Minnesota Energy Efficiency Potential Study: 2020–2029

Appendix K: Commercial Large Buildings Primary Data Collection Report

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Conservation Applied Research and Development (CARD) FINAL Report

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Background

Minnesota has a thirty-plus year history of leadership in energy efficiency policy and achievements. In order to continue to maximize the benefits of cost-effective energy efficiency resource acquisition by utilities, the project team, consisting of Center for Energy and Environment (CEE), Optimal Energy (Optimal) and Seventhwave, was commissioned to:

- Estimate statewide electric and natural gas energy efficiency and carbon-saving potential for2020-2029;
- Produce data-driven and stakeholder-informed resources defining market segments, end uses, measures, and programs that could be targeted in the decade ahead to realize the state's cost-effective energy efficiency potential; and
- Engage stakeholders in order to help advance robust energy policies and energy efficiency programs in the state, and to inform future efficiency portfolio goals.

The full report, supporting documentation, and associated presentations can be found at the following website: https://www.mncee.org/mnpotentialstudy/final-report/

This appendix describes the primary data collection in large commercial buildings that was undertaken to supplement the results of the recent CARD project that characterized small commercial buildings[1]. Using the CBECS definition of buildings with areas over 50,000 square feet, large commercial buildings use about half of the energy in all commercial buildings and have potential for individual projects with large savings. The CBECS data is traditionally used as a reference point for various building characteristics, and because it is a nationwide dataset, the number of Minnesota buildings in the sample is actually small. While the state location isn't part of the dataset, the Census Division (West North Central) can be used with climate data (HDD> 6,000 and CDD<1,200), to estimate that there are less than 50 large commercial buildings from Minnesota in the data set — 9 Healthcare buildings, 9 Office buildings, 13 Education buildings, 5 Public Assembly buildings, and 9 Warehouses (none refrigerated).

Because the 50 building sample in the CBECS data set that most closely matches Minnesota is too small to be statistically sound, our survey results are compared to the CBECS results for the Midwest region, which includes data on 1,459 individual buildings (representing approximately 1.2 million total buildings).[2] The tables in this discussion include the results of the current additional data collection

[1] "Small Commercial Characterization" 2018. LeZaks, J.S. Hackel, S. Schuetter, K. Swartz, M. Lord A. Lick, Minnesota CARD Contract #104450.

[2] More information on the CBECS sampling methodology can be found here: https://www.eia.gov/consumption/commercial/2012-cbecs-building-sampling.php

(called “Minnesota Buildings”) and the CBECS data for the Midwest region (called “CBECS Midwest”) for comparison.

The results of this additional data collection informed the potential model inputs in several ways, primarily in the measure characterization and savings. In many cases the results validated the parameters taken sources other than CBECS, such as the TRM, previous potential studies and utility CIP filings. In other cases the applicability factors for measures were modified based on these results, as were many estimates of retrofit not complete.

This is a brief summary of the process from that document: “The 2012 CBECS estimates that there were 5.6 million commercial buildings in the U.S. in 2012. Because it would be impractical and prohibitively expensive to conduct interviews at all 5.6 million buildings, the Energy Information Administration (EIA) used a statistical sample that was designed to represent the entire population. For the 2012 CBECS, the final sample size was just over 6,700 completed building interviews (over a 28 percent increase from the number of buildings in the 2003 CBECS). Trained field staff conducted interviews with building owners, managers, and other personnel to collect data at each of the buildings.

In order to select a statistically valid sample that will produce accurate statistics about the commercial buildings population, each building must have one and only one chance (probability) of selection, and the probability must be known. To do this, there has to be a frame or list of commercial buildings. Currently there is no existing comprehensive sampling frame of U.S. commercial buildings, so EIA must construct a frame. The majority of this frame is called the area frame portion; it is comprised of all commercial buildings in statistically selected geographic areas. For selected geographical areas, trained field staff walked or drove through these selected areas and recorded information about every commercial building.”

Methodology

Two hundred buildings across five building types: healthcare, education, office, public assembly and warehouses; were selected, as they make up the majority of the energy use in buildings larger than 50,000 square feet. The sample size is shown in Table 1 below. Telephone surveys and site visits were used to collect the data. As noted above, this survey was designed to complement the recent Seventhwave CARD study of small commercial buildings in Minnesota (that study defined small businesses as having 50 employees or less). The complementary business definition of "51 employees or more" was used for our initial list of candidate businesses. The phone surveys were conducted in October and November of 2017. The majority of the on-site participants were then recruited from the phone surveys. When there weren't enough volunteers, direct outreach was used to reach the total required sample. Supplemental data from programs and CARD research projects is included in this report when available.

The telephone survey collected basic building and equipment characteristics (e.g. construction materials, number of stories, type of heating, cooling and lighting systems) on 201 buildings, as shown in the table below. The survey included over 80 questions, many with multiple potential answers, producing approximately 220 data fields for the responses; on average 125 data fields were populated for each respondent. The telephone survey and site visit data collection form are included at the end of this section. The questions were similar or identical to those used in the small business survey, whenever possible, so that the two studies could be easily integrated in the potential study.

Table 1: Attributes of the Samples

Building Type	Estimated Total Buildings in MN (all Sizes)	Estimated Number of Buildings in MN that are "Large"	% "Large" by Area	Number of Phone Surveys	Number of on-site Assessments*
Healthcare	3,700	400	70%	48	10
Education	5,300	1,800	75%	56	10
Office	18,000	900	50%	57	10
Public Assembly	8,000	600	50%	15	
Warehouse	13,000	700	50%	25	
Total	48,000	4,400		201	

*Each building in the on-site assessment group is also included in the phone survey group

The estimated statistical error margins (90% confidence level) for proportion-type items (e.g. % of buildings with condensing boilers) are shown in the table below for the subgroups, along with the number of buildings in the CBECS Midwest sample:

Table 2: Statistical Attributes of the Sample

	Sampling margin of error*		Total Buildings in MN Sample	Buildings in CBECS Midwest
	Survey	Site visits		
Overall (MN)	±7	±16	201	502
Healthcare	±12	±25	48	98
Education	±12	±25	56	151
Office	±12	±25	57	132
Public Assembly	±16	NA	15	46
Warehouse	±16	NA	25	75

