Chapter 1
Energy-Saving Solutions for Five Hospitals in Europe

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Abstract This chapter is the result of a European research project developed by the University of Florence – Centro ABITA on adopting energy-saving strategies to reduce the annual energy demand in new and retrofitted hospital buildings. The research project, which is funded by the European Union, aims to apply energy-saving strategies, advanced technologies and plant solutions in five case studies in different climatic areas of Europe: Meyer Children’s Hospital in Italy, Fachkrankenhaus Nordfriesland Hospital in Germany, Torun City Hospital in Poland, Deventer Hospital in the Netherlands, and Aabenraa Hospital in Denmark. The research aims to demonstrate the significant opportunity to reduce energy demand in the European hospital sector, thereby contributing to a substantial reduction in CO₂ emissions. The main goal is the integration of strategies for energy efficiency in the hospital sector, in compliance with current regulations, improving environmental quality and ecosystems and promoting sustainable management of natural resources. Innovative strategies for the integration of renewable energies in buildings are combined with bioclimatic design to improve building control and management, upgrading energy efficiency, thermal control and comfort, natural ventilation, and daylighting. Moreover, the use of photovoltaic modules, high-efficiency heat pumps, integration with surrounding green areas, and the use of vegetation inside buildings are explored as opportunities to both reduce energy demand and improve patient comfort. At the end of the project, the researchers provide an overview of the results achieved on indoor comfort, energy savings, and CO₂ not emitted through the energy solutions adopted.

Keywords Energy • Environment • Daylighting • Energy savings • Renewable energies • Natural ventilation • Green roof
1 Introduction

Hospitals are energy- and resource-intensive buildings that contribute to climate change and to respiratory and other illnesses. The proper adoption of energy-saving strategies in the health sector can demonstrate a reasonable response to climate change, playing a leading role and supporting a healthy and sustainable future.

The implementation of sustainable energy systems is one of the principal objectives of the European Union’s (EU) energy policy, which aims to promote secure energy supplies with high-quality services and high environmental comfort. Moreover, Europe intends to build zero-energy buildings in the near future, and experiences in the hospital sector can be very useful for reaching these goals.

Research demonstrates that technological and plant strategies plus renewable energy technologies may be used with very positive results in the European healthcare building sector and in this way encourage the integration of renewable energies. This chapter aims to illustrate the reduction in energy consumption and the comfort achieved from the adoption of energy-saving and bioclimatic-design solutions, as well as the resulting reduction in CO2 emissions quantified in five case studies.

2 Objective

Energy efficiency reduces hospital energy consumption and costs. Hospitals designed on the principles of green building are responsive to local climate conditions and optimized to reduce energy and resource demands. Alternative energy generation produces or consumes clean, renewable energy on site to ensure reliable and resilient operation. Transportation involves the use of alternative hospital vehicles (such as electric vehicles). In addition, energy efficiency encourages walking and biking, promotes the use of public transport by staff, patients, and the community, and minimizes the need for staff and patients to use transportation by optimizing hospital routes, and encourages people to reduce, reuse, recycle, compost, use alternatives to waste incineration, and conserve water.

Standard operating procedures for most hospitals require significant energy use, such as for heating water, regulating temperature and humidity for indoor air, and controlling lighting, ventilation, and numerous clinical processes, all of which entails significant greenhouse gas emissions. Hospitals can implement many measures to improve energy efficiency while satisfying the energy requirements of these important energy-consuming end uses.

Using combined heat and power (CHP) technology, for example, facilities can generate onsite electricity and capture waste heat from the generation process as thermal energy. This can double energy efficiency by eliminating losses associated with the grid delivery of electricity. For artificial lighting LED light bulb can reduce energy consumption. Two principal objectives adopted in the case studies are:
Conservation, reduction, and control of solar radiation;
Provision of natural ventilation and natural cooling of external building surfaces by evaporative cooling.

