4.2.8 Energy processing

"Energy is the property of matter and radiation that is manifest as a capacity to perform work".[345]

Energy can neither be generated nor destroyed. Basically, all types of energy can be transformed into another. In all energy exchanges, if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state, but total energy remains constant. Heat energy increases constantly. Energy has the tendency to move from usable forms to non-usable forms, from higher concentrations to lower, and from ordered state to non-ordered state. Energy transformations reduce the amount of energy available to perform work.
Energy efficiency in biology is discussed earlier in the chapter on nature's design principles. Energy processing was discussed in the classical criteria of life section.

Just as in living organisms, architecture is open to energy exchange with the environment. The flow of energy in and out of a built environment is controlled in order to avoid unwanted side-effects. The methods of control depend on the kind of energy, and can be passive or active (the same can be said about material flow). Ecological design deals with energy efficiency in the built environment.

Forms of energy

Forms of energy affecting the built environment are: material bound energy, which - apart from fuels - is not available to perform work; kinetic energy; light; heat, which is less useful because its use in buildings is limited, and electricity, which is the most universally available and useful form of energy for the built environment.

Material bound energy

Building materials (as all other materials) contain so-called embodied energy. Chemically bound energy, which was needed for generating or producing the material, is one part of the embodied energy, which also includes energy used for processing and transporting the material. The terms "primary energy" and "grey energy" are used synonymously.

345 New Oxford American Dictionary, program version 1.0.1, 2005

Fig.253 Reflection mirror on the façade of the Hong Kong and Shanghai Bank, Hong Kong, Foster 1986.

There are many different methods for the calculation of embodied energy, and so different sources in literature include different values for the embodied energy of building materials.
Nonetheless, general advice is possible: heavy material should be sourced locally, as much more energy for transportation is needed than for lightweight material.
Aluminium, for example, contains a huge amount of chemically bound energy, consumed during processing, but transportation costs are relatively low.[346] The recycling potential of aluminium is excellent, so the material bound energy is not lost with the end of the building. Architects cannot usually influence the processing methods of materials, but they can influence economy and ecology by selecting materials that do not contain high amounts of embodied energy.

Light energy

Input of solar light, the main source of light in buildings, has to be controlled to avoid overheating and unwanted reflection and glare. Technical systems exist to enhance the flow of light deeper into buildings and thus enable larger buildings, which is more cost effective. Reflection and light conduction elements are common today in large-scale buildings, and is now also starting to be found in individually built houses.
Solar radiation carries a large range of frequencies of light energy as well as heat. This problem is met by new specialised types of glass, which are spectrally selective and can block ultra violet light (which has a damaging effect on interiors) as well as infrared (heat transmission). The production of glass fibre light ducts has also contributed to the separation of light input from heat entry.

346 Edwards, B.: Rough guide to sustainability, 2005, p.122

In spite of these developments the separation technique is not yet universally available, as the materials involved are still expensive.
Photovoltaic systems transform sunlight into electrical energy. Photovoltaic films and organic solar cells will soon be common as a functional surface on glass panes and building façades. "Energy harvesting" by exploiting solar energy is one of the keys to sustainable energy use in architecture.

Heat

Thermal energy is transferred by convection, conduction and radiation. Built structures soak up solar heat energy, and exchange thermal energy continuously with the environment.
Heating and cooling to maintain thermal balance are the largest factors in a building's energy consumption. According to the climate zone and building use, the comfortable internal environment differs from the conditions prevailing externally. To overcome the difference between inside and outside temperature, input of energy in form of material, electricity or hot/cool media (water, steam, air) has to be provided. Specific infrastructural elements are used to carry the heating or cooling media. Integrating low temperature heating systems in floor and wall areas is considered to be the best solution for constant temperature distribution and thus comfort. To prevent the equalisation of the temperature difference (attaining the "natural" balance), insulating material has to be used for the elements and layers that make up the boundary between inside and outside of the building.
Warm water is another essential resource needing energy. In developing countries the energy for cooking is still provided by the burning of any kind of available organic material. The huge volume of material used for this purpose corresponds to the equivalent amount of energy needed for this basic function, which contributes desertification in arid regions.
Superfluous, or "lost", heat of buildings is dispersed into the surrounding environment. On an urban scale, the thermal energy produced adds to the storage effect which occurs with any massive built element, resulting in the phenomenon of so-called urban heat islands.
The interrelation between light and thermal energy input into a building is solved with especially high architectural quality, but with considerable planning and execution effort in Renzo Piano's project in Houston, US, called The Menil Collection.

