The hope and possibility of net-zero hospitals in the US regulatory context

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US hospital energy consumption is high, relative to other US commercial facilities. Net-zero hospital seem a far goal. Much of the energy in US hospitals goes to HVAC systems. US hospital HVAC design is regulated by a set of prescribed air changes per hour for most spaces. This design paradigm could be updated and revised, incorporating learnings from best-practices in indoor air quality, comfort design, and energy conservation. New design ideas and code reform hold promise to move US hospital design towards the net-zero design ideal.

Keywords: health care, ventilation, energy

US hospital energy consumption and net-zero potential

US benchmarking studies use the metric Energy Use Index (EUI), in units of kBtu/ft^2-yr (kWh/m^2yr). Commercial net-zero buildings, or net-zero capable buildings often target a range of 20–45 kBtu/ft^2-yr (60–90 kWh/m^2yr). Such a building's annual consumption can typically be offset by an on-site energy plant (e.g. photovoltaic panels). Compared to other commercial sites, hospital sites are often large and include amenities and support facilities. A normally-developed hospital site, where 10–25% of the property could be devoted to photovoltaic panels, would need to consume between 40 and 110 kBtu/ft^2-yr (120–350 kWh/m^2yr) for an annual net-zero balance. We have proposed an average target of 60 kBtu/ft^2-yr (190 kWh/m^2yr) for the consumption of net-zero hospitals.

The average energy consumption of US hospitals, from the 2013 national survey data, is 230 kBtu/sf-yr (725 kWh/m^2yr), nearly four times the target. In contrast, the average commercial building energy consumption is 90 kBtu/ft^2-yr (290 kWh/m^2yr). The high energy consumption shows the need for technological development. At closer investigation, HVAC is the most important and meaningful opportunity. 60% to 75% of the typical US hospital's energy goes to ventilation, heating, and cooling. See **Figure 1**. Therefore, the primary focus to reduce US hospital energy should be that of reducing HVAC energy.

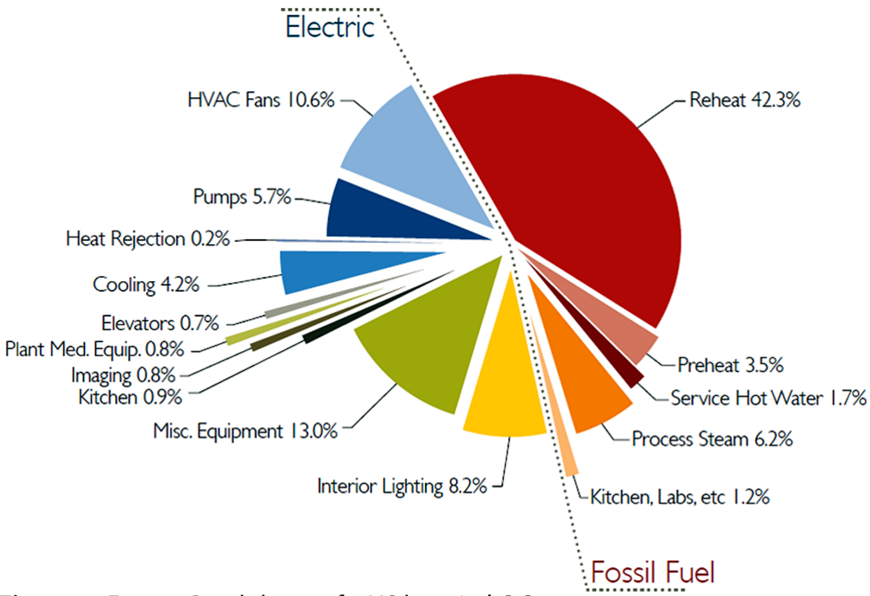

Figure 1. Energy Breakdown of a US hospital. [1]

To meaningfully reduce health care sector energy, technologies must favor existing applications. Turnover of US hospitals is slow. Due to the capital intensity of new development, hospitals have long facility lives. Remodel and renovation are quite common. New construction is a small fraction of the overall stock.

