade → function (e.g. cooling) for goal (e.g. comfort).
   - Think in alternatives and consider constraints
   - Find a robust alternative
   - Example: Installation, construction and façade could function for cooling. The goal is increasing the building comfort.
3. *Physical integration* (artifact: how?)
   Architect + building physicist + others → design process and product and integrate in building.
   - Design process (when, order calculations)
   - Design product (size, position)
   - Integration in building: size fit.
   - Example: An integrated air-conditioning system should be accounted for in early design concepts, because it has to be implemented in the building.
4. *Utility integration* (building use: where?)
   - Nothing found about this topic.

These different types are related in the following way:



7. How do you structure the overall integrated design process (in main phases) and what activities do take place?

An integrated design process not only increases the chances of finding the optimal design solution for the objectives at stake, but also forces each building discipline to take into account all aspects of the design in order to arrive at a balanced design for their own discipline. Steps are:

1. *Initiative phase*: within the design team and in detailed discussion with the client, the project and use objectives should be defined. The value is defined as the relative worth,

utility or importance in a certain context. This stage should lead to the formulation of the 'statement of requirements' integrating the most important goals and the basis is set for a good collaborative design team.

2. *Concepts phase*:
   Based on the design objectives, now design concepts can be generated for the building levels that can be distinguished (see figure below). In the development of the variants the value drivers provide a guideline for the design level at which to start the conceptual design. Functional integration should be strived for. During this phase the 'genetic code' of the building is determined, and more than 80% of the total costs and performances of the building will be determined.

   Evaluation of concepts is important to distinguish potential solutions from non-realistic ones. Three major types of evaluation can be distinguished which generally will be applied together:
   a. Objective evaluation techniques: the variants are evaluated against weighted design goals.
   b. Professional experience: years of design experience sharpens intuition.
   c. Experience with other buildings and situations: evaluation of buildings after commissioning provides valuable feedback to the future assessments of variants.
3. *Detailed design phase*: in this phase the optimum variant is designed in detail. Also, the manufacturing and construction process should be designed.
4. (The project is executed.)
5. (Effectiveness of the design in achieving the objectives can be tested.)

8. What is the essential benefit of using of value domains and functional levels of the building in the integrated design process? Explain what they are and how they are used.

With the design of a building a lot of complexity and dynamics are involved. By using value domain and functional levels, some structure can be brought into the process, which should facilitate the process. The different value domains are (B.E.S.E.L.F.):

- Basic values (building – people); individual occupants' sense of psychological and physical wellbeing. Examples: spatial and thermal comfort, air quality, office noise.
- Functional values (building – organization); how activities taking place inside the building are supported. Examples: support for production, O&M, cleanliness.
- Local values (building – community); based on special conditions that are unique to a particular place including anything that may prevent a building from being constructed in the most straightforward way. Examples: earthquake zones, regulations, historical contexts.
- Ecological values (building – environment); Examples: use of resources, waste/pollution.
- Strategical values (building – time); an abstract human-building relationship as it considers performance requirements associated with time and the future.
- Economical values (building – owner); Examples: Initial costs, life-cycle costs, O&M costs, demolition costs.

9. What are the important value drivers for a building and describe for each shortly what building characteristics are related to it.

Value drivers can increase the success of a building in a certain context. The value drivers are given by the examples in the previous question.

10. **Which value drivers should be given highest weight when designing a sustainable building and discuss why.**

11. **Describe a sensible design process for designing a sustainable building.**

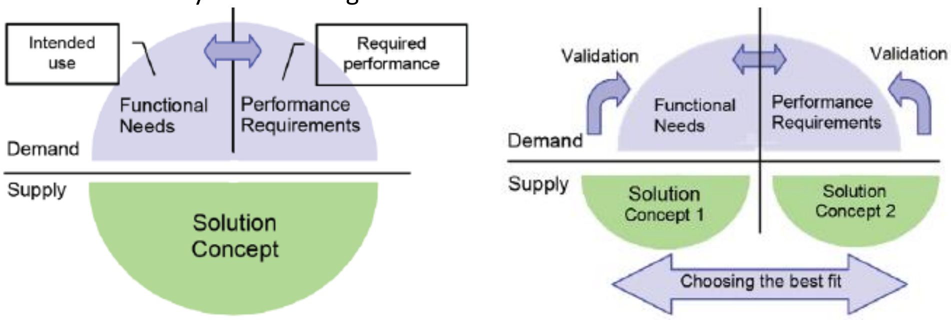
Evaluation tools

12. **Which categories of resolution levels for simulation (evaluation tools) can you distinguish and describe the feasibility of the use of these tools in the different parts of the design process.**
    - *Simple*: few inputs, limited information needed.
      Generally for exploration of design concepts. This level is desired in the pre-design and conceptual design in the design process. The main concepts can be integrated this way.
    - *Detailed*: many inputs, with detailed information required.
      Generally for exploration of more detailed designs.
    - *Special purpose*: dedicated to a single task or purpose.
      Single purpose tools for investigating individual building parts/components (e.g. shading (simple), HVAC system (complex)).

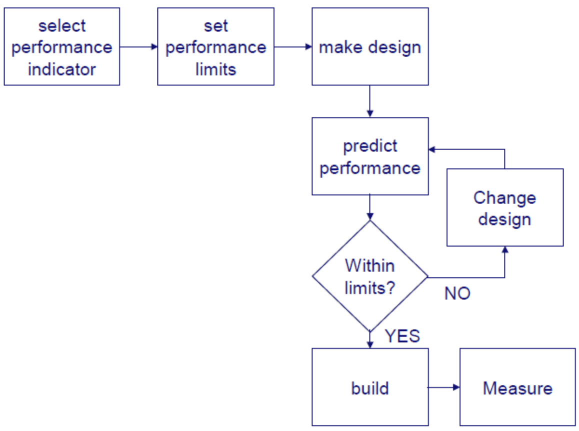
13. **What is Performance Based Building and describe how evaluation tools are indispensable when applying this approach.**

The performance approach is thinking and working in terms of *ends* (doel) rather than *means* (middelen). Performance is concerned with what a building or building product is *required to do* and not with prescribing how it is *to be constructed*. A design solution, traditional or novel, will always need a quantitative base for testing and evaluation of its performance.

This can be visualized by the hamburger model:



The general approach is showed in the following diagram. After measuring, the real performance limits can be determined.



