Principles to Define Energy Key Performance Indicators for the Healthcare Sector

Aaron Liu  
Science and Engineering Faculty  
Queensland University of Technology  
Brisbane, Australia  
lei.liu@connect.qut.edu.au

Glenn Crompton  
Science and Engineering Faculty  
Queensland University of Technology  
Brisbane, Australia  
g.crompton@connect.qut.edu.au

Wendy Miller  
Science and Engineering Faculty  
Queensland University of Technology  
Brisbane, Australia  
w2.miller@qut.edu.au

Yunlong Ma  
Science and Engineering Faculty  
Queensland University of Technology  
Brisbane, Australia  
yunlong.ma@connect.qut.edu.au

Abstract—Energy is essential to ensure the safe and reliable operation of healthcare facilities. To evaluate the energy performance of hospitals or aged care facilities, different sets of key performance indicators (KPI) have been applied in different settings. Often, those KPIs are often limited in terms of guiding energy investment planning or operation or not meaningful in comparing with other healthcare sites. This paper reviewed energy KPIs for hospitals abroad and in Australia. Environmental sustainability and health aspects of energy KPIs are recommended and a set of principles for defining energy KPIs for the healthcare sector is proposed for the purpose of sustainable energy investment planning or operation optimization, such as enabling renewable or energy efficiency measures. Further analysis will be conducted to real hospital and aged care facilities.

Keywords—energy management, planning strategy, auditing, decision making, electricity, energy efficiency, sustainability

I. INTRODUCTION

Around 4.4% of global emissions come from the healthcare sector and 56% of these emissions come from the US, the European Union and China [1]. The healthcare sector is defined by the WHO as “all organisations, institutions, and resources that are devoted to producing health actions. A health action is defined as any effort, whether personal health care, public health service or intersectoral initiative, whose primary purpose is to improve health” [1]. Energy use, transport, manufacturing and disposal of product are the main sources of healthcare energy emissions. Healthcare facilities and vehicles (Scope 1) and indirect emissions from energy sources (Scope 2) account for 29% of the emission. Supply chain emissions are Scope 3 emissions. Including electricity, gas and fuel, energy use is more than 50% of the sector’s emissions (including the three scopes) and fossil fuel is a main driver.

In terms of health care, the top ten carbon dioxide (CO₂) emitting countries are shown in Fig. 1. Australia has about 24 million people however, it is one of the top ten CO₂ emitters, accounting for 2% of these global health care footprint. If rank based on emission per capita, Australia along with Canada, Switzerland and the US are the top emitters with CO₂ emission over 1ton per capita [1]. Healthcare facilities are high energy use examples and healthcare services are estimated to use more than eight percent of the U.S.’ energy [2]. In Victoria, a state of Australia, the largest public energy consumer is health services and hospitals [3].

II. REVIEW OF ENERGY USE

Energy is essential to ensure reliable and safe operation in medical and diagnostic services, transport, and power supply [4]. Generally, depending on climate zones, hospital types, occupancy and equipment, hospitals’ energy use intensity (EUI) varies significantly. Energy per floor areas per annum (e.g. kWh/m²), energy per bed-day per year (e.g. kWh/bed-day), or energy per bed per year (e.g. kWh/bed) are common KPIs for EUI. The following section describes and reviews these KPIs in reference to the US, India and China first, and then the discussion moves onto Australia.

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A. Current Hospital Energy Status

In UK, hospitals’ total energy baseline was 550 kWh/m² per year and a good benchmark of UK hospitals was 445 kWh/m² [5]. 622 kWh/m² was the energy use benchmark for medium to large buildings in Wales [6]. However, major hospitals in Scotland had 467 kWh/m² as a better mean energy use value in 2003.

The Environment Protection Agency (EPA) in the US studied energy data from over 3200 hospitals over a 5-year duration up to 2013 [7]. Their study reported that the mean source EUI was 1473 kWh/m². Those hospitals’ EUI statistics were to some extent positively correlated with number of staffed beds per floor area, cooling degree days, full time equivalent workers and number of MRI machines per floor area.

Ten thousands inpatient facilities and one hundred forty seven thousand outpatient facilities were analysed by another US study [8] which reported electricity and natural gas are the top two end use energy sources for US healthcare buildings (Fig. 2). Heating Ventilation and Air Conditioning (HVAC), water heating and lighting are the top three energy uses by service (Fig. 3). These facilities’ average EUI was 545 kWh/m² per year which was higher than England or Scotland’s EUI figures. Overall, electricity EUI for these facilities was 278 kWh/m² per year which was 2.89 times of hospitals’ EUI in China (96.1 kWh/m² ) and 1.87 times of hospitals’ EUI in Thailand (149 kWh/m² ) [9]. Note that these EUIs of hospitals in China and in Thailand were reported on electricity use, not total hospitals’ energy use.

