A Roadmap to the Carbon Neutral Hospital

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ABSTRACT

In 2019, European Union committed to become a Carbon Neutral continent in 2050. Any activity developed in any EU country shall then be CO2-emissions neutral. This includes construction and operation of buildings, also hospitals.

Hospitals are one of the most energy consuming building types. This paper presents a strategy to move towards this very challenging objective: design, build and operate carbon neutral hospitals: buildings which their construction, operation and future de-construction will not release greenhouse gases, measured in equivalent CO2 tons.

The three steps towards this objective are: reduce energy demand (load), reduce energy consumption and use renewable energy sources. Starting from an average annual energy spending for a medium size hospital in the Mediterranean region of 320 kWh/m2 we propose to reduce this value by 40% and then provide the remaining 190 kWh/m2-yr with renewable energy sources.

MAIN HOSPITAL TRENDS

Hospital design is suffering continuous development to be adapted to the new requirements of patients, professionals, and health administrations. We can identify some clear trends on four different levels, as summarized in Figure1:

1. With regards to hospital organization and services, hospitals are developing more out-patient activity and reducing patient rooms and wards. Medical interventions and treatments that required, a few years ago, one or two weeks of hospital stay, now require only two or three nights at hospital after the intervention.
2. Regarding the interior design of the different hospital areas, the trend is moving towards the erection of patient rooms more “hotel-type”, looking for more comfortable conditions, both in internal finishes and in indoor environmental quality (lighting, thermal and acoustic comfort).
3. Next is the rise of the operational safety levels of the hospital, both for people and equipment. On top of the traditional energy redundancy systems, now we add the essential redundancy provisions for both management data and clinical data.
4. Finally, the quest for more efficiency and productivity in the hospital operation continues. Energy

efficiency, smart technology deployment for better management and environmental sustainability strategies (with different independent environmental certifications now present) are present in the design process of most new hospital facilities.

This paper focuses on the last of these design trends: the efficiency quest, putting forward a strategy to arrive to a very ambitious objective: the design, construction, and operation of carbon neutral hospitals: hospitals where their construction, operation and future de-construction do not release greenhouse gases, measured in equivalent CO2 units.

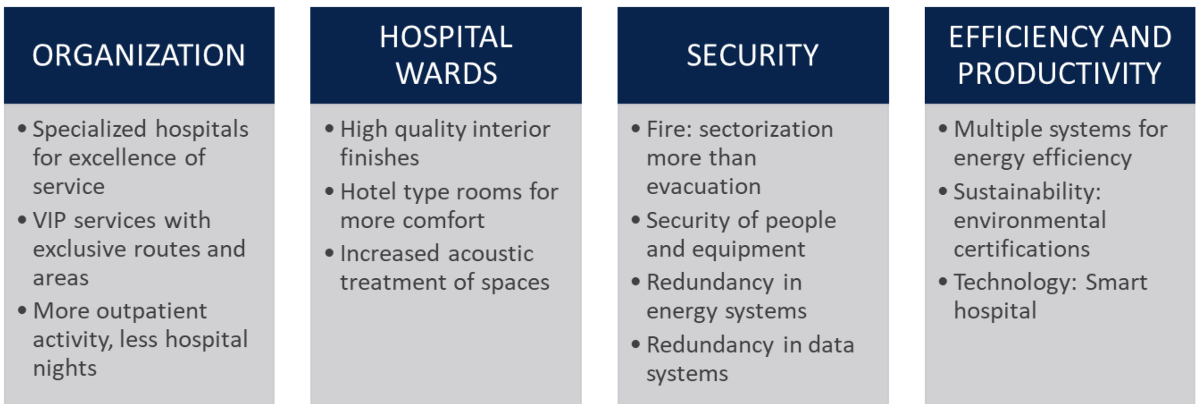


Figure 1 Actual hospital design trends.