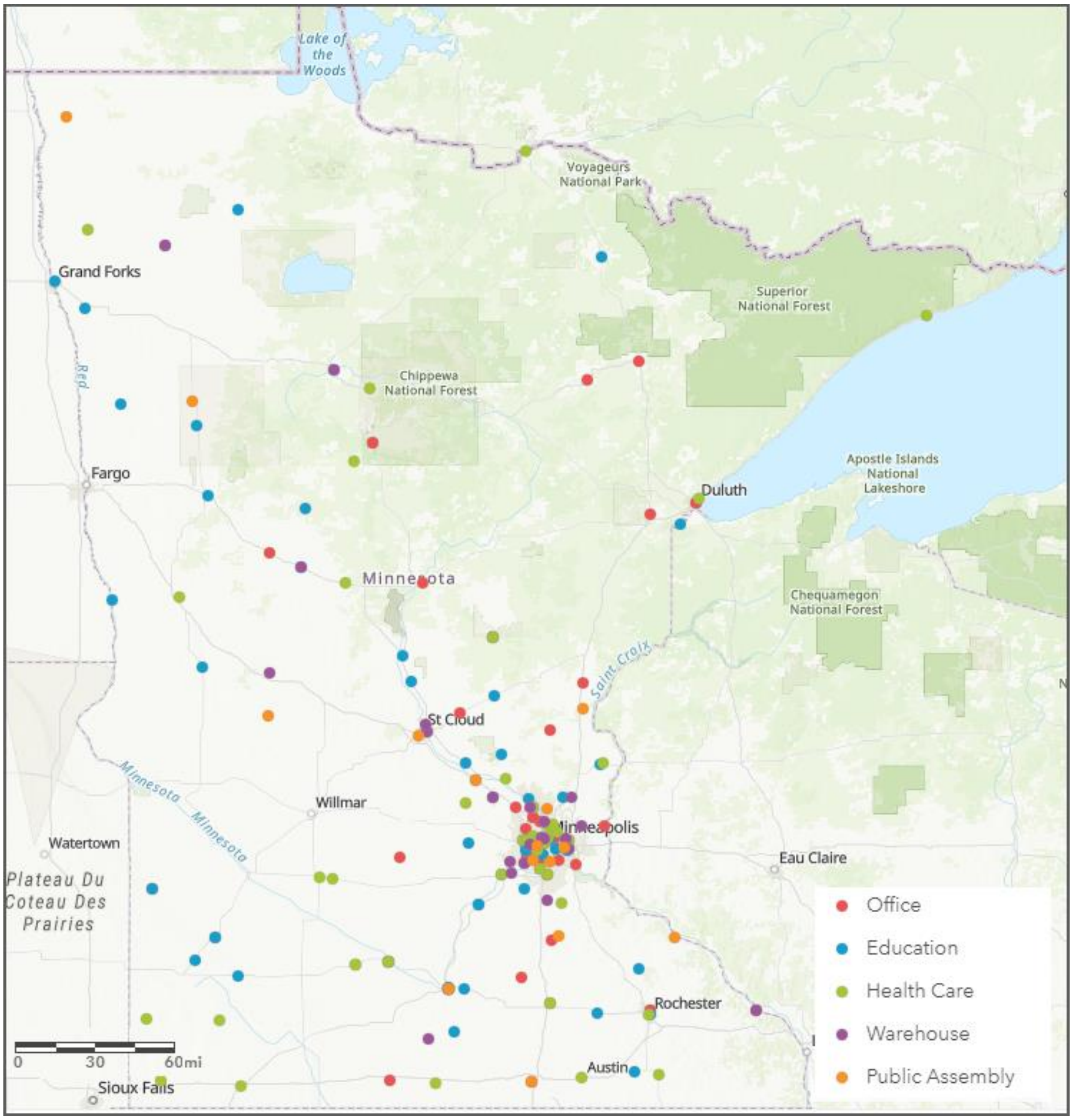
*Percentage point uncertainty at a 90% confidence level for p=0.5 proportion. Calculated margin of error includes effects of stratification and weighting.

In the discussion below, instances where the Minnesota survey data differs by more than the sampling margin of error from the CBECS data are noted.

Statewide coverage

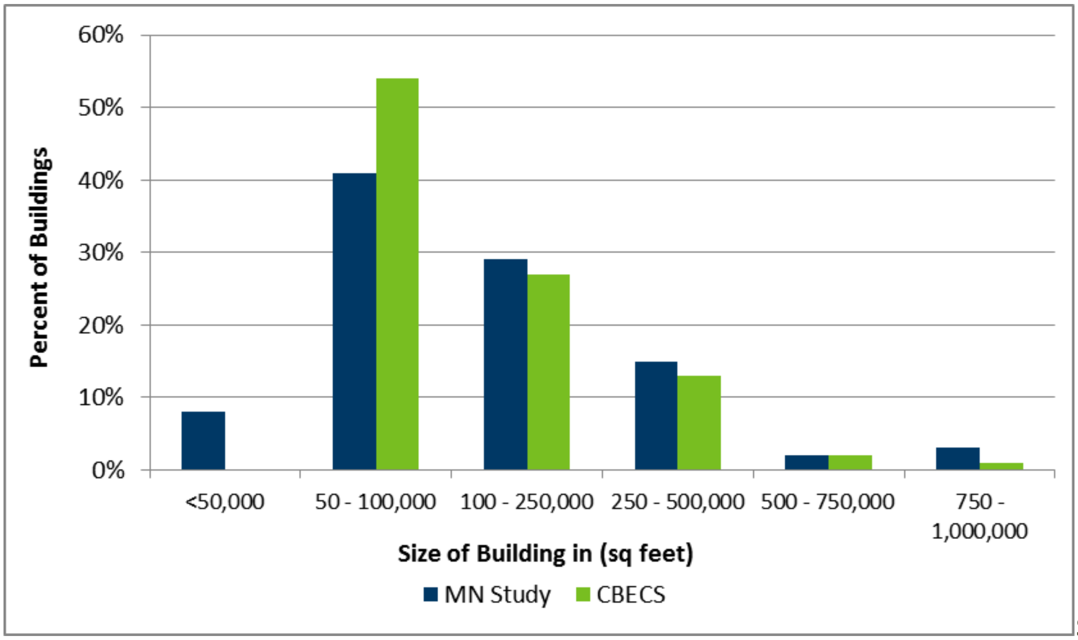
The map in Figure 1 shows the statewide distribution of the participants. The building locations are color coded by building type. For the on-site surveys an effort was made to include a diverse range of building sizes, ages and locations that reflect the building population of Minnesota.

Figure 1: Location of Large Commercial Building Participants



The building size and age distributions are compared to the CBECS 2012 data for the Midwest in Figures 2 and 3. The surveyed buildings include a small number of buildings just under 50,000 square feet, otherwise the shape of the distributions are similar.