In India, hospitals’ main energy source usually is electricity which is more than ninety percent of hospital energy use [11]. The kWh/m² per year and kWh/bed per year statistics are shown for seventeen public and seven private hospitals in India (Fig. 4). There are significant differences for the kWh/bed per year values between public and private hospitals. A possible reason is provision of different medical service levels. They also found that HVAC, water pumping and lighting are the top three energy users for five of those hospitals. 30% to 65% of their total electricity was used for HVAC and 30% to 40% of the total electricity was for lighting. A research in Greece has similar findings: HVAC and lighting form the majority of total electricity use (about 50 to 60%) [12].

In Australian hospitals, electricity along with natural gas is the top energy sources and the top electricity use is for HVAC which accounts for 47% of electricity use [13]. This study has different end use EUIs for hospitals of two categories:

- 427 kWh/m² per year across studied public hospitals (445 in total)
• 460 kWh/m² per year for 322 public hospitals in regional areas
• 393 kWh/m² per year for 123 public hospitals in capital municipalities.

Overall in Australia, regional hospitals had been less energy efficient than capital city hospitals. To summarise literature, hospitals’ EUIs were presented in a descending order in TABLE I.

### TABLE I. Hospital EUI Comparison by Countries

| Country                             | kWh/m² |
|-------------------------------------|--------|
| US                                  | 1473.2 |
| Wales                               | 622.2  |
| UK (average)                        | 550.0  |
| Scotland                            | 466.7  |
| Australia (regional public hospitals)| 460.3  |
| UK (NHS benchmark)                  | 445.0  |
| Australia (capital city public hospitals)| 393.1  |
| India                               | 200.0  |
| China (electricity only)            | 96.1   |

A few possible reasons for the differences among hospitals are:

- Cultural and climate prospects for indoor environment
- Building ages, asset and infrastructure, and energy efficiency of them
- Levels of medical specialisation
- Building configuration and sizes of hospitals
- Healthcare budgets at a regional level and a national level

This analysis so far highlights some key drawbacks of the common hospital’s energy KPIs: kWh/m² does not deliver actionable evidence to advise whether a specific hospital is energy efficient nor does facilitate comparison among facilities since different types of variables and factors can impact energy performance. Likewise, kWh/bed per year or per bed day per year does not provide a hint on the medical services level of a specific facility, or the social or cultural aspects of indoor environment. Those KPIs cannot tell how energy related investment or operation can be improved to enable more renewable or energy efficiency measures.

### B. Hospital Energy Profiles

Seasonal or monthly energy use can differ significantly due to climate differences. For example, for an investigation of 100 hospitals’ energy use in China, 22 of them were from a hot summer and warm winter climate (HSWW) [10], which was very similar to the climate in southeast Queensland. The HSWW climate’s energy use per unit (kWh/m²) was the highest from April to October (7months from spring to autumn). Out of the four climate zones, the HSWW climate’s hospitals had the highest energy use per unit on the average. A reason was air conditioning accounts for the largest electricity use for these 100 hospitals (about 50% of the total electrical energy use). In comparison to the other climate zones, the HSWW climate need more months of cooling, and air conditioners often contribute to high power demand and energy use. Note that hot summer cold winter climate (HSCW) had a comparable summer cooling need to HSWW, but the cooling period was much shorter. The end use energy in outpatient and inpatient areas were also analysed in the report, however no detailed study was conducted to different departments’ energy use within the hospitals.

EUIs of England’s eight medium to large general acute hospitals was analysed in [14]. Overall, 28 departments’ electricity use were studied. The energy use and power demand analysis by departments offers meaningful statistics for energy management, for example data about where power demand and energy use were for different departments, weekday and weekend patterns or seasonal. The peak load and base load characteristics of the report were presented in Fig. 5. The minimum power demand over a day was the base load. The maximum power demand over a day was the peak load. Generally, imaging and radiotherapy departments had the largest load factor. Operating theatres had the largest peak load. This indicated that a substantial power demand difference existed between their medical equipment on operation status and standby status. The lowest base load was day clinics.

