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Determining Cooling Loads in Health Care Clinical Spaces Using Historical Data

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ABSTRACT

As more buildings are connected to cloud-based large data systems, there is an opportunity to learn from the data. Predictive load and energy modeling calculations, which have long been performed based on assumptions, can be validated, or adjusted based on accrued data from in-service buildings.

This paper publishes zone sensible cooling loads, based on historical data. The results should serve as a guideline to cooling load and energy modeling calculations in future designs.

The data assessed includes room temperature, supply temperature, and airflow, collected on 5-minute intervals for one year of operation. Data assessed is limited to the cooling hours between 8 AM to 6 PM, May through October. Sensible load was calculated for each hour using the difference in temperature, multiplied by the airflow. Zones are classified into Zone Type, based on the room name where the thermostat resides. Loads are normalized to zone area.

The results include (1) cooling loads for the 75%, 50%, 25%, 2%, and 0.4% exceedance values, and (2) diversity factors indicating the maximum simultaneously occurring load in multiple zones of the same type.

INTRODUCTION

Hospitals are chronic users of reheat. Studies show reheat energy is the most dominant use of energy in hospitals (Bonnema, E., et al. 2010) (Burpee, Loveland and Michael 2012) (CBECS 2012). Since most hospitals use air systems with terminal reheat coils, reheat energy is thought to arise from a mismatch between space loads and system sizing. When zone cooling loads are lower than the minimum capabilities of the cooling systems, reheat results. Some of these mismatches may come from the code-required airflows (English 2017). However, the extent of code-driven oversizing is debatable in the absence of published historical load data.

Hospital design engineers size systems using load calculations – theoretical predictions of load expectations. Load

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calculation methods are standardized by ASHRAE (TC4.1 2021). However, variations arise from variance in inputs. Unless a problem occurs, most engineers do not regularly validate their load predictions with data from the actual buildings.

There are no publications offering feedback on the range of cooling loads in-situ in health care spaces. There have been some publications on energy end-uses (Hatten et al. 2011) (Sheppy, Pless and Kung 2014). However, none have delved into the incurred cooling load at the zones themselves.

The recent trend towards data analytics offers opportunity to learn more from existing buildings. Building automation systems have traditionally been deployed building by building, requiring access for each building. They frequently do not log and store trend data for more than a few weeks. Storage is often limited to a select number of points. Connected commissioning or fault detection platforms, by contrast, collect data from multiple buildings, make many buildings accessible in one place, and collect data on all points in those buildings, forming large data repositories. These repositories can reveal much about phenomenology of cooling loads.

Publication of historical loads and profiles could have multiple benefits. Historical loads could be used to validate designs. There is potential for first cost savings if assumptions can be reduced. Systems could also be designed for much more efficient operations if the selected systems and equipment could be better tailored to the actual loads and profiles.

SETUP OF THE PROJECT

This project is intended to be the be first of its kind. The project team endeavored to transparently explain data collection and data analysis methods. It is hoped other teams can replicate this effort or improve upon it, to publish more historical loads from more sites.

For this project, undertaken between August and December 2021, our goals were:

1. Assess historical peak sensible cooling load for several room functions.
2. Assess the diversity of simultaneous sensible cooling loads for several room functions.

Facilities included in the project are shown in Table 1. Within the project timeline and budget, included facilities were limited to those where the team could, in a timely manner, assemble both *cloud-based diagnostic data* and *zone and room design data*.

Table 1. Facilities Included in the Study

Facility Name	Facility Type	IECC Climate Zone	Climate Zone, CEC	ASHRAE Design 0.4% Outdoor Air Dry-Bulb (°F/°C)	Years of Trended Data	Actual 0.4% Outdoor Air Dry-Bulb (°F/°C)
San Leandro Medical Center	Hospital	3C – Marine	3	83.9/28.8	2020	97.9/36.6
Modesto Medical Center	Hospital	3B – Hot/Dry	12	101.7/38.7	2020	109.8/43.2
Riverside Cirby Medical Office	Medical Offices	3B – Hot Dry	11	101.8/38.8	2020	105.8/41.0
South Bay Medical Center	Hospital	3B – Hot/Dry	6	91.8/33.2	2020	92.9/33.8

Cloud-Based Diagnostic Data

Trended point data came from a cloud-based continuous commissioning and fault detection diagnostic platform. The site building automation systems (BAS) are connected to the platform. All BAS points are pulled into the platform at 5-minute intervals. These points are never deleted.