Figure 2: Size and Distribution of Sampled Buildings compared to CBECs



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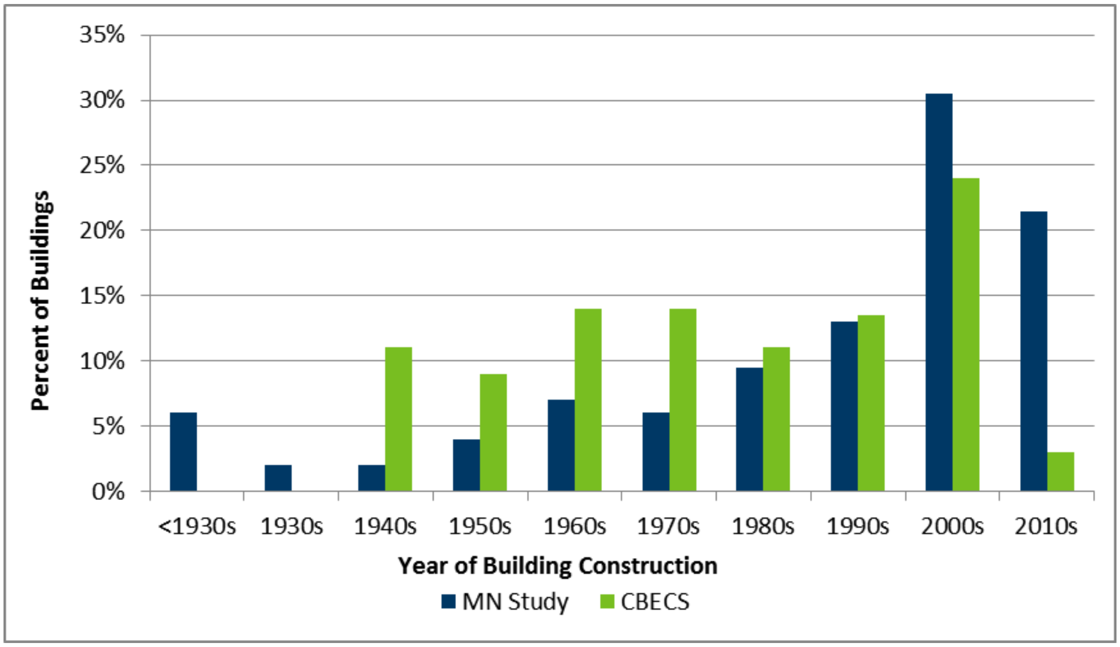
The buildings in the sample initially appear to include more newer buildings. However, this is due to the fact that CBECS only included three years of buildings from after 2010 (2010, 2011, and 2012), while the current study included seven years, a much larger base. In addition, the Minnesota survey includes more recently constructed buildings (less than 20 years old), overall. As with the building age distribution, the overall shape of the distribution is consistent with CBECS.

Figure 3: Age Distribution of Sampled Buildings compared to CBECS 2012



Onsite Survey Procedure

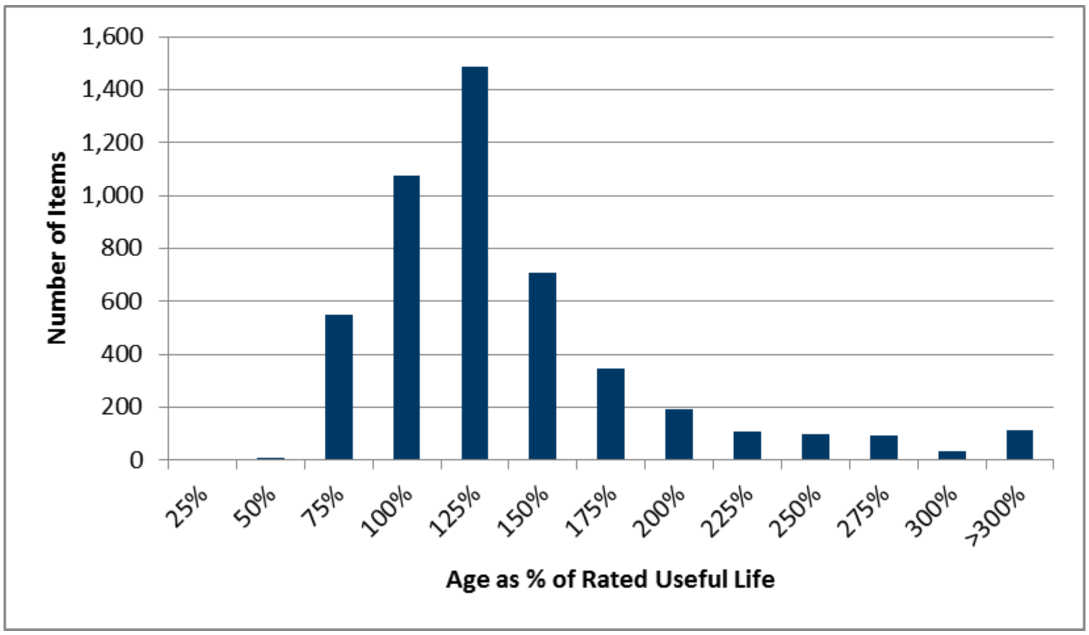
Thirty site assessments were performed during November and December 2017 by experienced energy auditors. These visits ranged from two to six hours, in contrast to the 180 telephone surveys which were only 15 minutes long. In addition to all the data that CBECS would include (other than actual energy usage), the onsite visits were used to get accurate, in-depth information about equipment age, state of repair, energy efficiency measures installed, building envelope, building staff knowledge, and interest regarding energy management. A $100 gift card incentive was offered to those hosting a site visit.

The onsite visit survey was generally conducted by two-person teams. The survey data collection included over 260 data fields, some of which had multiple entries. Each site visit began with an interview of the building operator, who generally accompanied the auditors as they walked through the building, gathering information on mechanical systems, public and private spaces, energy consuming equipment, and operational practices. The process was similar to a "Level One Audit" (without any utility bill collection) and no formal report was provided to the operators.

Age Distribution of Energy Consuming Equipment in Minnesota Buildings

The onsite visits allowed us to accurately assess the potential for energy efficiency improvements and the age and condition of existing equipment. As a benchmark, data provided by the State of Minnesota's Plant Management Division on 12,646 pieces of major energy consuming equipment from six state agencies[3] showed equipment lifetimes that significantly exceed their rated life expectancy (by 25% or more).

Figure 4: Age Distribution of Energy Consuming Equipment in State of Minnesota Buildings



The observations in the thirty on-site assessments were consistent with this finding. This has implications for the rate of adoption of energy efficient equipment that is installed when existing equipment fails, that is, if the rated useful life is used to estimate rates of equipment replacement, those estimates will be too large by as much as 50% a year. We also asked the managers at all the sites how often they replace equipment prior to failure; most said that was only done when it was a consequence of a large scale renovation project, but not just for energy savings.