3 Methodology

The adopted bioclimatic and technological design approach covers a range of strategies to save energy in buildings. What follows are some strategies adopted in accordance with local climatic conditions and with specific patient requirements:

- Building orientation and form
- Green building design
- Building envelope and materials: glazing and double-skin façade
- Envelope insulation
- Integration of renewable energy photovoltaic (PV)
- Green roofs
- Rational use of water
- Daylight strategies
- Appropriate shading devices
- Innovative bore holes

The five case studies examined here, with specific applied strategies, are as follows:

Italy: Meyer Children’s Hospital, Florence. The designed hospital creates a healing environment for patients and landscape as well. The hospital has abundant open spaces that are airy and bright and have high ceilings, which creates a comfortable place and peaceful setting for young patients and their families. The hospital is well integrated with the surroundings by a greenhouse, landscaped roofs, skylights, open buffer spaces, and an energy-efficient hybrid ventilation system. To monitor and conserve energy, the hospital design also includes a building energy management system and light tubes that create natural light throughout the building. The hospital consumes 40% less energy for heating and cooling and electricity than a standard newly built Italian hospital (Figs. 1.1 and 1.2).

3.1 Technical Solutions

Envelope insulation: external façades and roofs have an adequate U-value (0.32 W/m² K for external walls and 0.26 W/m² K for the roof) that is low enough to reduce as much as possible energy losses; they also have an adequate thermal mass (thermal lag is approximately 10 h) to reduce summer overheating on exposed surfaces (southern, western, and eastern exposure) (Figs. 1.3, 1.4, and 1.5).
Windows and shading: The windows are constructed with wooden frames. Patient rooms are protected from direct sunlight by an overhanging structure externally covered with copper plates to reduce the visual impact of the building in the park, with the internal surface covered in wood. The greenhouse is shaded by internal white blinds that are adjusted by an automatic control system.

Fig. 1.1 Aerial view of green roof of Meyer Children’s Hospital

Fig. 1.2 South façade of new part of building
**Fig. 1.3** Northern corridors and greenhouse

**Fig. 1.4** Solar pipes and skylights
Sun pipes and light ducts: To improve patients’ well-being, an important aspect is to provide daylight and positive surroundings, with plenty of sunshine and high thermal comfort levels. Sun pipes are installed to achieve a good illuminance value in patient rooms. Each room accommodates two patients and has two windows, one facing outside (surroundings) and receiving daylight, the other illuminated by sun pipes. Solar tubes and roof lights in hallways provide a good amount of daylight.

Heating: Heat pumps are used to generate heating and cooling. These are appropriate where both summer cooling and winter heating are required. Radiant panels and high-efficiency boilers are used for the heating system. Radiant floor heating panels are installed in patient rooms, where a decent level of thermal comfort is achieved at low energy cost. For winter heating and domestic hot water (DHW) generation there are two boilers, condensing combi boilers with an efficiency of approximately 106%. The boilers use gas, not electricity. Another conventional type of boiler kicks in only when necessary.

Cooling: For summer cooling there are two electric chillers. A third chiller is of the water/water type: the heat generated from this last machine is used for DHW.

Ventilation: Ventilation is guaranteed by windows that move up and down and open manually. A combination of shading and ventilation systems can keep indoor temperature to within 10 °C under outside temperature. To save on cooling energy, passive cooling and ventilation techniques are used as much as possible with air conditioning only where necessary. Glazing adopted for the greenhouse has a very low U-value, 0.78 W/m²K. This type of glazing reduces transmission losses and the greenhouse effect.

Photovoltaic: Meyer Children’s Hospital’s PV greenhouse is a structure with southern exposure and unobstructed solar access to the main solar glazing of the
greenhouse to maximize winter sunshine; it is not only a particular type of structure but also, and more importantly, a particular kind of space. The design considered not only energy and environmental aspects but also social impact: the primary objective was to create a pleasant and “socializing” space that could be used for semi-outdoor activities throughout most of the year with no extra energy space, a social space well integrated into the adjacent green park. The PV system is 30 kWp and realized with glass/glass PV modules.

Cogeneration: The design of the cogeneration plant is formed by a gas turbine, with an electrical power of 7.5 MWe (ISO), which allows the use of self-produced energy in the hospital complex.

Energy performance: The performance criterion was to achieve a 40 % reduction in consumed energy. The results of energy consumption are presented in this section and derived from simulation, calculation, and monitoring. Specific energy consumption targets were as follows: lighting sun pipes and roof lights in corridors and halls should provide a good level of daylight, and all installed lamps should be high efficiency.

