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Introduction

Sustainable building is currently a major trend in building design. It comprises structures and buildings which are environmentally friendly and do not consume energy and raw materials at a rate faster than they can be naturally renewed. This sustainability is essential to safeguard the future. Reducing greenhouse gas emissions, water pollution, soil contamination, while simultaneously conserving resources are issues which must be addressed as part of project development.

Anyone developing buildings for the future can find orientation in Figure 1 which illustrates the interdependencies in the eco-cycle.

This diagram shows the interaction between the outdoor environment, building structure, and services – depicting in poster format cold energy generation and the cooling of buildings.

In addition, buildings for the future are also those which are not adaptable to changing space requirements, organization and use structures, etc., they can also make intelligent use of the resources provided by the outdoor environment. The seasonal resources related to sun, light, rain, temperatures and humidity levels as well as green surroundings should be used as directly as possible, while individuals must be empowered to make adjustments according to their needs. If the outdoor conditions are such that, for example, direct natural ventilation is possible, it should also be put to use appropriately when mechanical, ventilation support systems, cooling systems, heating systems, lighting systems, etc. are shut down.

The same applies to solar heat recovery (spring, fall, and winter) and the use of ground temperatures for heating or cooling.

Sustainable building comprises a large number of factors which – as the eco-cycle shows – not only relate to the use of natural resources in the outdoor environment. The building, including its façades and roof structures as well as building elements and solar buffer zones, can make a significant contribution to minimizing energy consumption.

Active building technology complements the whole building project in a manner which assures thermally comfortable spaces to handle the extreme conditions of winter and summer by providing heating or cooling respectively.

The same applies to the ventilation of buildings when either there is no wind or when wind velocities, i.e. loads are too high. Active building service systems can be installed as conventional systems at reasonable prices or include high-tech elements which transform environmental conditions into resources.

The examples presented below show how natural resources can be used directly and indirectly in order to consume as little energy and natural resources as possible. As can be seen, the decision involves a mix of low-tech and high-tech approaches, for the use of natural resources can mean using both approaches which then complement each other.

Planning sustainable structures does not start with the building itself, it begins much earlier – when the urban planning concepts are developed.

Positioning and orienting buildings, putting in green spaces, forming wind channels to assure the passage of air through urban areas, limiting land requirements to a minimum and the exploitation of outdoor resources are central issues which urban planners should take into account. Figures 2 to 4 show an exemplary concept (Albert Speer und Partner, Frankfurt) of urban planning for the city of Chuongqing. As the figure shows, the city is located proximate to large bodies of water and features green spaces throughout to achieve dust reduction and an adiabatic cooling effect to improve the microclimate in the immediate vicinity of the building. In this city the prevailing winds are from the north (cf. Windrose), so that the building structures are developed to enable an adequate removal of pollutants and emissions. In addition, a large number of buildings are oriented so that they can exploit solar heat gain as effectively as possible.

1. Green spaces – improving the microclimate inside and around the building

Building in green spaces or using green spaces entails the influence of the building on its surroundings and the influence of the surrounding environment on the building. Figures 5 and 6 illustrate exactly these issues and clearly demonstrate that building with green spaces can be particularly exciting. Figure 5 leaves no doubt what the subject involves. The deciduous trees provide shade in summer for the building below them and permit ideal exposure to the sun in winter. The building is thus ideally supported by nature – shade and sunlight use correspond exactly to the building's needs as the seasons change.

Figure 6 shows an office complex (dvg, Hannover – architects Prof. Hascher and Jehle, Berlin), which is embedded in industrial size structures, on the one hand, and a park-type landscape in front of the building.