[3] Report of Minnesota Department of Administration: "Minnesota Enterprise Real Property Major Energy Consuming Equipment Within or Past Five years of Useful Life" 2015.

Characteristics of Large Commercial Buildings in Minnesota

The key characteristics of the building types, based on the telephone surveys, are shown in the tables below.

Table 3: Sample Set by Building Area

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Under 50,000	15%	0%	12%	13%	4%
50-100	33%	38%	54%	33%	44%
100-250	33%	50%	23%	27%	32%
250-500	13%	11%	5%	20%	16%
>500	6%	2%	5%	7%	4%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Under 50,000	21%	33%	58%	62%	58%
50-100	45%	41%	19%	30%	11%
100-250	15%	22%	17%	5%	22%
250-500	9%	4%	4%	1%	7%
>500	11%	0%	2%	2%	2%

The CBECS Midwest sample includes a larger fraction of buildings between 25,000 and 50,000 square feet (20%), but is otherwise a good match. These buildings were included in the CBECS sample because 10% of the Minnesota buildings were under 50,000 square feet. The CBECS sample was not further subdivided due to concerns about how that might affect the CBECS weighting factors. The reason that some buildings under 50,000 square feet were included in the Minnesota sample was that the formal selection criterion was not building area, but rather number of employees (over 50) in order to properly supplement the small commercial CARD study; some of these buildings were under 50,000 square feet. This was most notable in outpatient clinics, with about half of those falling between 40,000 and 50,000 square feet. While the floor area of these buildings was slightly below the target size, the building systems and operation of these buildings was the same as those that were between 50,000 and 100,000 square feet.

Table 4: Number of Floors above Ground

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
1 floor	25%	38%	25%	40%	56%
2 floors	33%	34%	32%	40%	24%
3 -5 floors	31%	27%	32%	13%	16%
6-10 floors	8%	2%	11%	7%	4%
> 10 floors	2%	0%	2%	0%	0%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
1 floor	23%	34%	9%	58%	42%
2 floors	15%	34%	27%	21%	38%
3 -5 floors	20%	31%	50%	20%	18%
6-10 floors	37%	0%	10%	1%	2%
> 10 floors	4%	1%	4%	0%	0%

The Minnesota warehouse and office buildings are more likely to be single story than the CBECS Midwest sample. On the other hand, the CBECS public assembly buildings were predominantly single story (58%), while the Minnesota sample had an equal number of one and two-story buildings. The Minnesota healthcare buildings had a higher fraction of buildings under five floors than the CBECS Midwest sample, this is driven by a higher fraction of outpatient (clinics) in the Minnesota data — clinics are mostly two or three stories, while hospitals tend to be six or more stories. The fact that there are fewer three-five floor office buildings in the Minnesota sample is probably an artifact of the sampling method. The telephone survey focused primarily on building owners with businesses with 50 or more employees. Many three-five story office buildings are multitenant, and while the number of building occupants is over 50, the probability that one of those tenants is also able to answer questions about the energy consuming equipment in the building, is reduced. Smaller office buildings are often owned by the occupant, while larger buildings have professional management staff that responded to the survey.

Table 5: Number of Occupants

Number of Occupants	Healthcare	Education	Office	Public Assembly	Warehouse
<50	17%	27%	23%	47%	40%
50-100	33%	29%	23%	20%	24%
100-250	23%	30%	26%	7%	28%
250-500	15%	7%	12%	7%	4%
> 500	8%	7%	9%	7%	4%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
<50	12%	63%	26%	89%	77%
50-100	7%	26%	30%	8%	14%
100-250	57%	9%	26%	1%	7%
250-500	8%	2%	8%	1%	2%
> 500	17%	0%	10%	1%	0%

There are a few differences between the Minnesota and CBECS Midwest data sets that are due to differences in the questions asked by the two surveys: the Minnesota survey asked for the number of building occupants during the peak period of occupancy (generally weekdays, 8 p.m. – 5 p.m.). In schools it included students, and in healthcare it included the number of people in the building during a single shift, not the total number who would enter the building during a day. The CBECS data was based on number of employees, excluding students and members of the public who are in a public assembly building. None of these differences has an impact on the building systems or operations that are the focus of the current project.

Energy improvements that have been done or are planned

The majority of those surveyed had either undertaken projects to reduce energy use in the past 2-3 years or plan to do so in the near future (although energy savings was never given as a reason for doing a project, rather there was always some other business purpose and energy savings was a secondary benefit).

Table 6: Have Completed an Energy Improvement Project in the Past 3 Years

Energy Improvements	Healthcare	Education	Office	Public Assembly	Warehouse
MN Buildings	85%	80%	75%	84%	93%
CBECS Midwest	61%	55%	68%	64%	44%

The Minnesota sample has a higher number of recent projects; most likely due to the difference in the timeframe of the two surveys. The Minnesota survey was done in 2017 during a period of economic growth and a strong construction market, the CBECS survey came shortly after the recession of 2008-10. In addition, LED lighting entered the mainstream after the CBECS survey was done. This is clearly shown

Table 7: Type of Energy Related Improvement

MN Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Audit	15%	13%	16%	24%	40%
Lighting	44%	34%	28%	28%	40%
Heating	19%	23%	12%	4%	7%
Cooling	13%	13%	11%	4%	7%
Controls	10%	13%	4%	0%	13%
All Other	13%	7%	12%	20%	13%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Lighting	29%	22%	22%	63%	18%
HVAC	33%	20%	29%	63%	19%
Windows	16%	15%	9%	44%	2%
Insulation	8%	9%	7%	14%	3%

The CBECS data does not include information about audits, and combines heating, cooling and controls projects under the single heading “HVAC.” There is a significant difference in the number of projects done in the “public assembly” buildings. The large number in the CBECS data may be due in part to the American Recovery and Reinvestment Act of 2009 (ARRA) funded projects during this time period, which concentrated funding in public buildings. There are many more window replacement projects in the CBECS Midwest sample. As noted in a previous CARD study, due to Minnesota’s cold winters, most buildings had already completed window retrofits between 1990 and 2010. The Minnesota survey included a question about plans for future energy related improvements that did not have a counterpart in the CBECS survey. It is noteworthy that about one third of the building owners report that they have completed all the improvements they had planned, and that of those that are not yet started, over one third do not have funding for the projects. These numbers help inform the values for “retrofit not complete” and the penetration curves for retrofits during the period 2020-2029.