![Fig. 5. Acute hospitals’ power demands in England [14]](image)

![Fig. 6. Acute hospitals’ energy characteristics in England [14]](image)

The same hospitals’ energy use characteristics of [14] are summarized in Fig. 6. Both similarities and differences existed when the energy uses were compared with the power demands. Laboratories had the highest all days’ energy use and weekdays’ energy use while operating theatres had the most energy use on weekdays. The highest weekday to weekend ratio was for day clinics and imaging departments. This was likely because some of those departments have specialised services and not normally open over weekends.
To achieve 30% energy savings compared to the minimum specification of ASHRAE 90.1-1999 standard, National Renewable Energy Laboratory (NREL) [15] published guidelines for designing new small healthcare facilities (up to 8360 m²). TABLE II summarizes the recommendation for lighting power density and peak plug loads. Among ASHRAE baseline models (1999 and 2004), ASHRAE low-energy models, advanced energy guidelines, and requirements with occupancy sensors, the lowest is lighting power density with occupancy sensors.

### TABLE II. LIGHTING AND PLUG LOADS

| Lighting Power Density: W/m² | Community hospital | Surgery centre |
|-----------------------------|--------------------|----------------|
| ASHRAE 90.1-1999 baseline model | 20.45 | 19.38 |
| ASHRAE 90.1-2004 baseline model | 11.84 | 11.84 |
| ASHRAE 90.1-1999 low-energy model | 19.91 | 20.13 |
| ASHRAE 90.1-2004 low-energy model | 11.95 | 11.41 |
| Small healthcare advanced energy design guide low-energy model | 9.903 | 9.47 |
| ASHRAE 90.1-1999 with occupancy sensors | 19.91 | 20.13 |
| ASHRAE 90.1-2004 with occupancy sensors | 11.95 | 11.41 |
| Small healthcare advanced energy design guide with occupancy sensors | 9.472 | 8.93 |

| Peak Plug Loads: W/m² | Community hospital | Surgery centre |
|-----------------------|--------------------|----------------|
| Small healthcare advanced energy design guide | 22.6 | 19.38 |
| Green Guide for Healthcare | 10.76 | 16.15 |

### C. Existing Hospital KPI Effectives

Existing KPIs frequently offer a general outline for healthcare facilities. TABLE III contains the evaluation for three common energy KPIs which are often understandable and the data to produce these three KPIs are comparatively easy to acquire and compute. All those KPIs have advantages and disadvantages.

In terms of healthcare' environmental impact, carbon emission intensity or avoided carbon emission intensity kgCO₂-e/m² per year can be used [16]. However, challenges exist in applying this KPI. To illustrate, the CO₂ emissions intensity varies in electrical power systems and fluctuates over time. For example, fuel mix changes as more renewables are added to the power system. As electric power systems are decarbonised progressively, the CO₂ metrics of healthcare sector may improve, even if no energy efficiency or renewable generation is implemented onsite. The same situation can happen when a facility establishes power purchase agreements with renewable energy suppliers: the CO₂ emissions may decrease however this does not mean lower energy use intensity.

Onsite renewable generation as a ratio or percentage of the total energy use could be a more appropriate KPI to show how a health facility has acted environmentally, rather than using kgCO₂-e/m² per year. Onsite renewable generation percentage is a LEED 2009 assessment item for Healthcare [17].

Furthermore, some regions may already have high PV installation rates in communities and suburbs [18]. Procuring renewable energy generation from nearby solar homes [19] (such as within 5 to 10km distance) may seem to be feasible to be included in onsite renewable KPI calculation, because within this short distance, no substantial energy is lost and community renewable installation may be more encouraged with this sharing initiative. For evaluating environmental impact, the advantages with using the renewable generation percentage KPIs are:

- the same health facility’s KPI values can be evaluated and compared over time
- a common ground can be set up for comparison among facilities
- facility’s renewable energy position or development can be reflected

### III. RECOMMENDATIONS TO IMPROVE ENERGY USE

Based on the review and analysis in the previous section, understanding the objectives of energy management or energy investment is quite essential to select purpose-oriented energy KPIs. Additionally, the following are recommended by literature:

- To consider energy use in calendar months to calculate KPIs, as opposed to energy use in billing months [21]
- To use a consistent energy KPI instead of a cost KPI [21]
- To understand departments service types: intensive or non-energy intensive, to categorise energy improvement opportunities [22]
To understand major equipment’s energy use and peak demand performance, as per ASHRAE Level 2 and Level 3 PMP (Performance Measurement Protocols)

To evaluate monthly or seasonal in energy use and peak demand to better quantify and validate the effects of energy management and improvement options [22]

Because different hospitals in different climates probably have varied energy performance, hospitals’ energy KPIs need to be attuned to two factors: hospital types and climate zones. For example, National Australian Built Environment Rating Systems (NABERS) for hospitals has 71 climate zones for Australia [23]. Also, Australian hospitals are classified into 14 types based on the same rating system.