For each zone, the team downloaded a comma-separated data file with columns for (a) Timestamp, (b) Supply Air Volume Rate, (c) Room Air Temperature, and (d) Supply Air Temperature. The supply air volume rate and supply air temperature are from zone air terminal unit sensors. The supply air temperature is sensed after the zone reheat coil. The room air temperature is from a wall-mounted zone thermostat. Each file was approximately 100,000 rows of data. The team downloaded 827 zone files, containing more than 84 million records.

For each site, the team downloaded a comma-separated data file with columns for (a) Timestamp, and (b) Outdoor Air Temperature.

Room and Zone Attribute Data

To be assessed, each zone needed to be mapped to its design details. The team compiled databases including (a) zone identification, (b) function of the room with the thermostat, (c) area of the room with the thermostat, and (d) total area served by the zone. Where possible, the team gathered additional data for: (a) peak design airflows (b) design cooling loads (c) interior or perimeter (d) floor number, and (e) direction of the façade.

The team dropped some zones from the sample if the zone served disparate spaces. For the results in Table 2 and Table 3, the zones included primarily served spaces with the same function as the room with the thermostat.

Data Collection and Aggregation

The team had to clean up the data to facilitate comparison. The primary data cleaning challenges included different timestamp formats, each BAS system had different naming for the points and the design data came from different sources. From the timestamps, the team calculated (a) month, (b) hour of the day, and (c) day of the week. The team merged each zone's diagnostic data with the average hourly outside air temperature.

All calculations were performed in IP units. The results in Table 2 include conversions to SI units.

Zone sensible load was calculated for each time interval with this equation: Q_s (Btu/h) =1.08*CFM*ΔT, where "CFM" represents zone supply air volume rate and "ΔT" represents the delta between zone supply air temperature and room air temperature. Net hourly loads were aggregated from the sensible load calculations in that hour.

The team decided to limit this assessment to cooling loads. After calculating net hourly load, the team dropped all heating hours (net hourly loads greater than zero).

Loads were divided by the area of the zone (in ft²) and expressed as Btu/hr-ft². The Zone Sensible Cooling Load results are presented using percentiles (See Table 2 in the Results section). The team identified the 75%, 50%, 25%, 2%, and

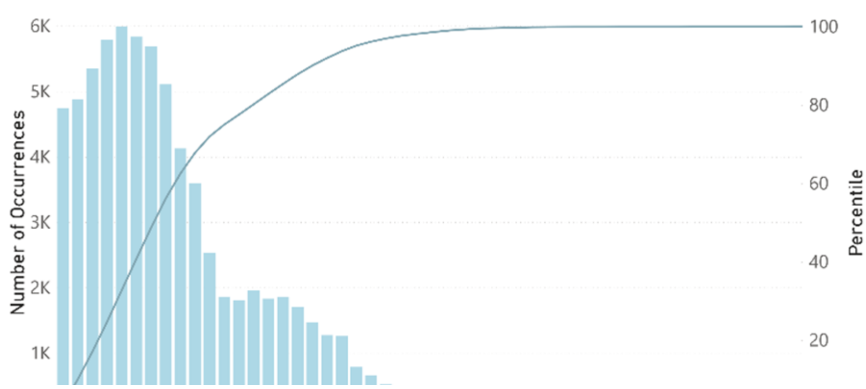

Figure 1 Histogram of Hourly Cooling Loads, for the sample Zone Type of "Patient Rooms"

0.4% exceedance levels. The team used percentiles in lieu of reporting mean and standard deviation, since the load data is not normally distributed. Using standard deviations as a measure of outliers is only applicable if the data fits a normal distribution, an example of which is shown in Figure 2. Additionally, there is precedent for the use of percentiles in cooling load calculations. ASHRAE Handbook of Fundamentals lists design weather conditions as percentiles to ensure they represent the same probability of occurrence regardless of seasonal distribution in temperature.