Table 8: Plan for Additional Improvements

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
All complete	23%	38%	21%	44%	47%
Planned	23%	20%	35%	20%	20%
Need $	46%	38%	39%	28%	27%
No plans	8%	5%	5%		7%

Table 9: Ownership & Management

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Private Owner	63%	14%	23%	33%	64%
owns w/tenants	15%	0%	16%	7%	8%
leases	2%	0%	2%	0%	4%
manages	6%	0%	12%	7%	24%
Government	15%	86%	47%	53%	0%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Private Owner	77%	26%	88%	37%	87%
Government	23%	74%	12%	63%	13%

The ownership breakdown found in the Minnesota survey largely agrees with that given in CBECS. The one notable exception is the number of government owned office buildings reported in Minnesota. This is probably a sampling artifact due to two factors: (1) one of our building lists included only public buildings, and (2) multitenant buildings, which are almost all privately owned, are underrepresented in our sample because (as previously discussed) the business list we used included only businesses with over 50 employees, which would exclude a building with several small businesses that taken together have a larger number of total employees at the location; in addition, we only received responses from a small number of property management companies. It did not appear that ownership was strongly correlated with any of the other building attributes we examined.

Table 10: Maintenance Practices in Minnesota Buildings

Responsible Party	Frequency	Healthcare	Education	Office	Public Assembly	Warehouse
Own Staff	Multiple times	71%	63%	54%	60%	28%
Own Staff	Seasonal	0%	9%	2%	0%	8%
Own Staff	As needed	2%	0%	0%	0%	28%
Contractor	Multiple times	23%	11%	33%	33%	20%
Contractor	Seasonal	2%	5%	4%	0%	0%
Contractor	As needed	0%	4%	5%	0%	4%

Many of the large commercial buildings have a dedicated maintenance staff; as a consequence, they were likely to be maintained by the owner, and maintenance activities are performed multiple times per year. In the warehouse category, there is a significant difference between the refrigerated warehouses (all are maintained multiple times per year) and non-refrigerated warehouses, which are the most likely to only perform maintenance when the need is apparent. While the telephone survey indicated that most large commercial buildings perform maintenance “multiple times per year,” the onsite visits showed a wide range of the quality of this work: at one end of the scale (the best) we saw mechanical rooms that were spotless with all equipment labelled and a full set of up to date operating manuals available at all times; at the other end were rooms that were piled high with other equipment making it impossible to easily reach access panels on equipment, and no manuals or maintenance logs visible.

Energy Plan

The Minnesota survey asked respondents if they had an energy plan, and overall about one-third had a plan. However, when asked in the on-site assessments about details related to their energy management plans, only about half of those with a plan could provide any details about it, or provide a copy of a written document. This implies that while energy plans are often created, they may not be followed in the long run. In addition, at about one-third of the sites, the energy plan was the created by a central owner’s office, property management company, or agency and the front-line staff was not familiar with its contents. This has implications for the willingness to participate in operator savings programs and was used in setting the applicability factors for those savings measures.

Table 11: Energy Plans in Minnesota Buildings

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Have an Energy Plan	40%	42%	20%	13%	5%

Envelope Characteristics

Only limited data on the building envelope was collected, primarily because most of the building owners and operators interviewed didn't know what was "inside the walls." Thus, any data reported is merely qualitative. The majority of respondents reported that their buildings were constructed to the code requirements at the time they were built, and no additional insulation had been added. The Minnesota results are consistent with CBECS, where less than 10% of the respondents to the CBECS Midwest survey reported doing insulation upgrades. These observations were used when assigning applicability factors for deep energy retrofits in large commercial buildings.

Table 12: Presence of Insulation in Minnesota Buildings

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Has Insulation	94%	77%	77%	87%	64%
No Insulation	2%	11%	14%	13%	28%
Unknown	4%	13%	9%	0%	8%

Information on windows is more easily observable, and is reported on in the two tables below. Minnesota buildings all but one of the building types have 90% or more multi-paned windows, the exception is warehouses (which have a very small overall window area, less than 10% of the wall area), with 64% multipane windows. As noted previously (following Table 7), window improvements were made in many Minnesota buildings earlier than in other parts of the United States (1980's and 1990's) and double pane windows have been standard in new construction for several decades, due to the cold winters.

Table 13: Window Characteristics of Minnesota Buildings

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Triple	0%	7%	2%	0%	0%
Double	88%	80%	84%	87%	64%
Storms	2%	2%	4%	0%	0%
Single	6%	7%	9%	0%	20%
Unknown	4%	0%	0%	13%	16%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Multipane	82%	63%	69%	70%	44%
Both	17%	28%	16%	26%	46%
Single	1%	8%	15%	4%	10%
Tinted (any number of panes)	52%	51%	68%	63%	42%

The fraction of buildings reporting over 50% window to wall area in the Minnesota phone survey is higher than that in the CBECS Midwest sample (for example, Healthcare 19% vs. 11%; Education 9% vs. 1%; Office 28% vs. 15%; Public Assembly 27% vs. 1%; and warehouse 12% vs. 0%). This is likely a systemic error caused by self- reporting in the telephone surveys. The on-site assessments were consistent with the CBECS Midwest values. In general, values based on estimates of capacities and sizes in the telephone surveys were found to be less accurate than those collected by trained building auditors in the onsite surveys. This data quality observation is consistent with information presented about the CBECS survey at a recent conference.[4]

[4] "EIA Building Data (RECS and CBECS) and Forecast Analysis (AEO) Update," J. Michaels, August 22, 2016 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA.

Table 14: Window Area of Minnesota Buildings

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
None	6%	2%	7%	0%	4%
<25%	40%	55%	46%	60%	84%
26-50%	29%	32%	16%	7%	4%
51-75%	13%	9%	19%	20%	8%
> 75%	6%	0%	9%	7%	0%
UNK	6%	2%	4%	7%	0%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
None	0%	4%	1%	52%	39%
<25%	56%	80%	49%	35%	49%
26-50%	28%	10%	16%	4%	9%
51-75%	9%	0%	6%	0%	0%
> 75%	2%	1%	9%	1%	0%
UNK	5%	3%	20%	9%	4%

Energy Using Equipment

Hours of Operation and Temperature Set Points

The most notable differences between the hours of operation in the two surveys are probably due to the small sample sizes for public assembly and warehouse buildings in the Minnesota telephone survey. In addition, in the Minnesota telephone survey, this answer was based on the hours that a building had some occupancy and was available for use, not the official “regular business hours of operations;” thus 7 of the 15 Minnesota public assembly buildings reported that they could be used for events from 6 a.m. to midnight, 7 days a week. On the other hand, the warehouses in the Minnesota telephone sample of 25 buildings apparently did not include any that were used for long periods every day.