The total annual electricity demand is 12.3 kWh/m². Compared with the energy demand in which all these features are not applied, the energy saving is 35 %. As for heating and cooling, the internal temperature and relative humidity measured during the monitoring phase are in accordance with simulations. The insulation used in walls and the roof gives energy savings of 35 % for heating and cooling. The annual heating demand is 73.4 kWh/m², and the annual cooling demand is 87.3 kWh/m². Regarding DHW, during the summer period, two chiller machines are used to cool the hospital. The heat produced is used for DHW. The annual heating for DHW demand is 13 % less than in a conventional Italian hospital. A cogeneration plant was not considered for energy performance because it must be completed. Project by: CSPE Architects, ABITA Unifi for technological strategies and renewable-energy strategies. Fachkrankenhaus Nordfriesland Psychiatric Hospital, Germany. The hospital is located near the North Sea and specializes in psychiatry and psychosomatic disorders.

Achieving superior indoor air quality is a priority in this psychiatric hospital. The designers’ emphasis on healthy, low-emission materials was a response to the hospital administration’s belief that indoor air quality improvements would markedly improve the treatment of patients with environmentally related illnesses.

Innovative strategies were adopted primarily to improve comfort, daylight conditions, and indoor climate for users of the buildings and secondarily to reduce energy consumption and CO₂ emissions. River- and rain-water-capture techniques, a solar mass wall with transparent insulation, a double-skin façade, and emission reduction are key performance indicators. Innovative and natural sources are used to minimize the use of metal in living rooms. Moreover, by improving daylight conditions, the need for electricity in the living rooms is consequently reduced, and the use of transparent insulation on the outer wall increases comfort inside the building. In parallel, energy consumption is reduced. Moreover, environmentally sensitive patients receive 100 % organic foods. Special attention is given to windows, which are treated as multifunctional building components with respect to all
the different parameters affecting indoor climate and energy consumption with a double-skin façade.

Double-skin façades with integrated natural ventilation and passive cooling are used in the glass façades facing east and west. The system was created to be used in different ways depending on the time of year and the weather. During summer the glass can reflect solar radiation and work jointly with a system of lamellas to provide shade from the sun. During winter the system is closed, thereby keeping hot air inside the buildings. The double-skin façades improve the daylight conditions and lead to reduced electricity use (Figs. 1.6 and 1.7). The hospital’s renovation was guided primarily by energy conservation concerns, innovations in material selection, and careful attention to ventilation.

Energy description: emission reductions are as follows: CO₂: 261,740 kg CO₂/year, SOx: 230 kg SOx/year, NOx: 2 kg NOx/year. Project by: Architect S&I Arkitekter A/S.
4 Deventer Hospital, Overijssel, The Netherlands

Deventer Hospital is a 380-bed hospital with specialty clinics for psychiatry and radiation therapy. The energy savings in the new hospital are 47% on heating and 13% on electricity compared to a standard hospital. This reduction in energy use is equal to 1299 tons of CO₂ per year and is accompanied by an important reduction in related emissions like SOx and NOx. The project design focuses on energy efficiency, with energy-efficiency measures that result in annual emission reductions of 1.943 tons of CO₂, 8.71 tons of SOx, and 3.35 tons NOx. This is a reduction of 69% compared with the average Dutch hospital. Patient comfort is guaranteed by the location of single-, double-, and triple-patient rooms away from public waiting rooms and high-traffic circulation areas and by improving patient access to daylight and views.

The roofs are partly covered with vegetation. Window frames are made of hard wood. Heat and cold storage is applied using a heat pump and concrete core activation for low-temperature heating. Heat is also recovered from ventilation air. Outside, rainwater is transported more slowly to open-surface water using cascades. The integral design has an energy-performance coefficient of 0.67. The environmental index of the building, according to the Greencalc method, attains a score of 212. The so-called hard facilities are located in the main part of the building. On the ground floor are less flexible polyclinics, on the first floor the perinatology center, intensive care unit, operating room, and daycare, on the second floor are patient rooms, and on the third floor laboratories and a pharmacy (Figs. 1.8 and 1.9).