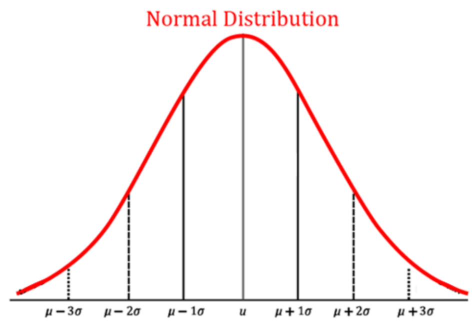

Figure 2 Example of a normal distribution where μ = mean and σ = standard deviation

The team performed quantile-quantile (Q-Q) analysis to assess normality and found it lacking. Q-Q analysis compares the quantiles of a given dataset against those of a theoretical normally distributed dataset. Figure 1 shows an example histogram for the Zone Type "Patient Room".

The team evaluated diversity by finding the maximum simultaneously occurring sensible cooling load in multiple zones of the same Zone Type (See Table 3 of the Results.) This is not air handling unit supply air or cooling coil diversity; however, zone type diversity can be used to inform duct main and shaft sizing. For most zone types, there were no hours where all zones in the sample, N_{total}, were cooling during the same hour. Figure 3 shows the variation in the number of zones that are simultaneously cooling. The biggest number of zones cooling in the same hour, $N_{max\text{-}cooling}$, isshown, with that hour. Interestingly, the hour where $N_{max\text{-}cooling}$ occurs is rarely the same hour where $Q_{block\text{-}max}$, the largest simultaneous hourly cooling load summed across all zones of the same type, occurs. Where: $Q_{block\text{-}max} = MAX\ (\Sigma Q_N)$ and $Q_{N,\ or}\,Q_{block,}$ represents the coincident sensible cooling load of a zone type at a given hour. $Q_{block\text{-}max}$ is shown in the table, with its hour. Zone Type Diversity, $D_{zone\text{-}type}$, is expressed as a function of the peak single-zone load from the sample, $Q_{zone\text{-}0.4\%peak}$. In Equation 1 below the term, $Q_{zone\text{-}0.4\%peak} * N_{total}$, represents the sum of the peak zone cooling load for a given zone type.

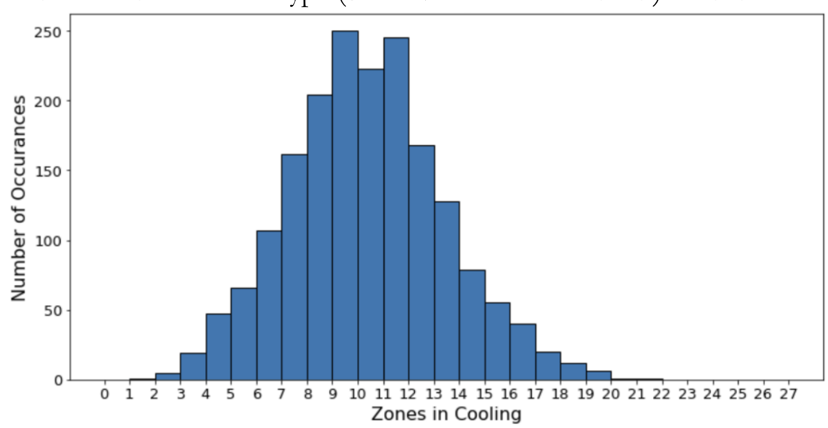

Figure 3 Histogram of the number of 27 Patient Room zones sampled in San Seandro simultaneously cooling during the same hour

$$D_{zone-type} = \frac{Q_{block-max}}{Q_{zone-0.4\%peak} \times N_{total}} \quad (1)$$

It is worth noting that while $Q_{block\text{-}max}$ and $Q_{zone\text{-}0.4\%peak}$ are shown in Btu/h-ft² in Table 3, the calculation above was performed with Btu/h units.

Outdoor air temperature. The results (in Table 2 and Table 3) include all cooling hours from May to October, for the hours of 8 AM to 6 PM.

At the project start, the team had goals to separately analyze *"neutral hours"* for perimeter spaces. *"Neutral hours"* would be those with outdoor air temperatures between 67°F and 76°F (19°C-24°C). The team assumed it would be simple to identify a strong relationship between peak load and weather. However, these analyses were not immediately conclusive. There was a strong, relevant, and reportable relationship between cooling load and time-of-day. However, analysis thus far has not revealed a strong and reportable relationship between cooling load and outdoor air temperature.