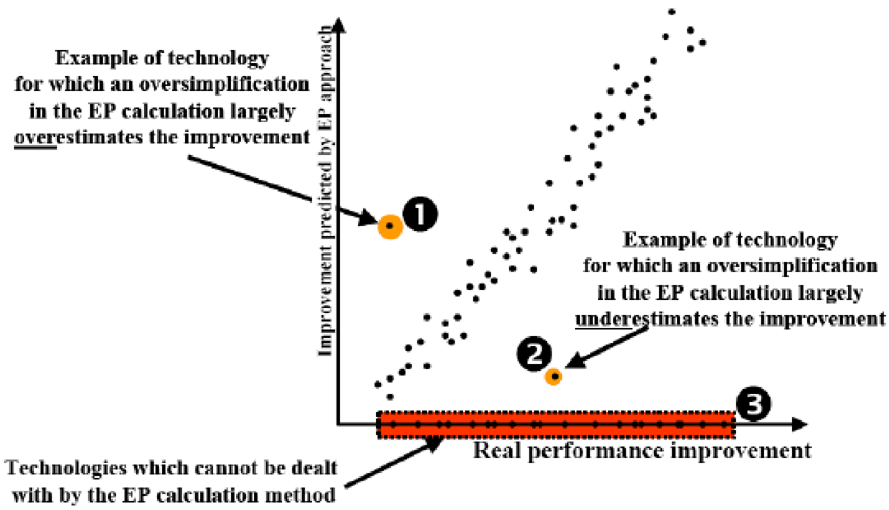
14. **Which performance indicators (at least five) could you mention that directly relate to the assessment of sustainable building designs? Give a short explanation for that for each indicator.**

Performance indicators *related to the assessment of sustainable building design*:

- Energy related
  - Heating energy demand: this demand can be lowered, for example, by good insulation of the building. Also, a heat recovery system will lower heat demand.
  - Cooling energy demand: For example shading will lower cooling energy demand. An aquifer system is an example of an active system to provide cooling.
  - Primary energy use: which primary energy sources are used, are they sustainable and environment friendly is a question to be considered here.
- Load related
  - Maximum heating or cooling load: these can be lowered by a high thermal mass of the building construction.
- Comfort related
  - Minimum or maximum room air temperature: If in winter a lower minimum room temperature is comfortable, and in summer a higher maximum room temperature is comfortable, energy can be saved. See also: adaptive approach question 17.
  - Ventilation: A heat (or cold) recovery system concerning ventilation air will save energy.
- Visual comfort related
  - Daylight use: Daylight can be used to lower energy demand for lighting or heating. Shading can be used to lower energy demand for cooling since it can prevent overheating.

15. **What is the main drawback of simplified evaluation tools for, e.g., energy performance assessment for innovative sustainable solutions?**

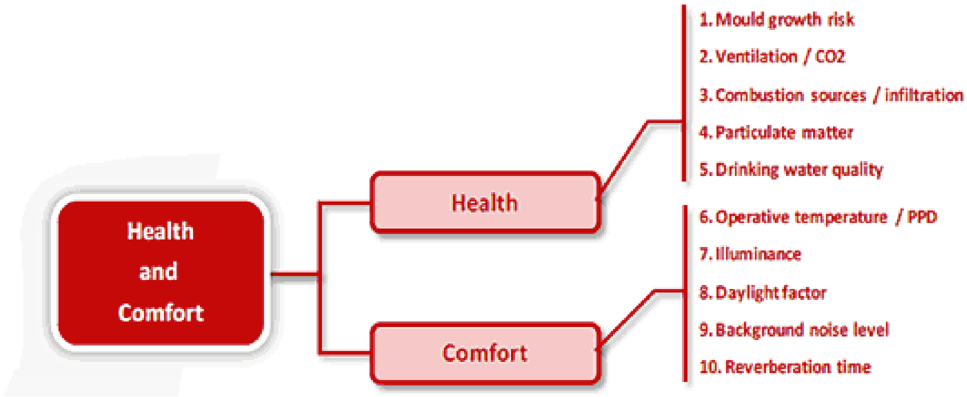
The main drawback is visualized in the graph below. Both overestimation and underestimation are risk in using a simple model. The alternative is, logically, to use a more detailed model.



Indoor environment

16. **In which main groups indoor environmental performance indicators can be subdivided, and give at least two examples of performance indicators for each group.**

See figure below (right column: examples).



17. **What indicators are available to assess thermal comfort in a building? (mention at least three). Why is the adaptive approach interesting from a low-energy use point-of-view for warm climates?**

The performance indicators used to measure the thermal comfort include air Temperature, Humidity, air motion and radiation.

- Thermal comfort (related to air temperature, Operative temperature, effective temperature, PMV/PPD, Asymmetric thermal comfort etc);
- Hygienic comfort (related to Ventilation; Indoor Air Quality, contaminant concentration level etc);
- Visual Comfort (related to illuminance, daylight usage etc); and
- Acoustic Comfort (related to sound pressure level, frequency level, reverberation time).

Adaptive approach: this system permits indoor operative temperatures of naturally conditioned offices spaces to slightly rise on hot days and can in this way lead to a reduction in energy consumption. This is due to the effect that the human acceptability of higher indoor temperatures is higher when outdoor temperatures are higher. The indoor temperatures are relatively cooler.

18. **Give some examples of ratings systems that currently are used to rate sustainability of buildings and describe which indoor environmental aspects are taken into account in these systems.**

- *Standard EN 15251:2007* (related to Energy Performance of Buildings Directive (EPBD)). Deals with: thermal comfort, indoor air quality, humidity, lighting, noise. Categorized in category I (high level, for fragile persons), II (norm for new buildings), III (acceptable for existing buildings) to IV (only acceptable for limited timespan).
- *Energy label*
- *LEED* (Leadership in Energy and Environmental Design)
- *BREEAM* (BRE Environmental Assessment Method)
  Deals with: visual comfort (natural daylight levels and glare control), indoor air quality (emission levels materials), thermal comfort (occupant control) and acoustic performance.
- *CABEE* (Comprehensive Assessment System for Built Environment Efficiency)

From AC-SET-document:

- LEED (Leadership in Energy and Environmental Design)
  - Sustainable sites
  - Water efficiency
  - Energy & Atmosphere
  - Materials & Resources
  - Indoor environmental quality

    - Innovation & Design process
- BREEAM (BRE Environmental Assessment Method)
    - Indoor air quality
    - Control of thermal environment
    - Natural daylight levels and glare control
    - Control of artificial lighting
    - Degree of occupant control over ventilation, temperature and lighting
    - General ambience and aesthetic environment
    - Acoustic environment
    - Scale of working spaces, which can effect degree of ownership
    - Social meeting areas, rooms and other amenities
- GreenStart (Australia)
- CASBEE (Japan)
- GreenCalc (Netherlands)
- GPR Gebouw (Netherlands)

19. Why should the indoor environment be taken into account when designing for low energy sustainable solutions?

Energy efficiency measures may have a higher rate-of-return when health, comfort and/or productivity is improved as well. In the figure below it can be seen that the energy-costs are way lower than the salaries-costs. So a company should not save energy at the expense of the indoor environment. Energy efficiency measures may have a higher rate-of-return when health, comfort and/or productivity is improved as well. Additionally, it is an important part of rating systems that assess sustainability of building designs.

20. What indoor environmental problems may arise if the only focus is at low energy design solutions? Mention at least one clear example.

One example is that illness and sick leave prevalence is much lower when the ventilation rate becomes higher. So indoor air conditions are more important than energy savings in this case. For instance in Amersfoort people developed chronic illnesses as a result of energy-efficient ventilation system in their homes.

Passive solutions (building/façade)

21. Provide a survey of design strategies for ecological value for the location level, the building level and the room level (each level at least 5 strategies with concrete examples);

Here, all design strategies are given, passive (○) and active (●).

Design strategies for location:

- Optimize solar exposure (passive energy for heating or active systems PV cells, solar collectors).
- Wind exposure (wind turbines, passive ventilation).
- Store energy seasonally (aquifer).
- Interlink energetically your building with surrounding buildings or industries that have a complementary energy demand profile (dwellings, factories etc).
- Geothermal energy.
- Availability of waste heat from utilities.