To operate the building naturally the park landscape was extended into the building and supplemented by a water basin, to cut down on dust and provide adiabatic cooling. Figures 7 to 10 show the planning approach and make plain that the structures positioned under the large glass roof which all year make use of what is practically a Mediterranean climate to get along on the least possible use of technical equipment. The building structures under the roof are heated directly by solar heat gain – heat energy needs are reduced by roughly 50 %. In summer the building is ventilated intensively by incoming air so that solar heat gains are directly vented out. Despite its high-tech requirements the building has a low-tech concept, since the design gives priority to using naturally available resources. The office structures' heating and cooling (building element cooling) systems are in fact merely support systems. The green space options inside the building must be carefully weighed for each location, since the halls as solar buffer zones rarely have temperatures below 0 °C. Depending on the building's orientation and air changes in the hall space, temperatures can be expected to be moderate (roughly 30 °C) in summer and substantially above outdoor temperatures in winter. Mediterranean plants are especially suitable since the temperatures in the halls, ventilated solely by incoming air, will approach 0 °C.

2. Wind – natural ventilation

Natural building ventilation relies on the prevailing winds at the location, nearby structures and their surface characteristics, the shape of the building and its surface structure.

Natural building ventilation becomes particularly interesting if these buildings are considered more or less impossible to ventilate naturally.

Buildings which have a maximum room depth of 5 x the clear height are generally considered suitable for natural ventilation. In general, large halls such as trade fairs, factory halls, etc. were previously only ventilated mechanically, and yet they can be designed to enable natural ventilation for long periods of time. Figures 11 to 13 show a trade fair hall structure (Hall 26, Hanover – architect Prof. T. Herzog, Munich), designed to be naturally ventilated. In this case, besides the exposure to wind and the positive and negative pressure areas on the hall structure, convectional air currents are also significant. The trade fair hall is generally ventilated by opening vertical wall surfaces (e.g.

gates, etc.) from below, i.e. the outdoor air enters at ground level. Due to negative shape coefficient, i.e. taking advantage of suction and thermal effects, the halls are ventilated upwards from the floor – the exhaust air is vented out of the peaks.

The halls are only ventilated mechanically during trade fairs, the air supply elements being designed as glass ducts at a height of 3 m and from which the cooled air sinks to the floor level of the halls, after which it begins to rise thermally. The relatively simple ventilation concept and the use of natural forces meant that merely one air supply element must be installed for every 75 m. In addition, this type of expanding air ventilation of the hall areas means that merely 50 % of the usually planned cool loads must be compensated. This made it possible to reduce the usual air quantities by half. Figure 14 shows a detailed view of a ventilation duct with additional hot air nozzles which are used if in the hall must be heated up quickly using recirculating air. Half of the supply air quantities and refrigeration capacity corresponds precisely to the requirements applied to ecologically sound buildings.

Formerly naturally-operated high-rise buildings may have been considered an impossibility, but now it has been shown that these buildings can be naturally ventilated to large extent if they are properly operated. The Parkhaven high-rise in Rotterdam (architects Kohn, Pederson, Fox, London) is a classic example of a building which can be sustainably operated. The building has apartments in the upper floors which can be extended downwards. In the center of the building a hotel is planned which can grow upwards and downwards, i.e. can be enlarged by adding on space formerly taken by apartments or offices. In the lower part of the building offices are planned which can grow upwards into the hotel area. So the point is to design a building in such a way that it can hold any service systems, in other words where any service systems can be put in.

Prevailing winds in Rotterdam, as in most of Europe, are west by south-west, and less commonly between north-east and south-east. The westerly winds are strong – average wind speeds are roughly 4 – 6 m/s.

The frequency distribution of the wind speeds enables a reliable estimate that natural ventilation of the building is ruled out for less than 600 hours a year due to excessive wind speeds, since the wind pressures would impact on the façades and thus, via the open windows, on the inter-connecting doors. The percentile frequency (approx. 12 %

of all the hours during the year) of high wind speeds is far less than other times during which natural ventilation is not practicable. This applies to winter operation when outdoor temperatures are under +5 °C and during the summer at outdoor temperatures above +25 °C (approx. 600 hours/a).