COVID-19 has made healthcare sector under spotlights regularly. For the healthcare sector, healthcare is the main focus. Even when financial saving is considered, energy or environmental sustainability is often not regarded as a priority for healthcare sectors [24], until energy management or improvement is associated with health and safety [25]. Consequently, to help enable more sustainable practice in health care, some sustainability KPIs need to be developed to relate to the health or safety improvement of patients and clinicians.

Patients’ recovery and wellbeing are important and could be indirectly related to energy KPIs [26]. This report revealed that high LEED rated hospitals may not automatically be regarded as ideal green healthcare facilities. Patients’ average length of stay (ALOS) may be a gauge to evaluate the health paybacks of energy improvement projects or construction of high energy efficiency facilities by means of better IEQ (indoor environment quality) [27]. This study identified that with better IEQ, ALOS, mortality rate and medication costs can be lowered by 11%, 19% and 21% averagely.

TABLE IV. A SET OF SMARTCHS PRINCIPLES

| Key criteria | Description |
|--------------|-------------|
| Specific     | Be strategic and specific, detailed, and meaningful for desired purposes |
| Measurable   | It can be measured, or calculated based on measurements/data |
| Attainable   | Have tools or resources to attain data/resources |
| Relevant     | KPIs need to be relevant to:  
|              | • the energy performance of the technologies under evaluation  
|              | • health and safety of staff and occupants |
| Time based   | A time period that provides the required resolution for the purpose (e.g. yearly, seasonal, monthly, weekly, daily or hourly) |
| Comparable   | The KPI can be compared with:  
|              | • itself over time  
|              | • other facilities KPIs  
|              | • benchmark KPIs |
| Hierarchical | Due to different risk levels at healthcare facilities, designed to reflect energy performance at different risk/priority levels |
| Systematic   | System thinking in designing energy KPIs |

| Purpose | Possible KPIs |
|---------|---------------|
| - To reduce site peak demand or demand charge | Highest kW (or kVA) in every month |
| - to enable onsite renewable energy, -Reduce energy charge | - Monthly energy use  
| | - Daytime energy use; peak demand |
| - to evaluate building energy efficiency improvement technologies e.g. louvre, paint, glazing | - Locational thermal comfort  
| | - Locational cooling or heating delivered  
| | - Locational energy use  
| | - Locational peak demand |
| - To assess new HVAC energy efficiency technologies | - Equipment specific cooling or heating output  
| | - Equipment specific energy input |
| - To assess environmental impact of energy performance improvement projects | -Greenhouse gas  
| | -Waste  
| | -Water and sewage  
| | -Avoided GHG emission  
| | -Avoided air pollution  
| | -VOC level |
| -To assess health impact of energy performance improvement projects | -Average length of stay (ALOS)  
| | -Less onsite infection rates |
| To assess safety impact of energy performance improvement projects | -Safety incidents rates  
| | -Near miss statistics |
| To assess network benefits | -Wholesale cost of peak 30-min electricity demand |
| | -Total self-consumption rate  
| | -Rate of PV used for HVAC self-consumption  
| | -Net facility load factor |

TABLE V. PURPOSE-ORIENTED KPIs

IV. CONCLUSION

This paper has studied literature from international resources and Australia to define, analyse and appraise a few energy KPIs for hospitals, such as kWh/m² per year and kWh/bed-day per year. Energy used in hospitals can vary considerably; accessible energy sources and technologies can also vary greatly; the prevailing energy use intensity KPIs (in relation to squared meters or number of bed days or beds) do not reveal sufficient details for planning or operating energy assets or for benchmarking. Also, there are different methods
calculating energy KPIs, which makes it challenging to compare energy productivity, or energy efficiency with other facilities or with other regions.

SMARTCHS principles have been developed to design purpose-oriented energy KPIs. It can be more suitable for purposes when KPIs are chosen depending on energy performance improvement goals, or energy management objectives, such as for enabling renewables, assessing environmental impacts or health aspects of energy improvement projects. Further study includes application of the SMARTCHS principles to real hospital and aged care sites in Australia.

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