Design strategies for building level:

- Use outside air to cool (all air air-conditioning system, free cooling potential depending on diurnal temperature swing and project characteristics).
- Minimize energy transport costs (air water air-conditioning system).
- Transfer coolness of the night to the day (thermal wheel effect: night cooling combined with thermal mass).
- Apply thermal mass to reduce amplitude of temperature swing.
- Store excess energy in energy storage systems for delayed use for heating or cooling in a daily cycle (water, ice, PCM's).
- Minimize undesired heat flows through façade (U-value, Solar Heat Gain Factor, sun shading devices).
- Make properties glass variable (electrochrome or thermotrope glass).
- Reject heat gain from façade before entering room (climate façade, double skin façade, overhang, outside sun-shading).
- Determine optimum shape of the building (optimize between daylight usage, daylight systems, sun shading devices, façade type, compactness of building and application of energy production systems on façade or roof, orientation).
- Provide natural shading (deciduous trees).
- Incorporate wind energy (wind turbines integrated in building).
- Use solar energy actively (solar collectors for heating and cooling (absorption cooling), PV cells).
- Store energy seasonally (aquifer, chemical storage, water storage vessels, PCM's).

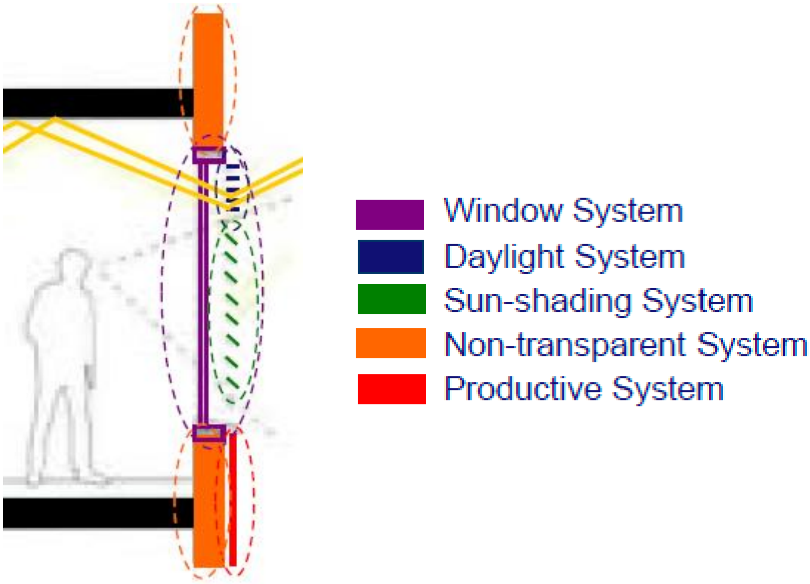
Design strategies for room level:

- Reduce internal loads (artificial light, equipment, transport).
- Reduce temperature difference between room air and temperature levels of terminal systems (large radiant surfaces) for high efficiency of generation systems (boilers, heat pumps).
- Low velocity air supply to the room (displacement ventilation).

Overall design strategies (to reach your design objectives for high ecological values one has to iterate as a designer between the following main strategies):

- Minimize energy flows (passive design).
- Co-ordinate and balance energy flows in the building or with surrounding buildings and industries or utilities (daily, seasonal cycle).
- Efficient comfort systems (thermal mass, radiation, high temperature cooling, low temperature heating, free cooling).
- Efficient generation systems.
- Local production of energy.

22. Give the five different functional systems in a façade and denote the basics of the physical processes that take place in these systems.



1. *Window system*: transmission heat losses, insulation, ventilation heat loss, cold air drop, thermal buoyancy (opwaartste druk) and air exchange due to wind.
2. *Daylight systems*: reflection, glass/wall ratio, light transmittance, daylight factor and light bending. Sunlight entering the building.
3. *Sun shading systems*: solar energy transmittance, solar heat gain coefficient. Controlling excess solar gain.
4. *Non-transparent systems*: temperature equivalent, inner surface temperature, sound level difference.
5. *Productive systems*: heat gain from sun, electricity generation. Utilization of solar energy in PV or vacuum tubes to generate electricity.

Optimize heat flow through the façade: For non-transparent components of the façades this mainly refers to low U-values (Thermal resistance; refer to use of thermal mass for optimum construction built-up) and air tightness. For the transparent components thermal resistance and air tightness is important, but also solar heat gains. Optimization is required with respect to the shape (see also built environment [location] level) and window-to-wall ratio (orientation dependent) as thermal resistance of transparent components generally is lower compared to opaque components. Solar heat gains from transparent components however may act positively on heating requirements and optimization of daylight use, whereas it may act negatively in case of cooling requirements. Sun shading devices, daylight systems are included in this optimization (relates to room level as well).

23. Describe the different façade systems that can be identified and give examples of sustainable solutions for each façade system. See also question 25. From AC-SET-document:

- Perforated façade: Cheap, solid, natural ventilation can be difficult according to circumstances (cold, windy). Use in low wind speed location and low noise.
- Elemental façade: High solar contribution, high transparency, prefabrication, cold air for natural ventilation, no external sunshade. Use in low wind speed location and low noise.
- Baffle panel: Less overheating, less natural ventilation. Use in medium wind speed location and medium noise.
- Alternating façade: Overheating in casement, high sound reduction, high cost. Use in high wind speed location and food air quality.

- Box window façade: Overheating in cavity, high sound reduction, shading. Use in high wind speed location and high noise.
- Corridor façade: Overheating in corridor, high sound reduction, extra space. Use in high wind speed location and high noise.
- Non-segmented double skin façade: Overheating in cavity, high sound reduction, high transparency, low natural ventilation (mechanical needed), sound transmission. Use in high wind speed location and high noise.
- Controllable double skin façade: No overheating in cavity, sound reduction controllable, high transparency. Use in high wind speed location and medium noise.

24. Give four different ventilation strategies of buildings with concrete examples and compare them in terms of basic value and ecological value.

1. *Displacement ventilation*

   The principle of displacement ventilation is shown in the figure on the right. Air is supplied at a low velocity at floor level. At heat sources in the room the air temperature will increase and will rise upwards due to buoyancy. The warm air is withdrawn from the room at the ceiling. Most of the pollutant sources in a room are also heat sources, and in this way are removed more effectively compared to mixing ventilation. Restrictions are given by the comfort requirements. Two factors are important, vertical temperature gradient and draught.