Table 15: Hours of Operation

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
40-50	6%	20%	39%	13%	16%
50-60	8%	18%	23%	7%	20%
60-80	19%	25%	23%	20%	12%
80-100	4%	9%	7%	0%	16%
over 100	38%	29%	2%	47%	0%
UNK	25%	0%	7%	13%	36%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
40-50	0%	31%	26%	9%	21%
50-60	30%	37%	40%	9%	35%
60-80	11%	10%	4%	54%	18%
80-100	9%	16%	17%	7%	8%
over 100	50%	6%	14%	21%	18%

Although the results are more qualitative than quantitative, the hours of operation are of particular interest when combined with the information about the use of temperature set point changes during unoccupied hours. A large fraction of the buildings that are occupied less than 100 hours per week do not report changing their temperature set points; this is shown in the tables below. This was used to determine applicability and savings potential of measures for advanced thermostats, building automation systems, energy management systems and operator savings programs.

Table 16: Use of Temperature Setups and Setbacks

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Setback	15%	63%	47%	73%	20%
Setup	10%	52%	42%	53%	16%
Night cool	4%	20%	18%	13%	4%
None	85%	38%	53%	27%	80%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Setback	20%	36%	41%	84%	48%
Setup	18%	32%	41%	81%	50%

The use of setpoint changes is slightly higher in the Minnesota buildings than in the overall CBECS Midwest data set. In either case, there is a large opportunity for increased savings from this simple measure, particularly in healthcare buildings, where the great majority (80 to 85%) don't ever change their temperature setpoints.

Figure 5: Temperature Set Points

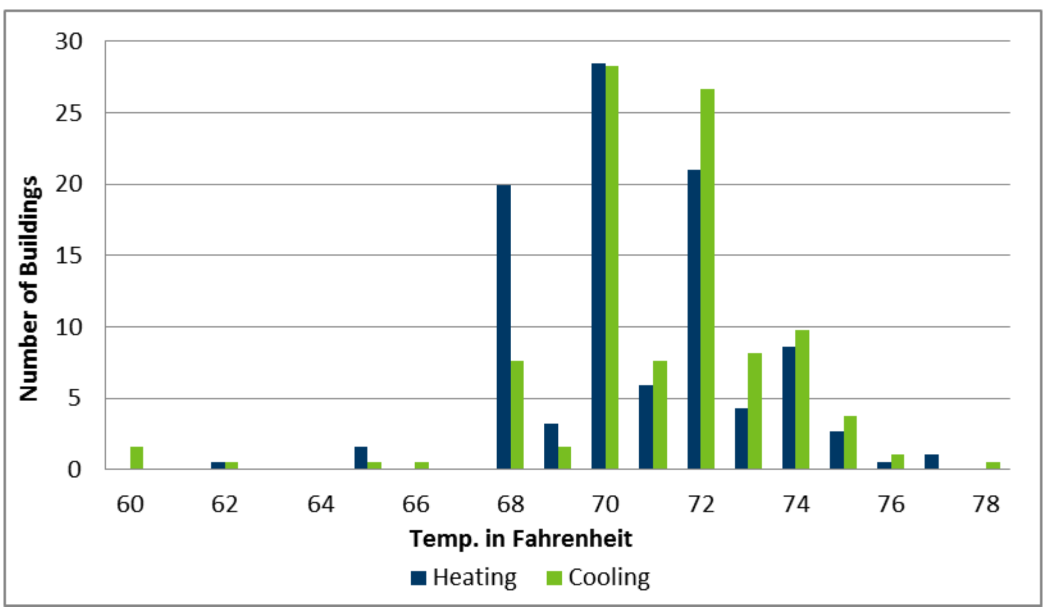
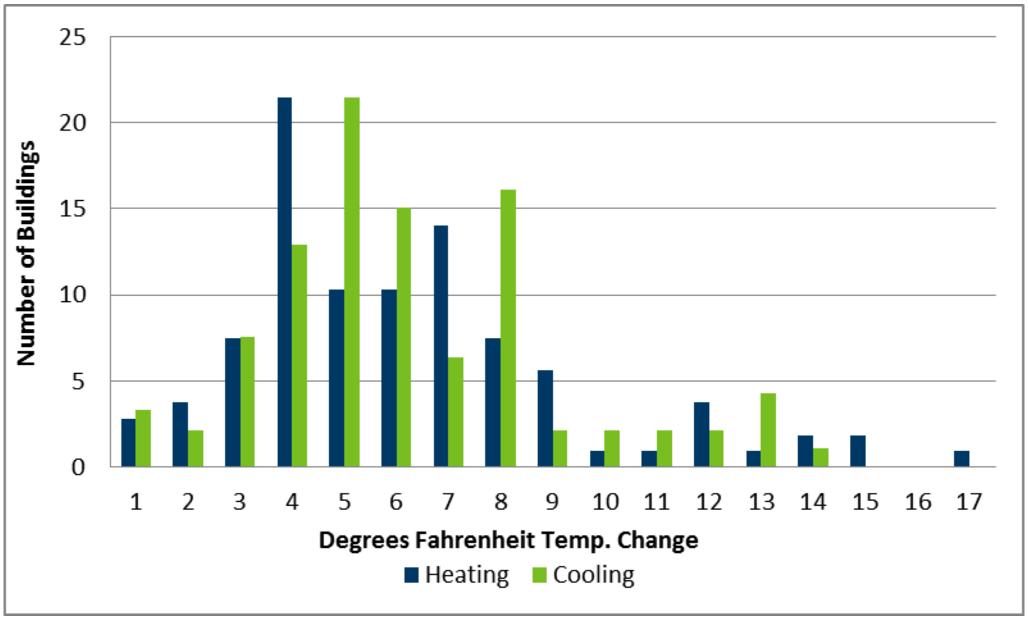


Figure 6: Set Point Temperature Changes



Actual temperature set points were reported in the Minnesota telephone survey, but there is no corresponding data from CBECS. The magnitude of the set point change is shown in Figure 6, although in winter the temperature is set lower during unoccupied hours (setback) and in summer it is set higher (setup)[5]. The average set up in summer (+5.3 F) is larger than the winter setback (-3.5 F), implying greater potential exists for increased heating energy savings.

Building Control Systems

The Minnesota survey results showed a much higher level of penetration of building automation systems than the CBECS survey. While some of this may be due to the implementation of new systems in the five years between the two surveys, it probably reflects a real difference in how large buildings in Minnesota are operated and controlled. The most extreme difference is in the public assembly buildings, where the Minnesota sample found 87% had building automation systems, while CBECS had only 29%. The primary control in the CBECS public assembly buildings was by programmable thermostats, as shown in the following table. These values were used in assigning the applicability factors for EMS related measures for these large commercial building types.