THE EUROPEAN CONTEXT

In year 2015, most world countries signed the UN Paris agreement on climate change, where a common objective is fixed: to limit the global planet warming, due to human activities, to +1,5 ºC in this twenty-first century. The main global warming reason, even not the only one, is the release of the so-called “greenhouse effect” gases into the atmosphere. They reduce the capacity of our atmosphere to release the ground source infrared radiation into the space. The most relevant greenhouse gas is CO2, because is the most present in the planet. Other gases with similar effect are methane, ozone, nitrous oxide, and even water vapor.

In year 2019, the European Union, following the Paris agreement, signed the European Green Deal, by which Europe commits itself to become a carbon neutral continent by year 2050. Although the eruption of Covid in our lives has put this objective to a secondary level in the last two years, the intention of the EU is solid, and this commitment will soon be developed in future cross-sector directives, aimed to achieve this objective:

- *Renewable energy directive*: 40% of the energy consumed in EU shall be renewable by 2030.
- *Energy efficiency directive*: the new directive will multiply the energy efficiency obligations by two.

The distribution of the Covid recovery funds (Next Generation EU funds) looks very much into this objective of energy source transformation when allocating funds to different projects in different sectors. And, for example, there is the intention that all buildings in the public sector shall be renewed into carbon neutral buildings at a pace of 3% every year, with the objective that the public administration acts as a locomotive for all the building construction sector.

The challenge is enormous. To demonstrate this, we can simply look at some intermediate objectives: we want that, in 2030, European CO_2 emissions are 45% of those in 1990, as seen in Figure 2. In the first 30 years of this period (1990 to 2020), we have only been able to reduce our emissions by 20%, so we only have 10 years to reduce the additional 35%.

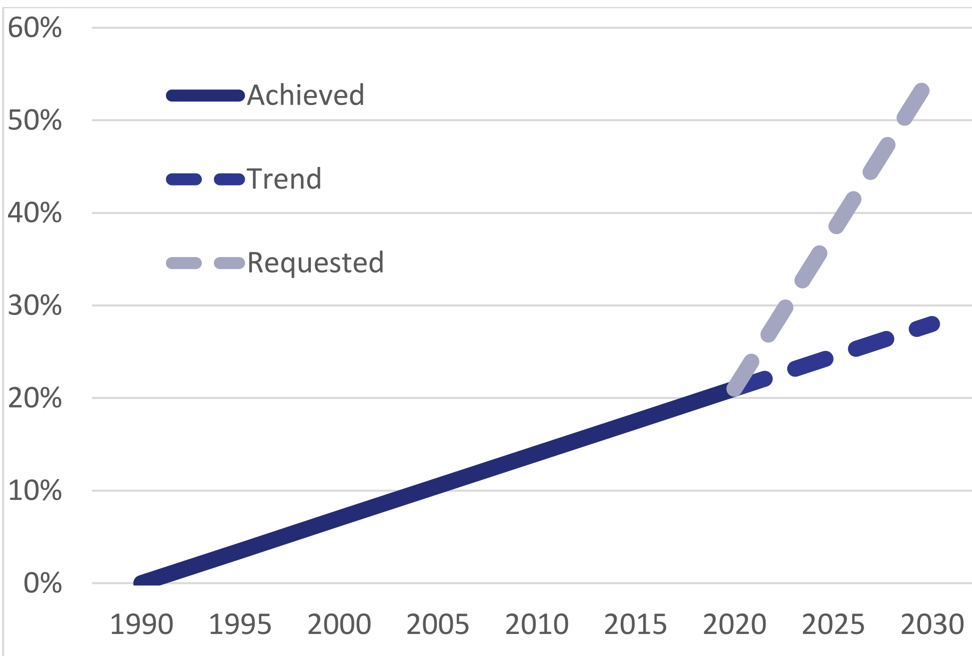


Figure 2 European Union CO_2 reduction objectives 1990-2030.

This very demanding European strategy will soon be transposed into different national regulations. Then we want to propose a strategy to also reach this carbon neutral objective for hospital buildings.

ENERGY PROFILE OF HOSPITALS

Hospitals are, as it is well known, large energy consumers. When the energy used in the hospital comes somehow from fossil fuels, the hospital is responsible for releasing CO_2 into the atmosphere.