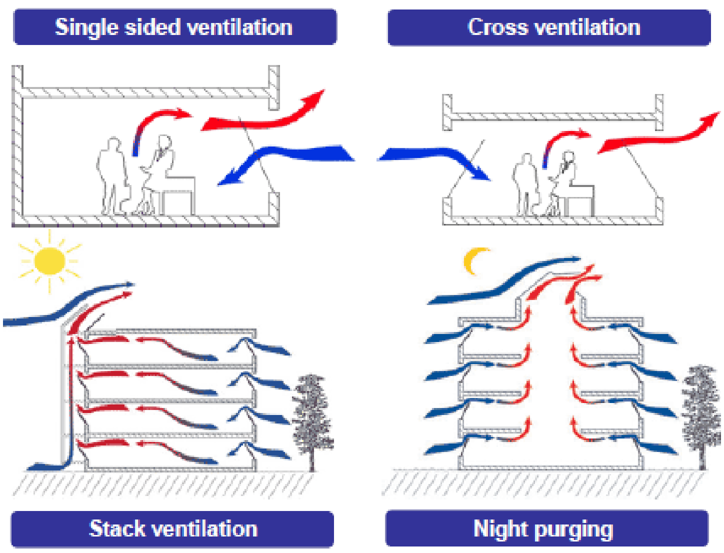
   Advantages: Less cooling needed for a given temperature in the occupied space because of the temperature gradient. Higher ventilation effectiveness, because of the large contaminant removal rate. Free cooling can be used in a climate with large day-night temperature differences.
   Disadvantages: Possibility of cold drafts along the floor. Wall mounte diffusers often require much wall space.

2. *Pure natural ventilation*

   Advantages:
   - Personal control/user satisfaction.
   - Extended bandwidth for thermal comfort.
   - No additional energy used for ventilation.
   - Night cooling possible.
   - No services room.
   - Limited maintenance.

   Disadvantages:
   - Less control on ventilation rate (air quality, heat loss)
   - Not possible in deep rooms.
   - Possibly not sufficient for high internal heat loads.
   - Sensitive to the outdoor environment (air quality, noise)

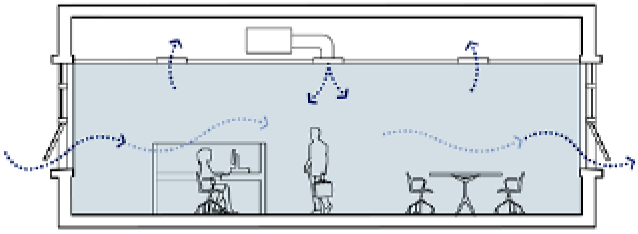
   Examples:



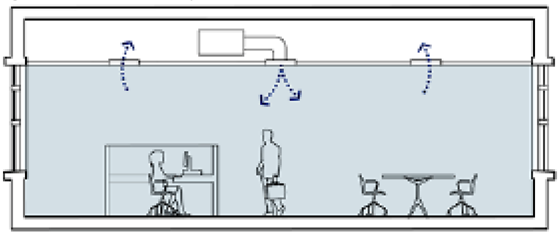
3. *Mixed mode*
Mixing flow ventilation is essentially a process in which the fresh air is directly and completely mixed with the air present in the room. As a result the temperature in the room is uniform and there is a minimal vertical temperature gradient. Air is normally introduced and removed at ceiling level and the interaction of upward warm air currents and horizontal supply air jets below the ceiling causes mixing and circulation to lower areas with relatively high air speeds. The cooling capacity depends on the temperature difference of the room air and the supplied air.

Advantages: Can be used in room with low heights and location of the inlet and return rills are not as critical as for displacement ventilation, but still require close attention.
Disadvantages: Lower contaminant removal rate than for displacement ventilation.

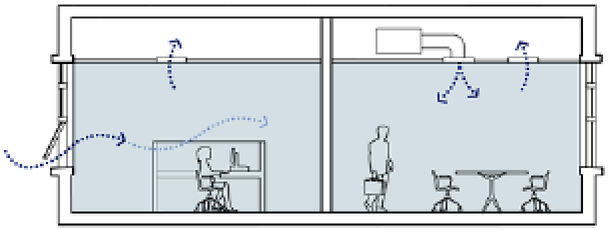
- Concurrent (same space, same time):



- Change-over (same space, different times):

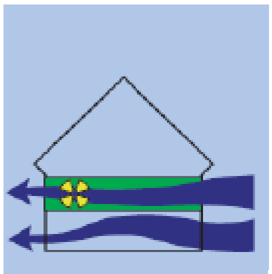


- Zoned (different spaces, same time):

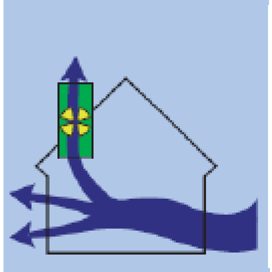


4. *Hybrid ventilation*
Hybrid ventilation systems can be described as systems that provide a comfortable internal environment using both natural ventilation and mechanical systems, but using different features of these systems at different times of the day or season of the year. In hybrid ventilation mechanical and natural forces are combined in a two---mode system. The active mode reflects the external environment and takes maximum advantage of ambient conditions at any point in time. The main difference between a conventional ventilation system and a hybrid system is the fact that the latter has an intelligent control system that can switch automatically between natural and mechanical modes in order to minimize energy consumption.

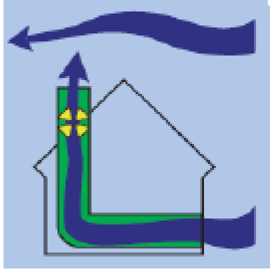
- Natural and mechanical ventilation (two autonomous systems switching/separate tasks):



- Fan-assisted natural ventilation (mechanical system assists to enhance pressure difference if required):



- Stack- and wind-assisted mechanical ventilation (mechanical system supported by natural driving forces with respect to required pressure):



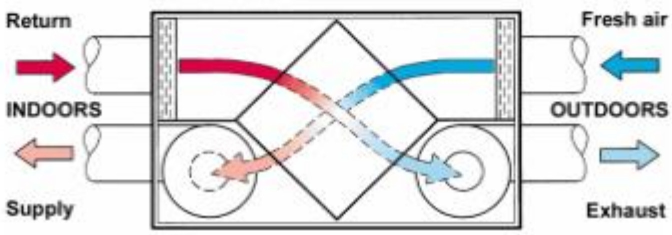
Advantages: It exploits the benefits of mechanical and natural ventilation systems.
Disadvantages: To make optimal use of this system an intelligent control system is required. Higher initial investment than a single ventilation system.

5. *Mechanical ventilation*

Example: balanced ventilation dwelling; heat recovery with and without bypass.

Advantages:
- Controlled and guaranteed flow rate.
- Air can be filtered before supply.
- Heat recovery possible.
- Control on indoor climate (T, RH).

Disadvantages:
- Energy required for air transport.
- Maintenance required for maintaining high air quality.