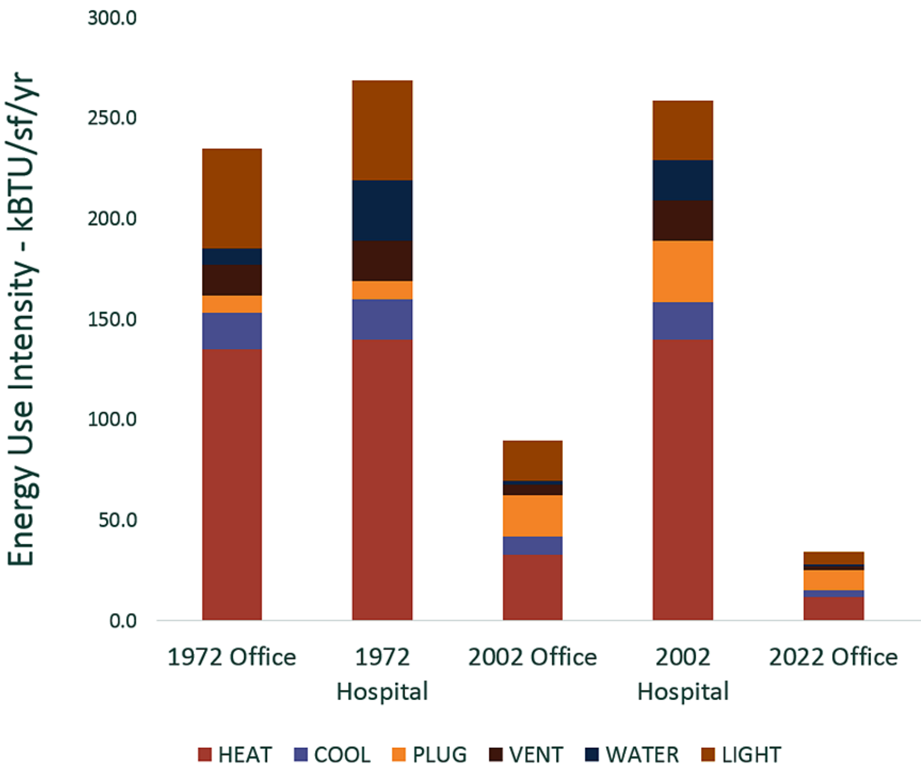

Figure 2. Historical Reduction in US Commercial Building and Hospital Energy.

While significant energy reductions may seem a daunting challenge, there is reason to believe much can be accomplished quickly. From 1976 to 2002, successive and progressive US energy codes have yielded a radical reduction in commercial building energy. Total energy reduced nearly 60%. HVAC energy reduced nearly 70%. Heating reduced nearly 75%. Much of the savings has been in HVAC. In particular, heating and reheat energy has vastly reduced. See **Figure 2**. Health care facilities, whose HVAC systems were granted exceptions from energy codes, have been largely unaffected. Today, for reasons discussed below, many health care spaces are over-ventilated much of the time, causing excess heating and cooling energy use. This energy may be opportunity for reduction.

The Air Change per Hour (ACH) US Code Paradigm

Hospital HVAC systems in the US are designed differently than other buildings. This is true for most spaces, not just critical spaces like operating and isolation rooms, which have specialty requirements in most countries. In the US, spaces that occur in both hospitals and other commercial buildings have unique requirements in hospitals. In other words, the HVAC design standards used for hospital restrooms, corridors, and linen storage spaces are completely discreet from the HVAC design standards used for hotels' restrooms, corridors, and linen storage spaces. On the whole, hospitals require significantly more air than counterpart commercial buildings at the turndown or minimum conditions.