For clarifying purposes, we should make a distinction between “net zero energy building” and “carbon neutral building”:

- A Net Zero energy building will achieve a neutral energy balance (and therefore CO_2 energy-related balance) in the operational stage of the building. In a specific operational period, normally a year, the net zero building will produce, with renewable technologies, the same amount of energy that it will use.

- A Carbon Neutral building is a building that maintains a CO_2 neutral balance during all the building life cycle: construction, operation, and de-construction. It is evident that this a quite more ambitious objective than the one fixed for net zero buildings.

From our experience in more than a 100 hospital projects in our half a century of professional life, we can characterize the energy consumption of a hospital (or equivalent CO_2 release) with the following analysis, valid for a hospital located in the Mediterranean:

1. For a "standard" building, 66% of the CO_2 released into the atmosphere will be done in the operational stage, and the remaining 33% in the construction and de construction stages.
2. In the operational stage of a hospital, 66% of CO_2 produced would be applicable to maintaining the environmental indoor comfort conditions, and the remaining 33% would be applicable to the operation of the different electromedical equipment.

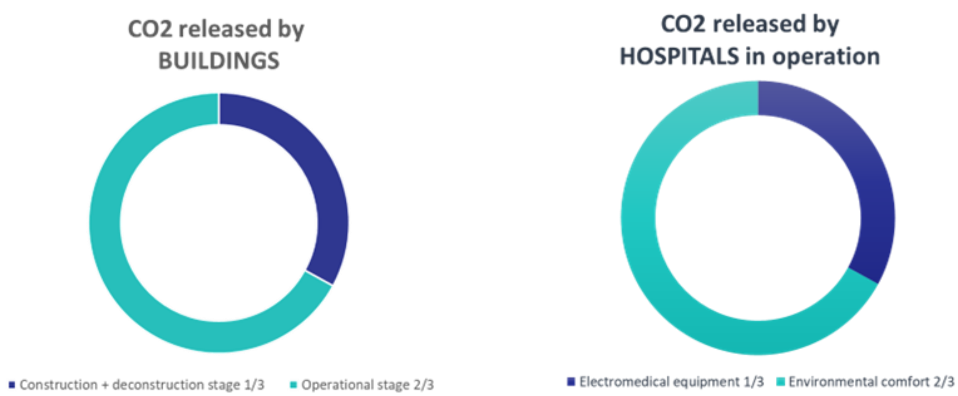
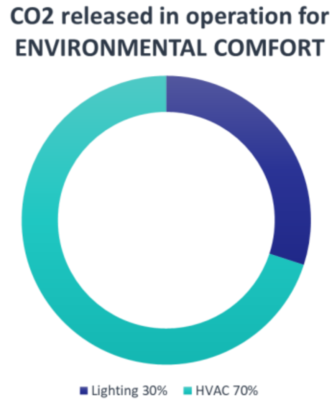


Figure 3 (a) CO_2 released by buildings in general and (b) CO_2 released by hospitals in operation.

3. When looking at the energy consumption for the environmental comfort, we see that 70% is used for HVAC purposes and 30% for lighting purposes.
4. Finally, when we look at the energy used when conditioning a hospital, we see that 38% of it is used to balance heat gains and losses from the façade, 37% is used to condition the fresh air into the building and 25% to cope with the internal heat gains in the building (people, lighting, equipment).



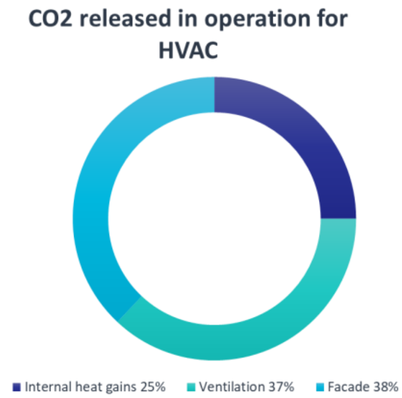


Figure 4 (a) CO2 released for environmental comfort and (b) CO2 released for air conditioning.