The three energy principles of the hospital are:

1. Good insulation and natural ventilation;
2. Heat recovery techniques like energy wheels, which recover heat, cold, and latent energy;

Fig. 1.8 Deventer Hospital building entrance and pond
3. Alternative renewable energy sources, heat–cool storage, and heat pumps and heat recovery applications in exhaust ventilation.

The ground is surrounded by a village and a natural reservoir, so groundwater-level fluctuations are not allowed. Since the conventional techniques could not be used in Deventer for heat–cool storage, a revolutionary new energy concept was designed with better performance, lower costs, and higher flexibility, and by implementing sufficient redundancy the failure risks are also minimized, which is important for the operation budget of a hospital. For this technique, 95% of the effects will occur on the projects ground. In addition, the effects on the environment will be positive instead of negative. For a dry winter they send only based on the heat requirements of the building, whereas for a wet winter they send also based on environmental requirements in the, such that the groundwater level fluctuates very little.

5 Aabenraa Hospital, Denmark

The renovation being undertaken at this hospital includes covering three courtyards with glass and a well-insulated opaque roof, changing the courtyards from outdoor areas to real indoor areas. For the Aabenraa Hospital, optimization of the use of daylighting has been given special priority since optimum daylighting conditions had to be provided not only in the glazed courtyards themselves but also in the rooms surrounding the glazed courtyards. For the hybrid ventilation – natural fan-assisted ventilation – careful planning of the system controls was necessary to
ensure that the patients would have optimum thermal comfort during summer, when there is a risk of overheating, and in winter, when the cold outdoor air needs to be preheated to provide draft-free fresh air to the building (Figs. 1.10 and 1.11).

The ventilation system in the glazed courtyards was designed as a displacement ventilation system. Fresh air is provided through external fresh air inlets and passed through the basement, assuring a constant air temperature around 16 °C. Fresh air then passes through a filter and a convector element. Exhaust is ensured via roof-integrated wind cowls, utilizing the wind load to create sufficient air under pressure in the glass-covered courtyard to ensure the required air change of approximately 1.0–1.5 h⁻¹. The roof-integrated wind cowls are equipped with assisting fans to ensure a satisfactory ventilation level when the
wind load is not sufficient. The hybrid ventilation system is controlled with a new building management system (BMS), including the necessary control points. For each building section, the BMS controls a number of throttle motors, valve motors, sensors for fresh air temperature, and combined room air temperature and CO₂ sensors. All sensors are placed 1.6 m above floor level. District heating is used for space heating and hot water. The generation of hot water is supported by a 150 m² thermal solar collector, which provides an annual yield of about 540 kWh/(m²a), meeting approximately 60 % of the annual need for DHW (Figs. 1.12, 1.13, and 1.14).

6 City Hospital, Torun, Poland

The Polish city of Torun is a member of the World Health Organization (WHO)’s “Healthy Cities” project, so when the city hospital needed renovation and expansion, authorities included environmental sustainability criteria in the plans. Both new and renovated buildings in this 249-bed hospital have upgraded insulation, room temperature controls, modern heaters, and advanced valves, among other measures. Energy savings are approximately 30 % in the renovated buildings, and new buildings use 54 % less energy than standard newly built hospitals.

In the Torun hospital, district heating from a CHP is used for space heating and hot water. A cooling system is not necessary because the hospital is located in a cool climatic zone.
A natural ventilation system is used. Fresh air enters rooms through gaps at tops of window frames. The warm air is conducted outward via a central duct system (Figs. 1.15 and 1.16, Table 1.1).
7 Results