Best practices in ventilation for indoor air quality are well-established in commercial buildings, with a body of scientific and engineering literature dating from the 1970s on attainment of indoor air quality. Indoor Air Quality (IAQ) is the "air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants" [2]. Air quality standards, stated as acceptable limits of contaminants, are developed by multiple sources including the ACGIH [3], OSHA [4] , NIOSH [5], and EPA [6]. The well-respected US ASHRAE Standard 62.1 - Ventilation for Acceptable Indoor Air Quality [7], provides a model code for commercial buildings in the US, but does not contain guidance specific to hospitals.

Best practices for comfort design are also well-established, with a body of scientific and engineering literature. Thermal comfort design in the US is represented in ASHRAE Standard 55 [8], which includes the well-known PPD/PMV (percent of people dissatisfied / percent mean vote) comfort model and survey protocol.

Building standards for hospitals in the U.S. rely on a different, legacy ventilation methodology requiring "air changes per hour" (ACH). Because of this reliance on the older ventilation practices, hospitals over-ventilate many spaces, much of the time. This contributes to relatively large amount of fan, cooling, and heating energy.

The legacy of US HVAC guidelines

US hospital HVAC standards come from an earlier era. As part of the 1946 *Hospital Survey and Construction Act*, "General Standards" were added to the US Federal Register in 1947. The title and authorship of these standards has changed over the years. The US Public Health Service (PHS) published "General Standards" until 1974, then "Minimum Requirements for Construction and Equipment for Hospital and Medical Facilities". In 1984, the American Institute of Architects (AIA), began publishing "Guidelines for Construction and Equipment of Hospital and Medical Facilities" in 1987. In 1998, the AIA turned them over to the Facilities Guideline Institute (FGI) who now published the "Guidelines for Design and Construction of Hospital and Health Care Facilities" [9].

The early versions of these standards contained ventilation requirements in narrative form. Beginning in 1968, ventilation requirements were compiled into a table of ACH rates. In the early 2000's, the table was removed from the FGI "Guidelines", and published as ASHRAE Standard 170.

Unfortunately, much of the thinking behind the ACH rates is lost to history. Entries are not cited to scientific or engineering literature. In 2015, a research paper collected as many historical entries as could be found, and published a table of ACH requirements for key spaces from 1959 to 2013. See **Table 1**. In another effort to discover origins, ASHRAE and FGI have co-sponsored a research project entitled "CO-RP 3 Evidence Based Research Project: Literature Review

Table 1. Selected Air Change Rates Across the Years, Outdoor ACH/Total ACH (Abridged. Source [10])

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991	1993	1997	2001	2006	2008	2013
	Source: ASHRAE Guidebooks, compiled in "Ventilation Designs" [11].											Source: FGI archives (FGI, 2013).				Source: ASHRAE 170	
Operating Room	8-12	**15**	15	15	**25/5**	25/5	25/5	25/5	25/5	25/5	25/5	**15/3**	15/3	15/3	15/3	**20/4**	20/4
Recovery		**4**	4	4	**15/6**	15/6	15/6	**6/2**	6/2	6/2	6/2	6/2	6/2	6/2	6/2	6/2	6/2
Nursery	**8-12**	**12**	12	12	**15/5**	15/5	15/5	**12/5**	12/5	12/5	12/5	**6/2**	6/2	6/2	6/2	6/2	6/2
Patient Room	**1.5**	1.5	**2**	**4/2**	4/2	4/2	**2/2**	2/2	2/2	**4/2**		**2/1**	**2/2**	**6/2**	6/2	6/2	**4/2**
Toilet Room						**10**	10	10	10	10	10	10	10	10	10	10	10
Intensive Care					**6/6**	6/6	**6/2**	6/2	6/2	6/2		6/2	6/2	6/2	6/2	6/2	6/2
Isolation Room		**4**	4	**6**	**12/12**	12/12	12/12	**6/2**	6/2	6/2	6/2	**6/1**	**12/2**	12/2	12/2	12/2	12/2
Patient Corridor						**4/4**	4/4	4/4	**4/2**	4/2	4/2	2	2	2	2	2	2
X-Ray D&T		**6**	6	**10**	**6/6**	6/6	6/6	**6/2**	6/2	6/2	6/2	6	6	6	6	**6/2**	6/2
Autopsy		**10**	10	**15**	**15/6**	15/6	15/6	**12/2**	12/2	12/2	12/2	12	12	12	12	12/2	12/2
Exam Room		**4**	4	4	**12/6**	12/6	12/6	**6/2**	6/2	6/2	6/2	6	6	6	6	6/2	6/2
Med Room								**4/2**	4/2	4/2	4/2	4	4	4	4	4/2	4/2
Treatment	**4**	4	4	**12/6**	12/6	12/6	**6/2**	6/2	6/2	6/2		6	6	6	6	6/2	6/2