To translate these relative weights into absolute values, we completed a recent study to conclude that the average annual energy spending of a medium size hospital (20.000 m2, 214.000 ft2) in the Mediterranean region is 320 kWh/m2, divided into: 120 kWh/m2 of thermal energy (heat generation by natural gas or fuel for heating and domestic hot water) and 200 kWh/m2 of electrical energy (including air conditioning chillers, electro-medical equipment, and the rest of electrical loads) This can be seen in Figure 5.

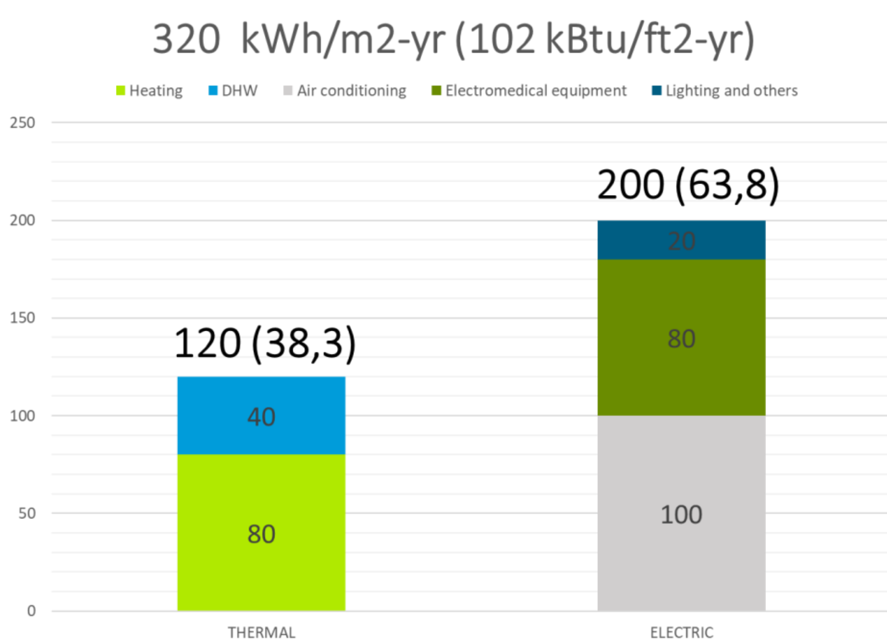


Figure 5 Average annual energy spending for a hospital in a Mediterranean climate.

A THREE-STEP STRATEGY TO FOLLOW

When we have fixed the situation as it is today, we can think on how to move towards our objective of a carbon neutral building. We should implement the well known three-step strategy:

- Energy load (demand) reduction.
- Energy consumption optimization: using very high efficiency technical systems.
- Finally, the adjusted energy needs should be satisfied with renewable energy sources.

Load reduction

The first step is to optimize the façade design and to maximize the incorporation of free-cooling strategies and natural lighting in the internal areas of the building:

- Optimize façade design.
- Lighting: natural light strategies, LED equipment, regulation systems
- Electromedical equipment: use of energy storage systems
- Ventilation: consider ventilation through facades or close to ventilation needs, to have low pressure drop ventilation systems
- Domestic hot water: instant production systems, no storage so no heat losses generated, and legionella risk is minimized.

Consumption reduction

When we have arrived at an optimal building load, we must define the different HVAC systems looking for the maximum efficiency. This relates not only to the energy production equipment but also to the distribution networks and units and the technical and automated management of these systems.

The set of measures that can be taken is quite large, and it is out of the scope of this paper, but we can suggest some general strategies:

- Energy machine rooms with multiple equipment, for better part-load performance
- Energy storage systems to reduce peak-to-valley energy consumption
- High efficiency energy production and distribution units
- Extensive deployment of heat recovery units and systems
- Use low temperature air conditioning systems, so they can maximize the use of recovered heat
- Distribution networks should be designed to move fluids at low velocity and pressure drop
- Variable flow distribution networks
- Location of energy production and ventilation equipment close to the conditioned spaces
- Proper commissioning and periodic recommissioning of systems

- Maintenance of comfort conditions related to space occupancy
- Predictive building management systems: smart hospitals

Renewable energy production

Finally, the optimal energy amounts the building needs for operation should be generated with energy sources. Here, photovoltaic electrical energy will have of course a main task. Also, being the thermal energy need quite relevant in a hospital building, we should consider other renewable sources, such as biomass or green hydrogen.