The following table summarizes the results achieved for indoor comfort, energy consumption reduction due to the installation of an advanced plant, CO$_2$ reduction achieved through the energy solutions adopted, and the behavior achieved by implementing sustainable strategies.
| Primary energy [kWh/(m²a)] | Meyer Children’s Hospital (Italy) | Fachkrankenhaus Nordfriesland (Germany) | Aabenraa Hospital (Denmark) | Deventer Hospital (Netherlands) | Torun City Hospital (Poland) |
|-----------------------------|----------------------------------|----------------------------------------|-----------------------------|------------------------------|----------------------------|
| Before                      | Newy built                       | Before                                 | Newy built                  | Before                       | Renovated                  |
| Thermal energy              | 212.5                            | 132.2                                  | 214.4                       | 116.6                        | 84.3                       |
| Electricity                 | 145.6                            | 97.00                                  | 173.4                       | 158.4                        | 293.6                      |
| Total primary energy        | 358.1                            | 229.2                                  | 387.8                       | 275.0                        | 475.0                      |
| Case study | Energy solutions adopted | Energy consumption | CO₂ emission reduction |
|------------|--------------------------|--------------------|------------------------|
| Italy: Meyer Children’s Hospital, Florence, Italy | • Green roof  
• PV façade  
• Solar ducts  
• Thermal insulation  
• Greenhouses  
• Shading devices  
• Green building design  
• Lighting strategies  
• Natural ventilation | The hospital consumes 40% less energy for heating and cooling and electricity than a standard newly built Italian hospital  
Total annual electricity demand is 12.3 kWh/m² | Annual 899 tons CO₂, 0.77 tons SOx, 7.91 tons NOx; this is 36% from the average Italian |
| Germany: Fachkrankenhaus Nordfriesland, | • Double-skin façade  
• River- and rain-water-capture techniques  
• Solar mass wall with transparent insulation | Energy savings are approximately 46% in the renovated buildings, and new buildings use 30% less energy than standard newly built hospitals | Annual 262 tons CO₂, 0.23 tons SOx, 0.002 tons NOx; this is 46% from average German hospital |
| Denmark: Aabenraa Hospital | • Daylighting  
• Hybrid ventilation – natural fan-assisted ventilation  
• Glazed courtyard  
• Control systems  
• Preheating | Energy savings are approximately 36% in renovated buildings, and new buildings use 7% less energy than standard newly built hospitals | Annual 974 tons CO₂, 0.18 tons SOx, 1.59 tons NOx; this is 60% from average Danish hospital |
| Netherlands: Deventer Hospital | • Green roof  
• Heat recover  
• Good insulation  
• Natural ventilation  
• Alternative renewable energy sources  
• Heat–cool storage and heat pumps and application of heat recovery in ventilation exhaust | Energy savings in new hospital are 47% on heating and 13% on electricity compared to a standard hospital. This reduction of energy equals a reduction of 1.943 tons of CO₂ per year, as well as a significant reduction in related emissions, e.g., 8.71 tons of SOx and 3.35 tons of NOx | Annual 1,943 tons CO₂, 8.71 tons SOx, 3.35 tons NOx; this is 69% from average Dutch hospital |
| Poland: City Hospital Torun | • Upgraded insulation room temperature controls  
• Modern heaters  
• Advanced valves | Energy savings are approximately 30% in renovated buildings, and new buildings use 54% less energy than standard newly built hospitals | Annual 3,537 tons of CO₂, 116 tons of SOx, 9 tons of NOx; this is 50% from average Polish hospital |
8 Conclusions

It was demonstrated through pilot projects that energy-efficient and sustainable hospital buildings can fully meet all architectural, functional, comfort, control, and safety features through the application of innovative and intelligent design and integrated design.

A very high insulation level, with a U-value for the walls between 0.2 and 0.3 W/m² K, for the roof between 0.12 and 0.8 W/m² K, and for the windows between 1.3 and 1.8 W/m² K (except Meyer Children’s Hospital, which had a U-value of 3.2 W/m² K), ensured low energy demand.

As a result of the planning for the hospital projects, it can be asserted that they comply with the requirements of the project, the reduction of primary energy consumption by approximately 30% on average.

Between 46 and 170 kWh/(m²a) primary energy can be saved. The primary energy savings for heating is between 26 and 170 kWh/(m²a). The average reduction in air pollution is approximately 26% for CO₂ and 23% for SO₂ and NOx.

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In the Meyer Children’s Hospital project, under a TESIS/ABITA experimental research program, the European Community financed the incremental cost of the innovative technological and environmental solutions that were implemented in the project, monitoring the effectiveness of the results retrospectively. In particular, the experiments involved a bioclimatic greenhouse, a PV system integrated into the translucent wall of the greenhouse, solar tube systems to capture and transfer sunlight to functional environments so as to reduce electricity consumption, innovative solutions of a green roof, and the environmental insertion of the complex into the landscape.

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