for ASHRAE Standard 170-2013" the purpose of which is to uncover or discover available evidence supporting the requirements in the US standard. As of this writing, the research is in progress. The researchers have identified over 500 studies and papers, and are attempting to extract what evidence can be found to support the over 850 unique requirements in the US standard.

The US health care HVAC standard story is analogous to a software developer having lost the source code to an application. Without source code, an application can still be used, copied, and installed on new workstations. It can continue to gain users. However, it can't be updated. Bugs can't be fixed. Features can't be added. Similarly, the US health care HVAC guide, with ACH rate requirements of uncertain origins, is still used. Authors add new spaces simply by copying entries from spaces already in the guide. However, existing entries are difficult to update. Problems are difficult to fix. New technologies are difficult to add.

Popular perceptions of US engineers

Ask many US engineers why the ACH rates are used or maintained, a common answer will be related to control or prevention of infections. We performed a survey of US engineers in 2013 that found many US engineers believe the HVAC guide requirements are related to infection control [12].

Naturally, there are spaces in hospitals where the HVAC practices are related to the clinical outcomes and infection control. In operating rooms, clean air is used to mitigate surgical site infection risk from airborne particles [13]. In protective environments, for transplant recipients or severe immune compromised, clean air is used to mitigate "opportunistic infections" from airborne particles [14]. Other clean spaces include pharmacy compounding and sterile packing. Facilities also have designated airborne isolation spaces, both short term and long term. When airborne disease cases arrive at facilities, they are isolated to a room which is exhausted, and held under negative pressure [15].

However, popular perception among engineers extends beyond these spaces. Some engineers believe air rates factor in typical inpatient infections, such as catheter infections or bloodstream infections. That this idea lacks scientific evidence seems to dampen its popularity only little.

The present and path forward

The path to next-generation, performance-based design and operating standards will be long and difficult. However, progress has begun; code groups are working on solutions. One group convened in early 2015 to coordinate across clinical standards and clarify operating protocols. Another independent group worked through 2015 and 2016, to investigate alternate health care HVAC design methods. A risk-based, less prescriptive approach has been proposed and is in development. A task group has done a preliminary investigation into allowances for natural ventilation, and is moving forward in development. A recent focus on outpatient facilities may result in recognition of alternate methods already in use in the outpatient portfolio. Smaller teams are also sharing knowledge and best practices among domestic standards.

Architects and engineers take creative approaches to forge ahead. They often stretch to the limits of standards, or slightly beyond. Chilled beams, natural ventilation, and displacement ventilators are deployed in US acute care projects. Facilities operators have adapted systems into more performance and risk based operational paradigms. A pilot project in development is investigating performance-based ventilation in an inpatient tower based on continuous indoor air monitoring. Outpatient projects are designing for very low design energy use, 40–50 kBtu/ft²-yr (120–190 kW/m²yr).

There have been a few US examples of net-zero, near net-zero, or attempted net-zero hospital designs. The trend will continue. Some of the examples to date are a bit opportunistic. They've invested in renewables, but they haven't been able to deeply reduce consumption.

Evolving to a new US HVAC toolkit, based on indoor air quality and comfort tool, will open the door to lower consumption, more net-zero hospitals, a greener health care building sector. ■

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