APPLICATION TO THE HOSPITAL BUILDING

The general plan proposed above shall now be applied to the hospital building. We need to reduce the energy load and consumption to the minimum (both related to comfort and equipment) and then we need to be able to produce the required energy with renewable sources.

The following Figure 6 explains this strategy: The global 320 kWh/m2 of yearly energy needs can be split into 240 for comfort and 80 for equipment, and the aim would be to reduce these values to 130 and 60 respectively, leaving the aggregated yearly energy need in 190 kWh/m2. This is 60% of the actual value.

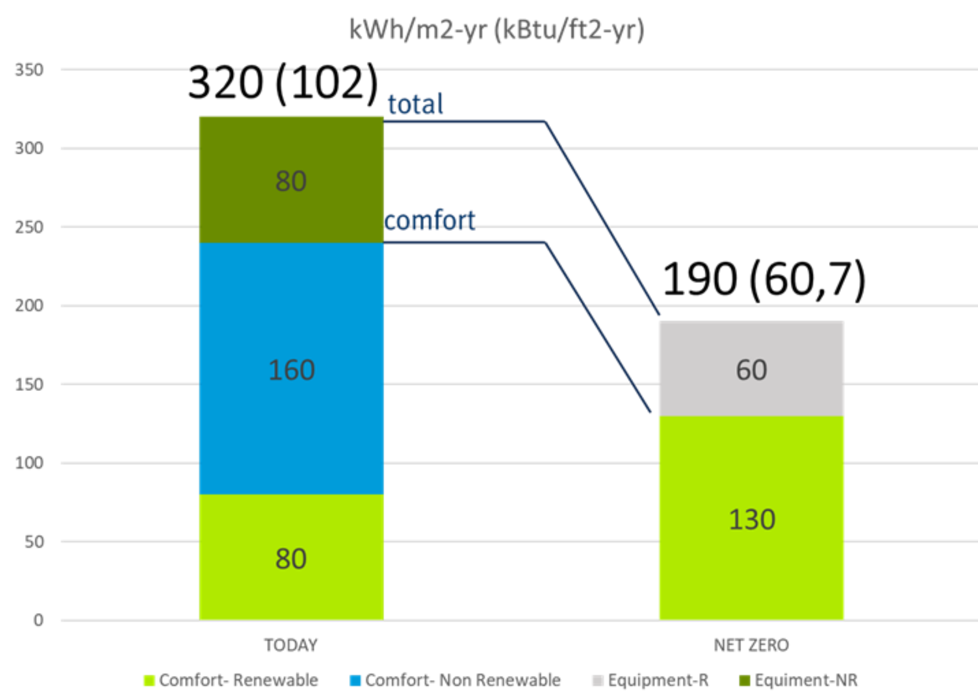


Figure 6 Reduction from 320 to 190 kWh/m2-yr.

Then we must set up the renewable energy strategy to achieve these 190 kWh/m2-yr. Our proposal is to generate 50% by photovoltaic electricity (for environmental comfort and electromedical equipment) and 50% by biomass thermal energy (comfort heating, absorption cooling, domestic hot water) or, in the very near future, with green H2.

In Spain, the average yearly production of photovoltaic cells is 310 kWh per m2 of plate. If we need to produce 95 kWh/m2 we will need 1 m2 of PV plate per every 3 m2 of hospital. For a 20.000 m2 hospital this means 6.600 m2 of PV plates.

For the required 95 kWh/m2 of yearly thermal energy, we can assume we produce heat during the 8.760 hours of a year, with a ratio of peak to valley of 3 to 1, resulting then in a biomass production plan of 33 kW for every 1.000 m2 of hospital. For a 20.000 m2 hospital, this means a 660 kW biomass/H2 energy station.