Fig.254 Panel production for Menil Museum, Houston, Texas, Piano 1986,

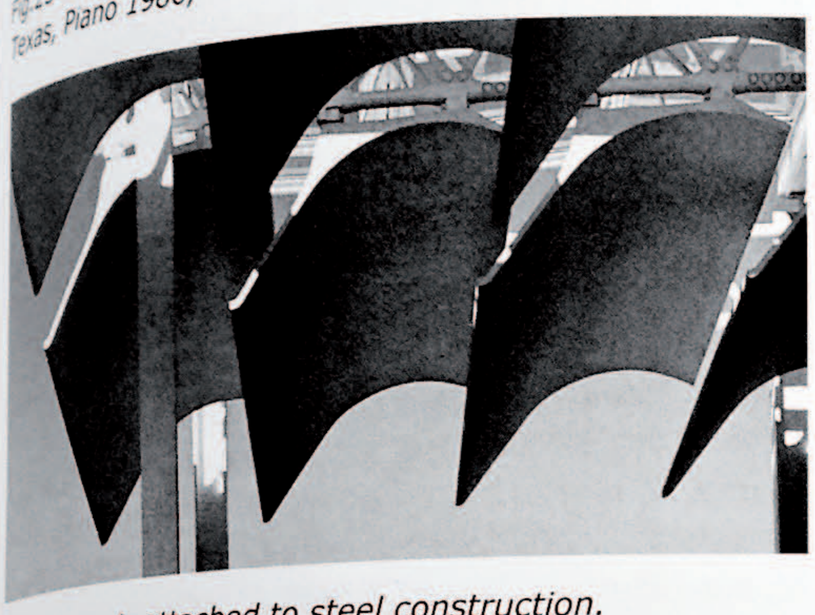
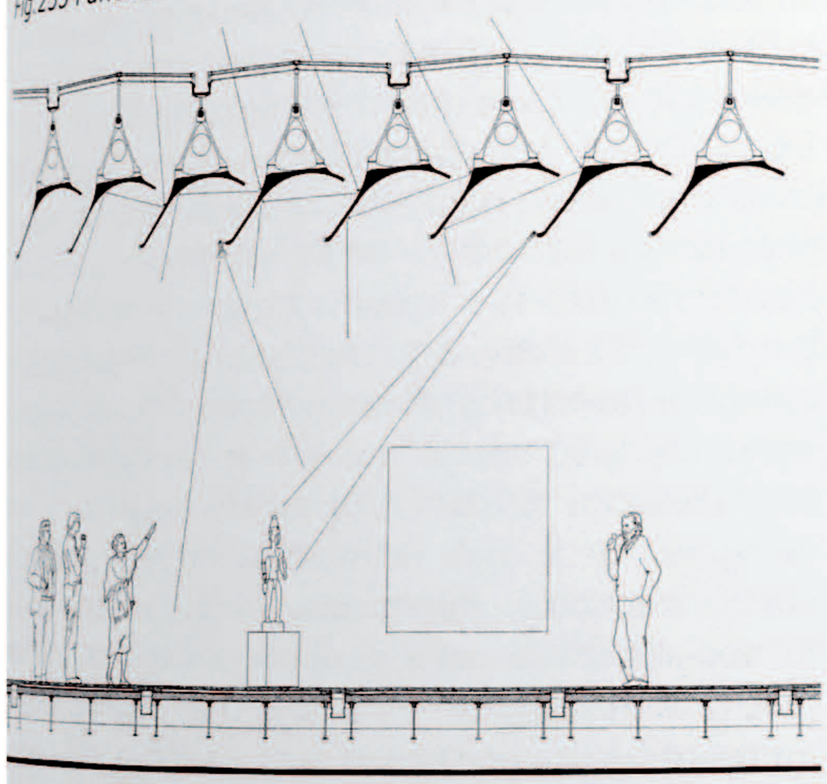
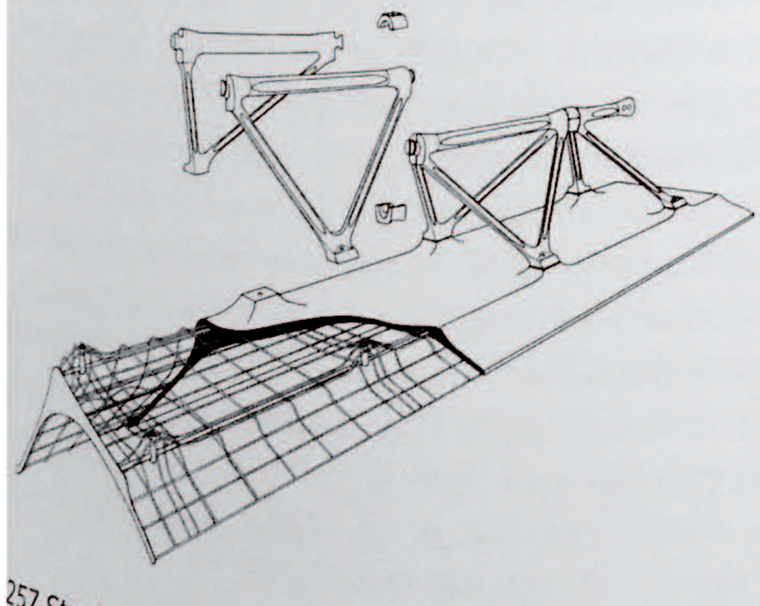