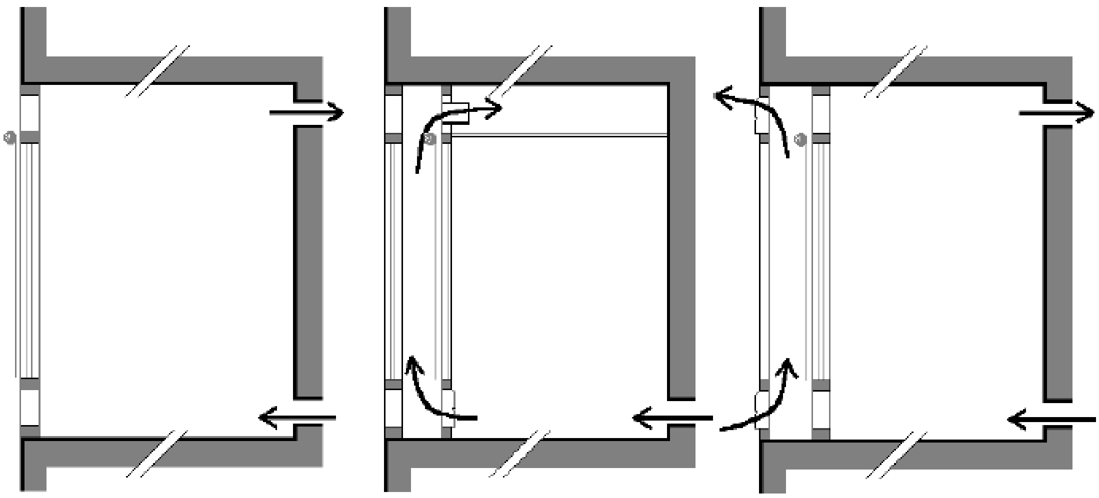
Comparison in terms of basic and ecological value: In terms of basic value, mechanical ventilation guarantees and gives the maximum comfort and control on air quality (Temp. and RH). So, mechanical ventilation is superior to other ventilation systems considering the basic value. However natural ventilation is the best alternative to reduce the energy required for ventilation so it is more advantageous to other ventilation systems in terms of ecological value.

25. What is a climate façade, a double skin façade and a traditional façade? How do they compare in terms of basic and ecological value?

Traditional façade:
Trivial. Simple design.

Climate façade:
A climate façade is built up out of 2 glass panels as a curtain wall, these panels are separated in a rather large distance (12” or more). Automatic sunshades can be installed in the space between the glass, this to avoid overheating, and can also be used to let sunlight in.

Double-skin façade:
Double skin façade also has 2 glass panels, but in that space between the panels, there is no sunshades installed, the ventilation system of the building extracts the air in the space between the panels. This space with preheated air (heat from the sun) acts as a buffer during colder times.



Traditional façade:

- Glazing provides thermal barrier between interior and outside.
- Shading device can be positioned at the inside or the outside.
- Opening of windows possible.
- Climatisation of the room is separate from the façade design.

Climate façade:

- Outer glazing provides thermal barrier between interior and outside.
- Inner glazing is single pane and is introduced to create a cavity between outer glazing and room.
- Shading device is positioned in the cavity.
- Opening of windows (outside) is not possible.
- Ventilation is part of the façade design as air is extracted via the cavity.
- SHGC ~ 0.2-0.3

Double-skin façade:

- Inner glazing provides thermal barrier between interior and outside.
- Outer glazing is single pane and is introduced to create a cavity between inner glazing and outdoor environment.
- The cavity may encompass several floors.
- Shading device is positioned in the cavity.
- Opening of windows (towards cavity) is possible.
- Climatisation is not part of the façade design; cavity is naturally ventilated.
- SHGC ~ 0.1

Comparison in terms of basic and ecological value:
Climate façade provides ventilation air (ecological). Double-skin façade has possibility to open window (basic value).

26. **What aspects of a climate do you need to take into account when building in a sustainable way and indicate for each aspect how this translates to the passive concepts that can be applied.**

From AC-SET-document: According to the climate, temperature and humidity are important factors. Especially, temperature variation during the day and year are important. By considering these parameters one could determine whether low mass or heavy mass will be used. Also, orientation and size of the building will be affected according to the climate. Moreover, shading equipment, utilization of sunlight will be designed according to the climate. For example, fixed shading is never used for moderate climate.

27. **Describe at least three passive measures that can be taken at building level and indicate the importance of these measures for a building located in the Netherlands (moderate climate) and a building located in Singapore (hot, humid climate).**

From AC-SET-document:

- Transmission Loss (Good Insulation in walls, floors and windows)(Also thermal bridges)(Compact building shape)
- Ventilation Loss (reduce airleakage)(Controlled ventilation)
- Solar Gain & Contribution (orientation of the building, overhang and use of green are important to control the solar gain)

Since during the winter, temperature in the Netherlands is decreasing below the 0 degree, transmission and ventilation losses are extremely important for the Netherlands. However transmission and ventilation losses are not that important for Singapore because the average temperature throughout the year is nearly constant and 26oC. Solar gain could be a problem for Singapore due to the excess heating in the summer. Also solar gain is important for the Netherlands climate to minimize the heating load.

28. **Which ventilation strategies at building level exist and indicate which strategies are best applied for a moderate climate when sustainability is of importance and why.**

See question 24. From AC-SET-document: Natural ventilation is the best choice for the moderate climate. It will reduce the energy required for the ventilation most so it is suitable for the zero energy consumption goal in the passive systems.

29. **What is the advantage of using phase change materials in a building. How does it work and what limitations are related to its use.**

PCM can reduce the home heating and cooling loads. PCM (phase change material) is a substance with high heat of fusion which, melting and solidifying at certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units. A limitation of PCM's is that the temperature at night should be lower than the melting temperature of the PCM, else it will not solidify and provide cooling during the day. Mostly in summer months, when cooling demand is the highest, nights are not cool enough to solidify the PCM and additional cooling is needed.

Solar energy

30. **What is a CSP system and give an explanation as to how it works?**

A CSP, or Concentrated Solar Power, system is a solar thermal system which uses reflectors (which follow the sun) to concentrate the light. Two types of CSP systems are parabolic-shaded reflectors and solar tower systems. There is a fluid that increases in temperature an typically a steam engine is used to produce electricity from heat.

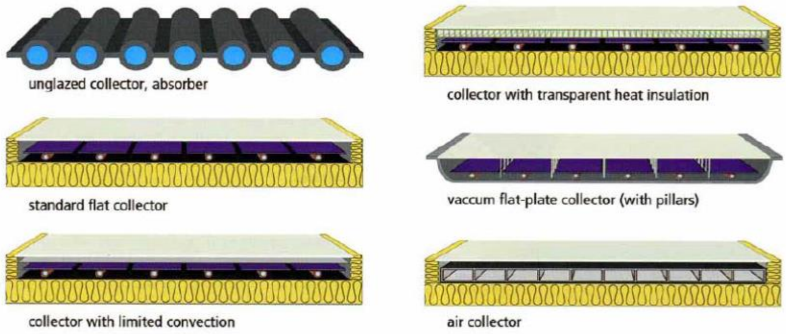
31. Give four important design aspects in optimizing the performance of PV panels in the built environment.

1. Shading of an individual cell causes an overall efficiency drop.
2. High temperatures of the cell should be avoided because the efficiency decreases with temperature. This can be done by active cooling systems (PVT: combination of PV and Thermal roof) or design in such a way natural convection is facilitated.
3. Orientation
4. Location (?)

32. What components play an important role in the overall efficiency op PV systems in the built environment?

- Cell efficiency. Typically (for single crystalline silicon solar cell) η = 15%.
- Invertor efficiency (DC from solar cell must be converted to AC electricity), cabling, switching and fusing. Typically η = 93% in total.
- Battery efficiency (if DC is stored for DC-devices to use indirectly). Typically η = 75%.