The following Figure 7 shows a prototype schematic for a Spanish hospital, incorporating this combination of PV cells and H2 boiler energy source to solve all energy needs of the building without CO2 emmisions.

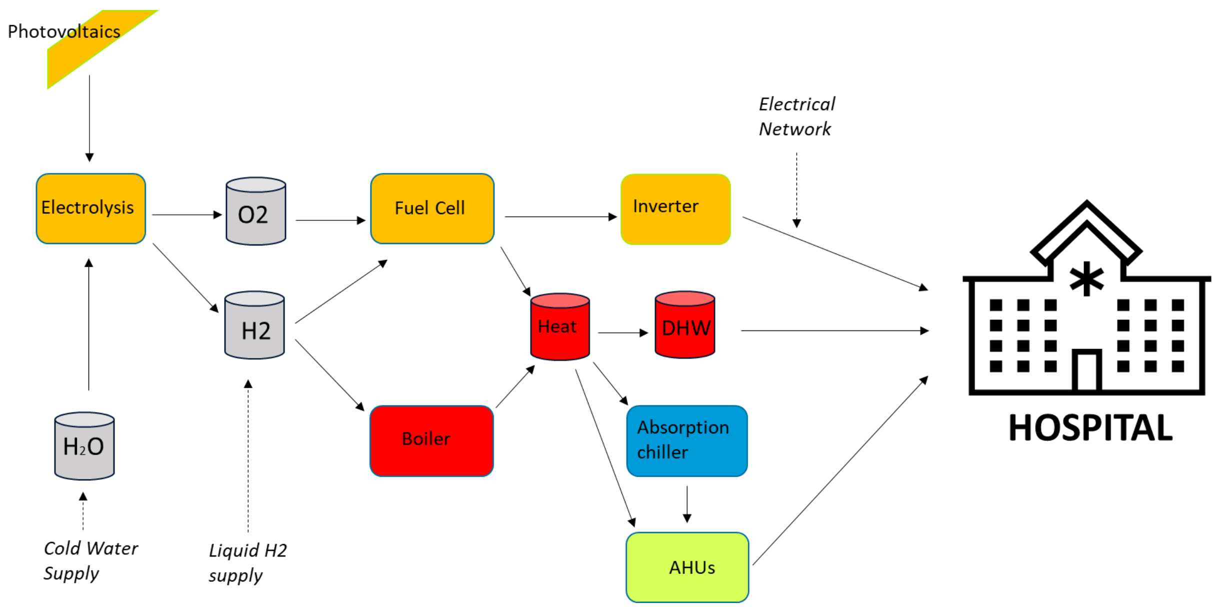


Figure 7 Prototype schematic for a CO2-free hospital.

THE ROUTE TO THE CARBON NEUTRAL HOSPITAL

Finally, when we have achieved the ambitious objective of running a net zero hospital, we can quantify the requirements to arrive to a carbon neutral hospital:

If we assume that the life span of a hospital is 50 years, and a CO2-to-energy conversion factor (average between electricity and gas) of 0,22 kg of CO2 per kWh produced, we can estimate the CO2 released along the whole operational life of the hospital as:

190 kWh/m2-yr x 50 years x 0,22 kg CO_2/kWh = 2.090 kg CO_2/m2

Then, the CO_2 released in the construction and deconstruction stage would be: 2.090 x 50% = 1.045 kg CO_2/m2.

To compensate for the “embodied” CO_2 (released to the atmosphere in the construction and deconstruction building processes), we will have to move from the net zero energy hospital to a positive energy hospital. We must generate in the 50 years of life of the hospital a surplus of renewable energy enough to compensate for the embedded CO_2 of the building. This additional production is quantified as an additional 50% of renewable energy production per year: 1.045 x 4,5 kWh/kg CO_2 / 50 years = 94 kWh/m2.

Even when we are still quite far away from this level of in-situ energy production, we think that this is the roadmap to follow.