Fig.255 Panels attached to steel construction.



g.256 Detailed cross-section of the museum.



257 Steel construction and fixing of the panels.

Fig.258 Menil Museum in Houston, Texas.

- **Renzo Piano: The Menil Collection, Houston, Texas 1986**

Renzo Piano has been investigating new spatial structures and new materials for decades. He became famous together with Richard Rogers for their design of the Centre Pompidou in Paris in 1971-1977. The optimised constructive design of his buildings recalls constructions and forms from nature.

The Menil Collection was completed in 1986, accommodating a private art collection. The challenge and precondition was to design a presentation space with natural light conditions.

The project was developed in collaboration with Peter Rice from Arup Engineering. Piano decided to utilize reinforced concrete elements for the roof. First sketches showed a direct constructive integration of the parts into the primary roof construction, and then the load bearing function was separated from directing the light. The primary construction is made of spatial steel trusses that are shaped according to their load, and the precast concrete panels that control the distribution of light and stabilise thermal conditions in the gallery. The heat that enters the building through the glass roof is partly reflected by the horizontal surfaces of the panels. They minimise downwards radiation and thus protect the gallery space beyond from the layer of warm air that is created below the glass roof.

Fig.259 Interior space of the museum.

The concrete panels are responsible for the directing of natural light. The design was carried out in collaboration with lighting experts and the owner of the museum. The modelling of the forms was carried out by a combination of light tests, structural analysis and architectural shaping. Prototypes were produced of glass fibre reinforced composites. A conventional glass façade is the outermost layer.
During implementation, it turned out to be difficult to find companies for the production of these sophisticated elements. Finally the production had to be carried out by a UK company which was familiar with the production of refined precast elements. The production process had to be tested and confirmed with prototypes, because no finishing was possible. A spraying method was used to produce the panels according the defined criteria for construction, form, surface structure and colour.[347]
The particular quality of light and the contact of the gallery's interior spaces with weather condition outside causes a notion of daytime for the visitors to experience. The control of light and the prediction of interior conditions in this sophisticated way could only be done by modern computational methods. Implementation took place from 1982 to 1986, and 15,000 pieces of art are shown in turn.

347 Rice, P.: Peter Rice, 1994, pp.87

Electricity

Electricity has become indispensable, as almost all of today's activities are connected to some kind of electric device. Operation of cities or a building's technical equipment, operation of all household appliances, work and leisure depend on the availability of electricity.
Electric energy is transformed into light, electromagnetic waves, heat and kinetic energy. It is the most common form of energy expended in built environment.
Electricity is provided by supply networks, which until recently used to be national monopolies in Europe.