2020 versus 2019. Given that the time window for our analysis was 2020, coinciding with the COVID-19 pandemic, we performed a comparative analysis with 2019 data for a subset of zones. We selected ten patient zones in San Leandro and compared hourly loads between 2019 and 2020. We used the same monthly and hourly constraints. We found a difference between the mean hourly loads for 2019 and 2020, 4.4 Btu/h-ft^2 to 4.7 Btu/h-ft^2, respectively. While this is statistically significant, the difference is not a large one relative to cooling load planning. Additionally, the differences in loads were unrelated to visiting hours (before 6 am and after 7 pm), which had been hypothesized.

Diversity Across Sites. To help ensure that diversity calculations, shown in Tanle 3, were not unique to San Leandro Medical Center, the same calculations were performed for patient rooms at South Bay Medical Center as well as Modesto Medical Center. Patient rooms were selected for this comparison, as this zone type had the greatest available sample size across all sites. As anticipated, patient rooms in South Bay and Modesto tended to match those in San Leandro. While actual values varied due to different conditions across sites, trends followed a similar downwards pattern. As the number of simultaneously cooling zones increased, diversity decreased.

RESULTS

Table 2 shows the results for Zone Sensible Cooling Load. Table 3 shows the Diversity of Cooling Loads for multiple instances of Zone Types at the San Leandro Site.

Table 2. – Cooling Zone Sensible Cooling Load for Health Care Zone Types

Zone Type	Sample Counts					Zone Sensible Cooling Load (Btu/h-ft^2,W/m^2)				
	Total Sample Size	San Leandro	Modesto	Riverside Cirby	South Bay	75% exceedance	50% exceedance	25% exceedance	2% exceedance	0.4% exceedance
Patient Room	67	27	24	-	16	3.7, 11.8	7.0, 22.1	12.4, 39.1	24.7, 78.0	30.1, 95.1
Exam Rooms	56	23	-	33	-	2.0, 6.2	3.1, 9.6	5.6, 17.6	19.4, 61.3	30.8, 97.1
Office or Staff Workspace	56	29	-	27	-	3.2, 10.0	5.4, 17.1	9.4, 29.8	25.2, 79.5	35.8, 109.6
Patient Room ICU/CCU	40	23	8	-	17	5.5, 17.4	9.1, 28.8	13.8, 43.6	22.2, 70.1	25.4, 80.0
Nurse Station	20	20	-	-	-	8.5, 26.8	15.5, 48.9	33.2, 104.6	62.2, 196.3	70.2, 221.5
Break room or Amenities	19	9	-	10	-	3.9, 12.2	8.9, 27.8	17.0, 53.5	47.3, 149.2	54.7, 172.4
Corridors/Hallways	18	6	-	-	12	3.0, 9.4	5.4, 17.1	9.2, 29.1	49.9, 157.5	63.9, 201.7
Nursery, well-baby	15	15	-	-	-	5.1, 16.1	11.3, 35.8	21.6, 68.0	60.0, 187.9	63.4, 199.8
Imaging, X-Ray, CT, Ultrasound	14	7	-	7	-	2.5, 7.7	5.5, 17.2	11.2, 35.4	48.2, 152.1	57.0, 179.8
Waiting	12	7	-	-	5	5.1, 16.2	11.6, 36.6	23.4, 73.8	32.1, 101.4	34.6, 109.0
Procedure	11	1	--	10	-	2.0, 6.4	2.6, 8.2	3.7, 11.8	8.4, 26.4	10.2, 32.2
Airborne Isolation Room	10	9	1	-	-	7.6, 23.8	11.5, 36,3	20.3, 64.0	31.7, 99.9	34.3, 108.3
Post Anesthesia Care Unit	10	2	8	-	-	9.9, 31.3	14.2, 44.7	21.0, 66.2	51.7, 163.0	67.4, 212.5
Operating Rooms	10	10	-	-	-	4.1, 12.9	6.6, 20.7	8.9 28.1	12.4, 39.2	13.8, 43.6
Clean Workroom or Storage	7	7	-	-	-	1.9, 6.0	4.6, 14.7	11.6, 36.5	20.6, 65.1	21.3, 67.2
Med Prep Room, IV Prep	6	3	-	3	-	2.4, 7.7	4.1, 12.8	25.6, 80.9	47.9, 151.1	51.7, 163.1