[5]) Some users reported setting their temperatures "back" in cooling season. This probably indicates a misunderstanding of the survey question, or a data entry error by those recording the survey responses, as no pre-cooling during off peak hours was observed in any site visits.

Table 17: Buildings with Automation Systems (BAS)

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
BAS	80%	82%	75%	87%	5%
BAS has dedicated computer	76%	77%	57%	73%	5%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
BAS	41%	28%	27%	29%	8%

The number of manual thermostats in Minnesota buildings is higher than the CBECS Midwest sample. The number of buildings with manual thermostats correlates well with the number of buildings that do not change their set points during unoccupied hours.

Table 18: Temperature Control Systems

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
BAS	77%	77%	68%	80%	8%
Programmable Thermostat	4%	7%	12%	7%	60%
Manual Thermostat	15%	5%	16%	7%	12%
Other	0%	2%	2%	0%	4%
None	4%	9%	2%	7%	16%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
BAS	45%	56%	39%	16%	5%
Programmable Thermostat	3%	20%	39%	58%	42%
Manual Thermostat	1%	9%	3%	10%	6%
Turn Off	0%	2%	0%	0%	2%
NA	52%	13%	18%	16%	46%

Heating and Cooling Systems

The tables below show the main heating and cooling systems by building type. The majority of buildings used only a single type of system for heating, while multiple systems were more commonly seen with cooling. For example, a large school that has had multiple additions over the years may have a central chiller, but new additions may have dedicated roof top units (RTU's). These tables show only the primary source of heating or cooling. The Minnesota values were used for the applicability factors of heating measures in the potential model.

Table 19: Primary Heating Systems

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Boiler	79%	76%	42%	53%	16%
RTU	6%	5%	22%	40%	32%
District	11%	9%	16%	0%	4%
HP	2%	9%	9%	0%	12%
Forced air	0%	0%	9%	0%	20%
Radiant	0%	0%	0%	7%	8%
Unknown	2%	0%	2%	0%	4%
Electric baseboard	0%	0%	0%	0%	4%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Boiler	67%	61%	43%	29%	22%
RTU	26%	24%	41%	26%	0%
District	7%	7%	3%	4%	4%
HP	0%	2%	3%	0%	1%
Forced air	0%	1%	6%	12%	32%
Individual space heaters*	0%	3%	4%	30%	27%
Other	0%	2%	0%	0%	15%

*Individual heaters includes baseboard electric heat, infrared radiant heaters, unit heaters, wall heaters and portable space heaters.

The Minnesota data includes a higher percentage of boilers for healthcare, education, public assembly buildings, and a lower percentage of RTU's for all building types except for public assembly and warehouses. Heat pumps were seen in a number of buildings, primarily those between 50,000 and 150,000 square feet. District energy was also more common in the Minnesota buildings than in the CBECS Midwest data set, possibly due to our sample that included buildings in the larger Minnesota cities that have district systems and campuses with central heating plants for a group of buildings.

Table 20: Primary Cooling Systems

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Chiller	53%	44%	27%	47%	4%
District	4%	4%	4%	0%	0%
RTU	36%	35%	42%	33%	64%
HP	0%	5%	13%	13%	0%
Residential	0%	0%	5%	0%	0%
Other (incl split systems)	4%	0%	8%	0%	16%
Window	2%	5%	2%	7%	8%
None	0%	7%	0%	0%	8%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Chiller	63%	38%	35%	5%	6%
District	4%	4%	3%	2%	0%
RTU	33%	35%	51%	44%	53%
Heat Pumps	0%	3%	2%	0%	2%
Residential AC	0%	7%	9%	48%	24%
Window Units	0%	11%	0%	0%	1%
NA	0%	3%			15%

There are two notable differences between the Minnesota buildings and the CBECS Midwest data set, the first one is probably due to the sample — the Minnesota public assembly buildings are mostly cooled with chiller systems, while the CBECS sample is served equally by RTU's and residential systems. Residential style units were not common in these large Minnesota buildings, although they are a significant source of the systems in the CBECS sample. (They were commonly seen in the characterization study of Small Commercial buildings in Minnesota.) However, this may be an issue of definition. The second difference is probably due to the fact that the Minnesota survey is more recent and, thus, includes an emerging technology that was not even listed in the CBECS Midwest data: split systems. These systems do offer the potential for energy savings.

In the Minnesota survey, information was collected on system age in order to determine the average lifetime of equipment. The results below show that over half the equipment is replaced after 20 or more years of use. This is consistent with the data from the State of Minnesota's building equipment inventory shown in Figure 4. Comparable information is not included in the CBECS data.

Table 21: Age of Primary Heating Systems

Age at replacement (years)	Cooling	Heating
<5	5%	9%
6-10	12%	13%
11-15	10%	9%
15-20	15%	18%
20-30	16%	15%
30-40	15%	15%
>40	26%	22%

The CBECS survey also included information on economizers, which is shown below. This information was not collected in the Minnesota telephone survey and was only a qualitative observation in the on-site visits. These values result in the values of retrofit not complete for many energy efficiency measures to be higher than would be expected if all equipment were replaced at the end of its "useful life," as opposed to when it fails to perform adequately.

Table 22: Prevalence of Economizers (CBECS only)

CBECS Midwest	Healthcare	Education	Office	Public Assembly	Warehouse
Air side	81%	58%	58%	36%	28%
Water side	3%	2%	0%	0%	0%
No economizer / unknown	17%	39%	42%	64%	72%

Energy End Uses by Building Type

Large buildings frequently have multiple end uses of energy, some of which may not be expected based on their primary use. The table below shows the percentage of buildings in each category that have one of eight common energy end uses. The major impact of this result on the potential for future savings is that many measures can lead to significant savings in buildings that are not in the common target markets of programs (for example refrigeration focused only on food sales, service, restaurants and convenience stores would miss large opportunities in healthcare, education and public assembly buildings).

Table 23: Primary Energy End Use by Building Type

MN Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Laundry	42%	36%	11%	20%	0%
Commercial Kitchen	60%	88%	26%	53%	12%
Data Center	65%	73%	68%	73%	76%
Medical Equipment	77%	0%	0%	0%	0%
Pool	15%	16%	4%	33%	0%
Refrigeration	67%	84%	21%	53%	28%
Process	44%	55%	21%	60%	68%
None	0%	4%	19%	13%	16%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Laundry	8%	0%	0%	0%	0%
Commercial Kitchen	25%	18%	1%	9%	0%
Data Center	20%	8%	10%	1%	6%
Medical Equipment	18%	0%	1%	0%	0%
Pool	5%	3%	0%	5%	0%
Refrigeration	53%	44%	46%	95%	88%
Process	0%	1%	1%	3%	29%

The Minnesota data differs significantly from CBECS in many of these categories, especially laundry, commercial kitchen and data centers, all of which are at least double the values found in Midwest CBECS. Detailed information on the end uses is provided below.