Kinetic energy

Kinetic energy is used for transportation and for actuation in control systems. Potential kinetic energy is stored in a building (see the destruction of the World Trade Centre towers - the sheer assembly of a building contains potential energy).
Sound and wind are manifestations of kinetic energy, and represent another continuous input source for energy harvesting in architecture.
Sound is a difficult topic - it is needed for communication and information but is often disturbing. Sound is most important for spatial orientation, in the interior of buildings influenced by the flexibility and surface characteristics of building materials. Building mass and absorption passively decrease external and internal sound transmission. But architecture is still not usually designed for sound. Only when extreme emissions occur (airports, highways, industry...) or when a sophisticated sound environment is wanted (concert halls, lecture halls...) does sound become an issue for the design of built environment. Active noise cancellation is a new method of controlling noise through eliminating sound waves by adding the exact opposite sound waves or vibrations. It is applied in headphones and in HVAC systems, which have a simple sound geometry, and in the US experimental projects deal with the integration into architectural elements.[348]
Ventilation is a precondition for the availability of fresh air. The supply of fresh air is important on all architectural scales, but is technically enhanced only in the scale of buildings.

348 http://architecture.mit.edu/house_n/web/resources/tutorials/House_N%20Tutorial%20Active%20Noise%20Control.htm [11/2007]

Passive systems for natural ventilation rely on temperature differences created by differences in height, material etc., or the exploitation of wind energy.
Wind has recently been rediscovered as an energy source, wind power plants being subsidized by government bodies as alternative sources of energy. Wind energy can already be used on a regional scale, but it is not highly efficient (and technologically difficult as well - wind generators require fast moving elements and transformers, causing problems with sound and vibrations).
Strong aerial kinetic energy is felt more than heard. Feeling kinetic energy exerted on the human body by the elements (wind or water) is usually unpleasant.

Harvesting and transformation

On a global scale, energy is used for the production of building resources: materials. The industrial production of building elements and transport contribute to the energy embodied in buildings.
Energy is "produced" by the transformation of energy from natural sources into usable forms.
There are renewable and non-renewable sources of energy: fossil and nuclear fuels deposited in finite reservoirs are non-renewable. Furthermore nuclear, geothermal, solar, wind, hydro energy is all harvested from nature. "Alternative energy sources" are solar, geothermal, hydro, and wind energy. Decentralised harvesting of energy is more common in areas where supply chains do not exist or do not work properly (the wish for independence triggers decentralisation).
The "production", or more precisely the transformation, of energy takes place in power plants, and needs equipment. Facilities for the central production of energy are technically sophisticated, but at the same time part of basic infrastructure that we already regard as normal. Energy production facilities usually have a profound impact on the environment, as they either change the landscape considerably (hydroelectric power plants, regarded as one of the "cleanest" forms of energy damages landscape and ecosystems, as can be seen at the Three Gorges dam in China) or produce secondary impacts (e.g. toxic gases, nuclear waste). Storage and distribution facilities are necessary as well as buildings for the production of energy.
On a global scale, energy is also bound in matter, e.g. in traffic infrastructure. A continuous energy input is necessary to maintain our traffic network in the public space.

- **Energy transformation in buildings**

Depending on the source of supply of energy, transformation is most common from chemically bound energy to heat and electrical energy, and from electricity to heat, kinetic energy and light. In general, huge quantities of energy are lost in transformation due to low efficiency as - in contrast to many biological energy transformations - enormous amounts of heat is produced.
During a given timeframe, which corresponds to the state of the building, different transformations take place (planning, production, building, operation, dismantling, recycling): during the material production phase, chemical transformations occur; during the building phase, assembly prevails and kinetic energy is used and stored within the assembly; in the operational phase, electricity and thermal energy is used ("produced" on a large scale via kinetic/chemically bound or solar energy).
To sum up, energy processing on the building scale includes: embodied energy in the built structure - material and assembly, collection of solar energy and light, storage of energy (thermal energy within building mass and use of storage media, e.g. water), and input and output of thermal energy through different sources, heating and cooling, input of electricity for all sorts of uses and the use of kinetic energy for movement of parts and control systems.

- **Transport of energy**

The distance that energy travels is considerable. Supply networks have spread over almost all inhabited areas of the planet. Infrastructure for the transport of energy is important. Energy is transported via specific media embedded in large supply networks, controlled centrally.
Chemically bound energy is transported in pipelines or by ship, truck or train; electricity is easily transported over long distances in power cables.
Within buildings, it is again distinct infrastructural elements that transport energy. The thermal storage abilities of architectural elements and space are the only characteristics that appear independent of distinct infrastructure.

- **Control**

Energy in- and output in architecture is controlled whenever possible. Building energy management systems have been developed to control the flow of energy by processing information on energy usage and components that use energy, as well as environmental data. They represent a centralised method of control.