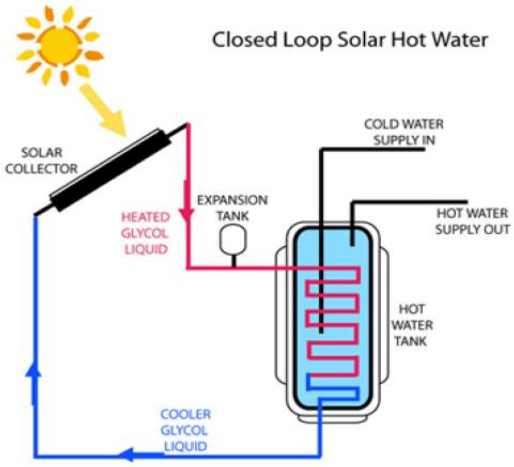
33. What types of solar collectors do you distinguish and what are the typical ranges of application in the built environment?



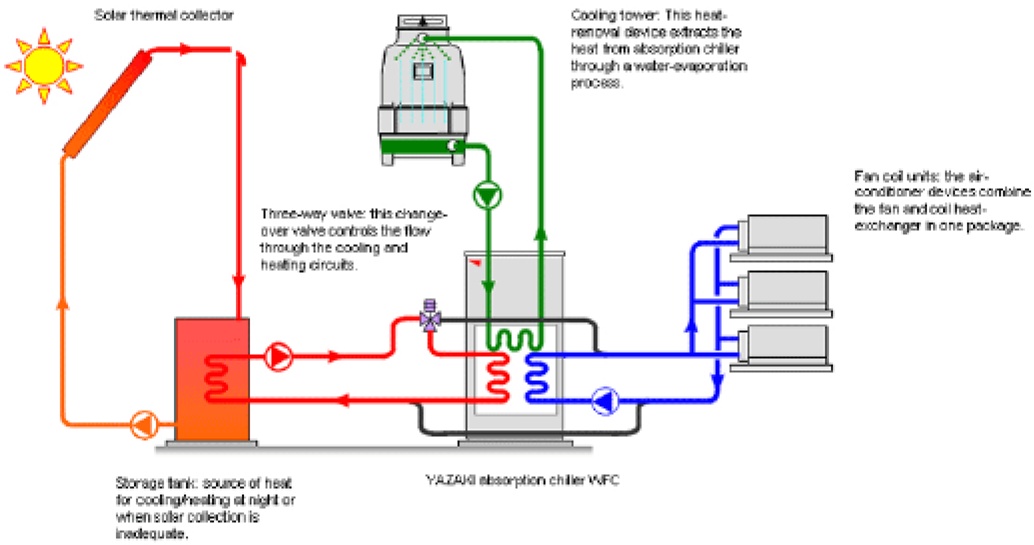
1. *Unglazed collector, absorber*: heat is collected by large area (not flat) of dark material and transported by water. It can be used on roofs and is very flexible, robust and lightweight. Heat losses occur due to convection.
2. *Glazed flat plate collector (or: standard flat collector)*: higher temperatures can be reached due to cover of glass (less convection). (40-60 degrees Celsius)
3. *Vacuum tube collector (or evacuated tube collector)*: even higher temperatures can be reached since there are no convection losses due to vacuum environment, and it will function also in cold environments. (80-100 degrees Celsius)
4. *Air collector*: same working principle as flat plate collector, only the heat transfer medium is air instead of water.

34. Show three system configurations of solar thermal energy systems with their working principles.

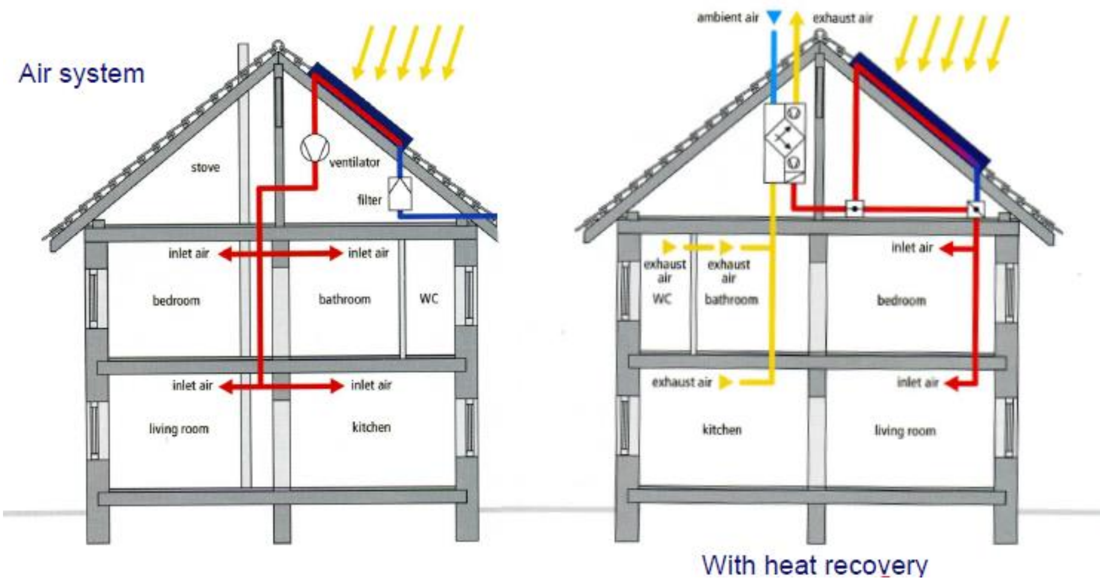
Solar thermal system:



Solar air conditioning:



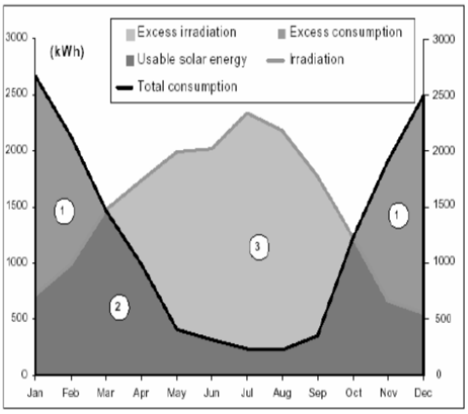
Air system (without and with heat recovery):



35. **What is the relation between the surface, the peak capacity and the annual yield, regarding the use of thermal solar system.**

36. **What does FSC stand for? Please explain its relevance in the design for efficiency of solar thermal systems.**

FSC stands for Fractional Solar Consumption, and is a way to evaluate the efficiency of a solar thermal system. FSC = 2 / (1+2); see picture of annual energy consumption below.