Table 3 - Diversity of Cooling Loads in Multiple Zones at the San Leandro Site

		Max Number of Zones Simultaneously Cooling		Max Block Sensible Cooling Load			Zone Peak Sensible Cooling Load		
Zone Type	Total Zones in Dataset (N_{total})	Number of Zones	Day (Hr)	Block Load (Btu/h-ft², W/m²)	Num. of Zones Cooling	Day (Hr)	0.4% Peak Load (Btu/h-ft², W/m²)	Day (Hr)	Max Zone Type Diversity Factor (%)
Office or Staff Workroom	29	23	9/28 (17)	5.5 , 17.3	21	6/03 (17)	38 , 119.8	9/16 (15)	19%
Patient Room	27	21	9/28 (17)	4.3 , 13.6	18	5/27 (17)	28 , 88.3	7/24 (16)	31%
Patient Room ICU/CCU	23	23	8/18 (16)	9.4 , 30	21	7/08 (10)	21.4 , 67.5	5/19 (11)	48%
Exam/Treatment, Consult	23	20	9/25 (17)	9.7 , 30.6	17	8/23 (17)	38.5 , 121.4	8/24 (10)	25%
Nurse station	20	19	5/01 (17)	12 , 37.8	18	5/27 (17)	70.2 , 221.4	7/29 (17)	39%
Nursery, well-baby	15	13	5/09 (16)	18.5 , 58,3	12	5/08 (16)	63.4 , 200	9/08 (14)	25%
Operating Rooms	10	10	5/01 (17)	9.3 , 29.3	10	9/08 (9)	13.8 , 43.5	6/16 (8)	67%
Airborne Isolation Room	9	8	5/05 (11)	16.1 , 50.8	6	8/21 (14)	34.5 , 108.8	5/27 (8)	41%
Break room	9	8	5/08 (17)	12.4 , 39.1	6	10/19 (16)	50.2 ,158.3	10/4 (14)	24%
Clean Work. Storage, Linen	7	7	8/04 (17)	10.1 , 31.9	6	6/19 (17)	21.3 , 67.2	7/31 (17)	32%
Imaging, X-Ray, CT, Ultrasound	7	7	10/12 (17)	16.4 , 51.7	6	5/01 (17)	61.5 , 194	5/20 (14)	49%
Waiting (combined)	7	5	6/01 (17)	8.4 , 26.5	4	9/01 (17)	19.3 , 60.9	7/03 (9)	23%
Corridors / hallways	6	6	5/07 (17)	12.8 , 40.4	6	6/09 (17)	69.6 , 219.5	10/30 (14)	47%
Equipment Room	3	3	5/01 (17)	12 , 37.8	3	9/28 (17)	15.5 , 48.9	9/01 (8)	50%
Med Prep Room, IV Prep	3	3	5/12 (17)	8.9 , 28.1	3	7/28 (17)	53.4 , 168.4	8/09 (16)	76%
Laboratory	3	3	5/01 (17)	15.5 , 48.9	3	7/17 (16)	19 , 59.9	5/08 (8)	69%
Staff Sleep Rooms	3	3	5/26 (17)	8.7 , 27.4	2	6/15 (11)	17.6 , 55.5	10/30 (17)	62%

CONCLUSIONS

This data in Table 2 can be used to check the quality of load calculations and energy models. For reasonably similar climates, calculated loads which are greater or less than those identified here should be scrutinized. Likewise, if an energy model shows a profile of cooling loads that varies significantly from the percentiles, the inputs should be scrutinized.
The diversity factors shown in Table 3 can be used to check the sizing of systems which serve more than one of the various load types.

RECOMMENDATIONS FOR FUTURE WORK

There are a great many opportunities, recommendations, and ideas for further analysis. Sample size could be increased. Data could be collected from sites with more disparate weather. Data could be parsed into internal loads and external loads. The relationships to weather peaks and annual weather profiles (such as CDD and HDD) should be characterized. Internal load profiles could be developed, which could be directly input into energy models.
Readers interested in furthering this type of analysis should be aware the computing power needs are somewhat demanding. The datasets used in this project are too large to be loaded into a spreadsheet on a laptop. The team could have written a second paper on software and data management alone.

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