Familiar, already existing high-rises featuring a similar design support the assumption that on approx. 30 – 35 % of all the days of the year the building should be closed, during the remaining days the building can be operated naturally. The drawings (Figure 15) show the recirculation of air in the building and the overpressure and underpressure fields created on the surfaces. The building's shape with its soft edges for sufficiently large overpressure fields on the windward side, extremely high, negative shape coefficients are not created by the airflow around the building. When winds are strong, the double-layer skins of the façades clearly reduce wind pressures so that within the façade construction moderate wind pressures and speeds result which permit opening the inner façade elements for long periods.

Figures 16 to 18 show the individual use spaces and the façade designs as well as the supportive technologies for operating the building during the changing seasons.

A futuristic example of a high-rise structure using as little land area as possible is shown by Figure 19 – a workshop study by Prof. Richard Horden who holds the chair for Building Services at the ETH in Zurich.

The fictional building consists of large, glass bubbles, in which multi-story use structures are situated. These structures are extremely easy to naturally ventilate due to medium and high wind speeds and, due to the outer glass skin structures, they are ideally suited to make use of solar energy directly and indirectly. Rain water can be collected on the surface and be stored in a cistern to supply most of the water needed. The fictional design shows a structure which is sustainable in every respect and can be adapted to a wide variety of purposes.

3. Sun – natural heating – natural lighting

The energy potential of solar energy can be used passively and actively as in all buildings.

Passive solar gains are automatically provided by double-layer façades and wintergardens and clearly help to reduce overall energy needs in winter. Spaces behind double-layer façades or wintergardens acting as solar buffer zones use passive solar energy to reduce their heating needs by approx.
40 – 50 %.

Figures 20 and 21 show an educational center in Herne, near Dortmund (architects Jourdan et Parraudin and Hegger, Paris / Kassel), which was developed as a building within a building, to get along on as little energy consumption as possible. The building displays all the typical features of a sustainable structure, starting from the materials wood and stone to interior open spaces featuring green and water (adiabatic evaporative cooling effect) to an actively effective photovoltaic roof capable of meeting all the electrical needs of the buildings under the roof.

During the summer and transitional seasons, the building is opened by vertical glass structures in such a way that it is completely ventilated, i.e. the interior building structures use the outdoor air directly. In the winter the building is kept closed practically at all times, although an approximate
0.5 – 1 air change flows through the halls in this period which provides sufficient fresh air to the interior buildings.

BMW AG, Munich, intends to develop a building which will be a superlative embodiment of ecological building design. One approach (architects Coop Himmelblau, Vienna) shows in Figures 22
to 25 a structure which can be nearly continuously naturally ventilated in summer and in transitional seasons and whose operation relies heavily on the use of solar energy. The electrical energy generated by special, newly developed solar receivers can be used to produce hydrogen. The generation of heat energy is to drive the absorption systems as well as to heat the building itself.

Figures 26 to 28 show the principles of the system, while to perfect the concept even more rain water is used as gray water and ground heat or cold is used to cool the building.

The solar system in the cone of the building, when heat and electrical energy are used, capable of achieving an effectiveness of nearly 80 %. The extraordinarily high efficiency is finally achieved by the fact that heat energy is not released but used by absorption. Based on this, the amortization period for the overall system can be estimated to be approx. 12 years, so that this system can be exemplary for buildings in individual cases. While certain measures such as natural ventilation of the building, the design of envelope surfaces to avoid heat loss and the storage capacity of the building's structures can be classified as low-tech, the overall active solar technology, including hydrogen generation, is a typical high-tech issue.

4. Rain water – an interesting resource to use

The costs of drinking water and the disposal of sewage are increasingly significant from year to year, so it makes sense to consider using rain water. While Central Europe generally has sufficient quantities of water to supply drinking water, in many regions of the world there is already evidence that water tables are clearly dropping.

Figure 29 shows for what water is normally used these days. Acceptably hygienic drinking water accounts for a mere 3 % of total water consumption. Thus there is evidence that at least a large share of water needs can be met by rain water. The principal roof surfaces which can be considered for collecting rainfall are those which carry the lightest loads. Green roofs are particularly interesting because they prefilter the rain water.