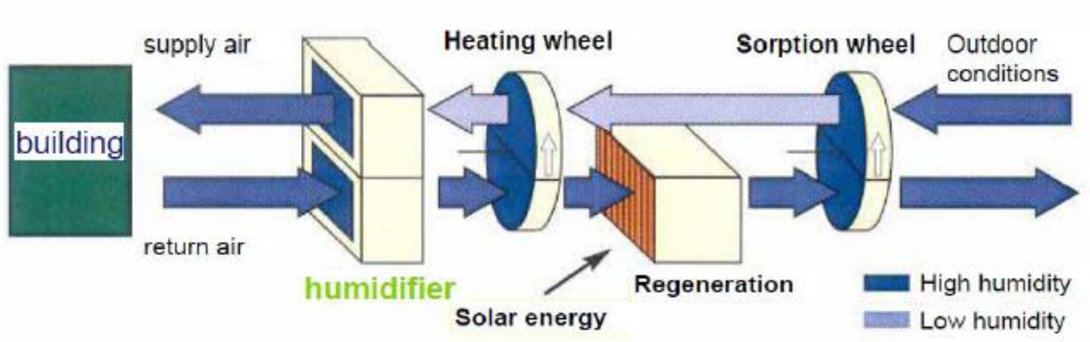
FSC is a dimensionless quantity simultaneously taking into account climate, the building (space heating and domestic hot water loads) and the size of the collector area, such that is does not depend on the studied solar collector system. FSC is calculated on a monthly basis by the following formula:

$$FSC = \frac{\sum_1^{12} \min(cons_{ref} \cdot A \cdot H)}{\sum_1^{12} cons_{ref}}$$

With A $[m^2]$ the solar collector area, H $[kWh/m^2]$ the monthly global irradiation in the collector plane, and $cons_{ref}$ [kWh] the monthly reference consumption without solar combisystem.

37. **Make a schematic of a DEC system and explain its working principle.**

Open sorption-assisted air conditioning systems are fresh air systems that dry the outside air through sorption, pre-cool it with a heating wheel and finally cool it to room temperature through evaporation-humidification. Solar energy is used to dehumidify the sorbent. DEC stands for Desiccant Evaporative Cooling.



Outdoor to indoor:

- Outside air is coming in at ambient temperature and with a significant relative humidity.
- The moisture is removed by letting the moist air flow through a sorption wheel, typically filled with silicagel.
- The air comes out with reduced moisture content and increased temperature, and is cooled down to approximately the indoor temperature in a heat exchanger.

- The actual cooling is generated by moistening this dry air in a humidifier, by spraying moisture in the dry air. The evaporation heat of this moisture is extracted from the air, resulting in a low air temperature.

Indoor to outdoor:

- Exhaust air is taken from the building and is humidified to its maximum capacity, thereby reducing the air temperature by extraction of the evaporation energy.
- This air is flown through a heat exchanger to cool down the incoming air that was heated (and dried) by the silicagel bed.
- Next, the air is heated by a solar thermal collector,
- and the hot air is flow through the sorption wheel, to dry the silicagel.

Active systems

38. Mention at least five low energy cooling techniques and describe how cooling is provided for.

- *Night Cooling / Natural Ventilation*: in this technique, cooling is mainly achieved by a controlled opening of the different ventilation openings such as windows. It is mainly effective by cooling the building mass during night time, and letting to store the excess heat in the building during day time.
- *Night Cooling / Mechanical Ventilation*: in this technique, the building will be provided with a selection of cooling options such as natural and mechanical night cooling. The building will be cooled depending on the type of features in the building such as wind towers, extracting air from the atrium etc.
- *Slab Cooling*: this cooling technique utilizes the building structure as energy store to absorb the excess heat in the room and often removed by night cooling. Water or air loops can be used as a cooling medium inside the concrete slab. The cooling effect can be assisted by different systems such as mechanical ventilation to provide displacement ventilation through the loops of the cooling system.
- *Evaporative Cooling*: Evaporative cooling can be used either as 'direct' in the supply air or "indirect". The principle in evaporative cooling is liquid will be evaporated by excess heat from the building, and thus the building will be cooled down. One application of evaporative cooling is supply air will be cooled by evaporating cold water in a cooling coils. Another application, as in the case of humidifiers, is the supply air can be cooled in air-air heat exchanger by humidifying the return air.
- *Chilled ceiling/Beams*: With this system the temperature is controlled by chilled water supplied to convector coils at ceiling/floor level. This cools down the room temperature.
- *Ground cooling*: ground heat exchangers with duct systems are used to cool down the supply air.

Other Examples:

- *Displacement ventilation*
- *Aquifer*
- *Sea/River/lake water cooling*

39. What additional information reveals the exergy concept compared to the energy concept? Where are the biggest gains to be found for the energy concept and for the exergy concept?

Energy can be neither created nor destroyed during the process: it can only change forms. The energy change of a system during a process is equal to the net work and heat transfer between the system and surroundings. Energy has quality as well as quantity. *Exergy* is the maximum useful work that can be extracted from an energy flow by bringing it to equilibrium with the environment. The exergy of an isolated system during a process always decreases or, in the limiting case of a reversible process, remains constant. In other words, it never increases and exergy is destroyed during an actual process. Exergy is also called the available energy. A system in equilibrium with the environment is said to be in the dead state, since it has no exergy.

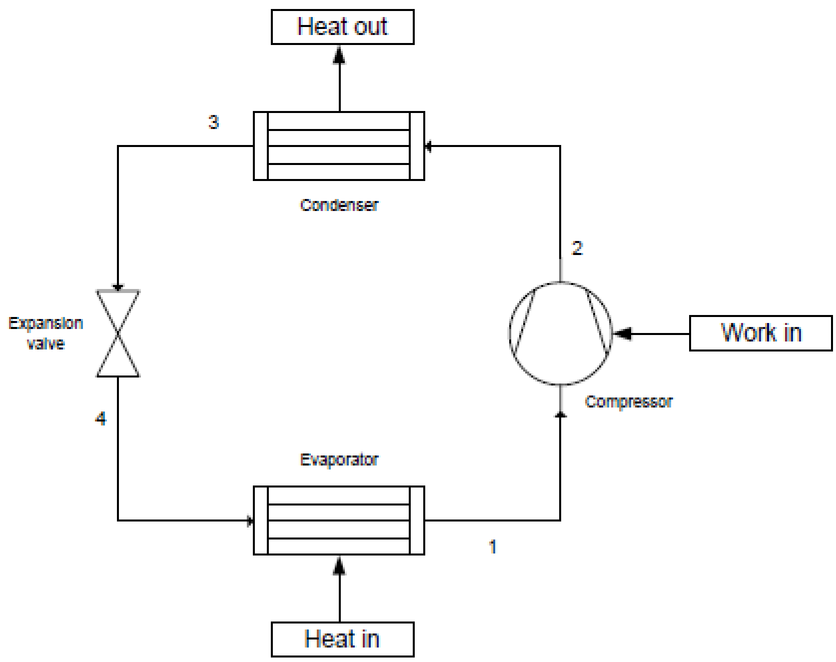
Extra info:
Kelvin-Planck statement: It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work. *Clausius statement*: It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body. The fraction of the heat input that is converted to net work output is a measure of the performance of a heat engine and is called the *thermal efficiency*. The *Carnot efficiency* is the highest efficiency a heat engine operating between the two thermal energy reservoirs at temperatures T_L and T_H can have.

40. Draw a simplified scheme of and describe the heat pump concept. Describe why it forms an important contribution to the use of sustainable active building systems.

An electrical heat pumps basic functioning is as follows (see picture):

1. Liquid is evaporated at low pressure (and therefore at low (ambient) temperature).
2. A compressor is used to increase pressure of the refrigerant fluid.
3. Under pressure, the liquid condenses, releasing heat.
4. An expansion valve lowers the pressure.

Its contribution to the use of sustainable active building systems is that it can promote low grade heat (from aquifers for example) to high grade heat.



41. How is the exergetic quality of heat defined. What is the Coefficient of Performance (COP).

Exergy is the maximum useful work that can be extracted from an energy flow by bringing it to equilibrium with the environment. The maximum exergetic quality of heat is thus the maximum work that can be extracted from the heat.

$COP_{Heat\ pump} = Q_H/W = Q_{condensor}/W = (Q_{condensor}/(Q_{condensor}\ Q_{evap})$

The Carnot efficiency is:

$$\eta_{carnot} = 1 - \frac{T_L}{T_H}$$

The COP of a heat pump is:

$$COP_{H,carnot} = \frac{1}{\eta_{carnot}}$$

The COP of a refrigerator is:

$$COP_{L,carnot} = \frac{1}{\eta_{carnot}} - 1$$

42. What are the main variables influencing the Coefficient of Performance (COP) of a heat pump.

See formulas above. The only variables influences the COP are T_{high} and T_{low}.

43. When applying an aquifer, an energy balance is required over a year. Which part (warm or cold source) is generally more difficult to obtain when applying an aquifer for an office building in the Dutch environment? Give an example of how this balance is corrected for.

The water in an aquifer is naturally low (about 8-10 degrees Celsius). So in the first place, an aquifer system is used for cooling (office buildings). The water is warmed up and pumped back into the ground again so the ground will heat up. It is essential to an aquifer system that also the heat is extracted from the warm well, because else the energy balance cannot be guaranteed to be stable. Unfortunately, the water from the warm well is not hot enough for heating (18-25 degrees Celsius), so a heat pump is needed to upgrade the temperature of the extracted water.

44. An aquifer is one example of a thermal energy storage (TES) system. Which three types of TES systems can you mention and give at least four examples of TES systems and indicate for these examples which storage period is normally related to it.

1. Sensible heat storage (c_p, ρ): best with large storage volumes to be placed, low costs, applicability and good storage capacities water.
    - Solar collector (diurnal)
    - UTES in aquifer / ATES (seasonal)
    - UTES in boreholes / BTES (seasonal)
    - Thermal mass (hours-diurnal)
    - Reduce start/stop of heat pump (hours)
2. Latent heat storage (T-range, k): best at systems with low storage temperature difference, or integrated in building elements, cost are higher. Very good storage but the thermal conduction is low.
    - PCM's, e.g. organics (water, fatty acids) or inorganic (salt hydrates); (diurnal)
3. Chemical heat storage: best with little possible room for storage devices to be placed, but are costly and still most in the demonstration phase.
    - Chemical reactions
    - TCM's, e.g. adsorption (silicagel) or absorption (salt hydrates); (seasonal)

Terminal systems

45. Which three types of terminal systems can be distinguished? Provide for each type at least two representative examples of terminal systems.

In a heating or cooling system, energy is generated or extracted and transferred to a certain distribution medium. This medium is distributed through pipes or ducts to a *terminal system* that delivers the energy to the room of a building. Three types can be distinguished. The boundary conditions for choosing a terminal system are required heating/cooling demand, outdoor climate conditions and thermal comfort requirements.

Water systems	Water/air systems	Air systems
Floor heating / cooling	Fan coil system	Displacement ventilation
Concrete core conditioning	Induction units	Mixing system
Climate ceiling	Ceiling induction unit	Natural convection
Low T convector		Hybrid ventilation
Chilled beam		

1. Water systems
   - *Concrete core activation* is used as heating or cooling system. In concrete core activation system; the concrete is used as heat storage mass. Flexible pipes will be incorporated in the floors of the building, and circulating water through these tubes will keep even temperature in all rooms of a building. The principle is high Heat in some areas of the building will heat the ceilings and is absorbed and slowly and evenly given off to the whole building by the circulating water. During cooling, cold water will be circulated through the pipe system, the concrete is cooled down and the heat is withdrawn and transported from the rooms.
   - *Radiant Panel Heating* is the using of radiant panels for heating the buildings. Radiant heating panels are installed in the floor (for flooring heating), wall (for wall heating) or ceiling (for ceiling heating), and a radiant energy is used to heat the room/building.
   - *Chilled ceiling, Chilled beam*: these systems have the same principle. In chilled ceiling panels, panels are installed in the ceiling, so these panels will interact with the surrounding room air to achieve convective effect, thus it will cool down the air in the room. In chilled beams, cold water will flow through the panels so it will collect the heat in the room and dump outside the room. During cold time, the reverse will happen; hot water will dump heat into the room. The water in these chilled beams will be heated/cooled by a separate system outside the room.
2. Air/water systems
   - *Convectors*: use convective devices to heat/cool the incoming air. A convector heater is a heater which operates by air convection currents circulating through the body of the appliance, and across its heating element. This heats up the air, causing it to rise and being replaced by colder air, and thereby creating natural ventilation, warming the surrounding area. A convection heater may have either an electrical heater element, hot water coil, or steam coil. Because of the natural ventilation, these systems are quieter in operation than fan heaters.
   - *Induction devices*: uses centrally preconditioned supply air and it is conducted through ducts to induction devices. The main purpose of these induction devices is to remove and cool the air from the room and increase cooling output.
3. Air systems
   - *Displacement ventilation*: is buoyancy driven “displacement” process; fresh ventilation air is introduced at low velocity and at low level and displaces upward by buoyancy effect and thus heat gains and contaminants are ‘displaced’ towards the ceiling.
   - *Air coolers (Re-circulatory)*: in this system, air is extracted by fans, cooled in water-operated cooling register, and blown back into the room to re-circulate.
   - *Air Conditioning Systems*: in this system, centrally cooled and dehumidified air is supplied into the room.

46. Which heat transfer mechanism is to be preferred when designing low energy buildings and why? Give an example of a terminal system that relate to this mechanism and adheres to the response of the first part of the question.

Literally copied from reader section 8.2 Sustainability, but not a sufficient answer:

In general, terminal systems do not use the energy; they only transfer it to the room. Therefore, terminal systems are not always taken into consideration when looking at sustainability. but, terminal system can be the link to better application of renewable sources and therefore to a higher economic feasibility.

A heat pump is more efficient at small temperature differences. Therefore, a terminal system with a low working temperature for heating can help improve feasibility. Also, when looking at energy reduction, natural ventilation or hybrid ventilation can have positive effects, especially when combined with free cooling.

From AC-SET-document: Convective heat transfer is preferred when designing low energy buildings. This is because, in low energy buildings, the terminal systems mostly work on water system, air system or a combination of air and water. In these mediums the main heat transfer mechanism is convection. Additionally, the heat sources used in the low energy buildings are usually low energy/temperature intensity, and thus the appropriate heat transfer mechanism for the above mentioned mediums will be convection. Due to this reason, most of the existing terminal systems in low energy building applications are basically working by convective heat transfer mechanisms. To mention as an example; Heating panels (under-floor, wall heating, ceiling heating) mainly by radiation and convective; Flat radiators – mainly by radiation and convection; Chilled ceiling panels –by convective heating/cooling; Chilled beams - by convective heating/cooling; Displacement ventilation – by convective; Induction devices – by convective; Air coolers – by convection; Convectors by convections; Indirect (combined) systems such as Heat pumps – support by convection; and Fan coils – mainly by convection.