The use of rain water to flush toilets i s familiar. Less familiar, but just as interesting under certain circumstances, is to use rain water for cooling purposes, i.e. to save refrigeration energy. Figures 30 and 31 show the central entrance hall of the Leipzig Trade Fair (architects von Gerkan, Marg und Partner) with a sus-pended glass roof structure, which is cooled in summer, fall and spring by rain water to lower the inner surface temperatures. The whole hall structure is also naturally ventilated in summer, fall and spring, the necessary air changes being assured specifically by convection currents.

Figures 32 to 33 show property owned by the Nürnberger Versicherungsgesellschaft, Nuremberg (architects Bifang und Bifang, Nuremberg), for which the architects wanted to include a pond for design purposes within the large court. In the course of the project this pond was designed to act as a reservoir of cooling water, which permits cooling parts of the building by active building cooling. Figure 34, beside the outdoor temperatures, the water temperatures and the prin-ciple of adiabatic cooling of pond water for use as cooling water inside the building. Figure 35 shows the replaceable technologies for using cooling water and, thus, for quiet cooling of indoor spaces without the use of refrigeration machines. That the use of this technology is limited is related to the size of the reservoir in relation to the size of the space to be cooled.

5. Exploiting shallow ground temperatures

The temperatures prevalent in the ground can be put to good use on many projects, sometimes also for the direct cooling of building structures. In this context it is important to check the temperature levels at various depths under the site, Figure 36, to assure the appropriate impact in relation to the season.

As a rule, indirect applications are put in place since they are less expensive. Indirect applications of geothermal potential are based on heat exchange between a heating medium or coolant and the ground itself. For pile foundations under buildings and, when the surface area under or around the building is limited, consideration can be given to drilling heat sinks (Figure 37) either to use the cooled water directly or, in connection with heat pumps, to raise water temperatures in winter for heating purposes.

Figure 38 shows a corresponding system with flat lines, heat pump and aquifer reservoirs, in which energy can be temporarily stored. Corresponding aquifer reservoirs can be sensibly installed under water. Figure 39 shows temperature curves in connection with underground pipes and their impact in relation to sink lengths for various outdoor conditions. Normally one can assume that in their first use in Central Europe, where prevailing ground temperatures are around 8 – 12 °C, an energy gain of approx. 60 W/lm sink is possible.

A direct form of ground cooling can be achieved by a thermal labyrinth. With this system, outdoor air is fed through underground ducts (e.g. between foundations), which warms the outdoor air in winter and cools it in summer. For roughly every 100 m of length, there is an approximate temperature increase or decrease of 3 – 5 K, with exceptionally long labyrinths the temperature of the outdoor air passing through approaches the ground temperature. Using thermal labyrinths, given the right circumstances, can supply a substantial share of the cold or heat energy which then need not be generated by refrigeration machines or boilers. This enables the desired effects of minimizing primary energy needs, the system meets the requirements for sustainable building.

Résumé

Planning sustainable buildings is more than just an interesting field and it should be worked on by all the parties involved in the planning. It is leading not only to new technologies but to new kinds of architecture as well, and the standards of sustainable building are gaining ground. The use of natural resources for buildings, in the end, is always dependent on the building itself as well – it must feature the relevant prerequi-sites to permit the use of renewable forms of energy. In this regard all those involved in the planning are called upon to deal increasingly with this subject if they want to make a contribution towards the future and help ensure that future generations will find a planet worth living on. Especially engineers in the fields of supplying buildings and disposing of waste can not only make an interesting, they must be part of the planning activities right from the start if a consistent, overall concept is to be the result. Fantasy and eccentric thinking are called for, while remembering low-tech concepts also assumes a
crucial role. In this spirit one can only hope that the trend towards building sustainable buildings, described at the outset, will continue on a more widespread basis.

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