Lighting

Table 24: Lighting Types by Building Type

Minnesota Buildings: PRIMARY lighting	Healthcare	Education	Office	Public Assembly	Warehouse
Linear fluorescent	66%	69%	76%	60%	68%
CFL	15%	5%	7%	0%	4%
LED	19%	24%	15%	40%	28%
HID	0%	2%	0%	0%	0%
Incandescent	0%	0%	2%	0%	0%
CBECS Midwest: ALL lighting present	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Linear fluorescent	56%	44%	55%	92%	89%
CFL	47%	29%	37%	89%	55%
LED	18%	8%	14%	24%	13%
HID	34%	15%	12%	50%	20%
Incandescent	39%	18%	23%	48%	37%

The two data sets are consistent with one another once one accounts for two things: (1) the Minnesota data lists only the primary lighting type, while the Midwest CBECS data includes all lighting types found in a building, and (2) the CBECS sample was taken before LED lighting became commonplace, so those numbers are out of date.

Table 25: Prevalence of Lighting Controls by Building Type

MN Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Occupancy sensors	11%	39%	19%	36%	33%
Timeclock/BAS	26%	15%	6%	7%	4%
Dimmers	2%	0%	4%	0%	4%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Occupancy sensors	21%	21%	32%	46%	29%
Timeclock/BAS	25%	15%	22%	63%	14%
Dimmers	13%	7%	6%	24%	1%

There are several major differences in the penetration of lighting controls reported in the two samples: significantly more dimmers are reported in CBECS Midwest, and slightly more occupancy sensors. In the CBECS Midwest survey these two lighting controls are reported when present, while in the Minnesota data we attempted to measure the percentage of lighting that could be affected by the control. Both samples are only useful for qualitative analysis. They do indicate a slowly growing adoption of lighting controls.

The CBECS Midwest data included information on lighting that is left on when buildings are unoccupied, shown below. This data was not collected in the Minnesota survey.

Table 26: Buildings with Lights on During Unoccupied Hours (CBECS Only)

CBECS	Healthcare	Education	Office	Public Assembly	Warehouse
None	2%	30%	21%	62%	48%
<25%	32%	59%	71%	36%	44%
26-50%	44%	6%	5%	1%	7%
51-75%	8%	4%	0%	0%	1%
>75%	14%	1%	3%	2%	1%

Hot Water

The water heating fuel was recorded in both surveys and is shown in Table 27. Overall, it is observed that Minnesota has a significantly higher proportion of gas hot water heating than the CBECS Midwest sample, and none of the surveyed Minnesota buildings reported fuel oil or district energy as the primary fuel for water heating.

Table 27: Hot Water Heating Fuel by Building Type

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Electric	5%	10%	31%	0%	30%
Natural gas	92%	85%	66%	100%	70%
Propane	3%	4%	3%	0%	0%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Electric	9%	14%	36%	6%	52%
Natural gas	44%	33%	20%	85%	47%
Propane	0%	1%	0%	8%	0%
District	6%	2%	0%	3%	0%
Fuel Oil	0%	0%	0%	0%	9%

The Minnesota survey collected more detailed information about water heaters than CBECS. The categories include water heater type — “boiler” means that a combination system that uses the same boiler that heats the building is used for producing hot water; “All others” includes instantaneous, (tankless) systems and other endpoint water heating (including water heaters built into equipment like dishwashers). CBECS does not include reporting on either of these, which are shown in the tables below.

Table 28: Hot Water Type Distribution (No CBECS Data)

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Boiler	20%	24%	6%	8%	9%
Commercial storage	68%	73%	65%	92%	55%
Residential Storage	5%	0%	23%	0%	36%
Other	7%	2%	6%	0%	0%

Table 29: Hot Water Heater End Uses (No CBECs Data)

	Healthcare	Education	Office	Public Assembly	Warehouse
Sinks	94%	91%	93%	77%	96%
Dishwashing	51%	72%	24%	38%	20%
Showers	62%	48%	20%	54%	4%
Laundry	32%	19%	11%	23%	4%
Facility cleaning	17%	15%	7%	8%	16%
No HW	0%	4%	0%	0%	0%

The data in the tables above was used to determine the applicability factors in the potential model.

Plug Loads (also called Miscellaneous End Uses)

Plug loads include computers, shared office equipment (this category includes break room equipment like shared refrigerators and microwaves, but not commercial kitchen equipment which is in the "cooking" end use), data centers, and loads such as plug-in space heaters, elevators, and escalators. The survey looked at office equipment for which energy efficiency measures are included in the potential analysis.

While both surveys collected information on the presence and approximate size of data centers, as well as number of computers and occupants, it appears that the questions were interpreted differently in the two survey groups. This is most clearly seen in the percentage of buildings reporting a data center (including server closets). According to the Minnesota results, half or more of all the buildings had data centers, while according to CBECS the numbers were much lower, only 26% of office buildings and 11% of education buildings. In our onsite visits we observed dedicated rooms with one or more server racks in 60% of the buildings (many in the under 500 square foot category); these values were used for the applicability factors in the potential model.

Table 30: Prevalence of Data Centers and Data Closets

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Data center	51%	64%	60%	67%	48%
Network closet	40%	27%	26%	27%	28%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Data center	46%	11%	26%	1%	6%

About half of the data centers had some form of cooling, most commonly as either a distribution point or actual zone within their building cooling system; about 10% overall had dedicated cooling from computer room air conditioning (CRAC) units. Details are shown in the table below.

Table 31: Data Center Cooling (No CBECS Data)

Minnesota survey data	Healthcare	Education	Office	Public Assembly	Warehouse
CRAC	13%	7%	9%	7%	8%
RTU	15%	29%	37%	20%	24%
Split AC	21%	20%	7%	20%	20%
Heat Pump	0%	5%	7%	7%	0%
Exhaust Fan	4%	4%	2%	7%	4%
4 Pipe Fan Coil	2%	0%	0%	0%	0%
Chilled water system	2%	0%	0%	0%	0%
Chiller	2%	0%	0%	0%	0%
Window Unit	2%	2%	0%	0%	8%
None	2%	5%	4%	13%	4%

Data was collected in the Minnesota survey on number of computers and number of building occupants in order to get space densities as shown below.

Table 32: Occupant and Computer Density by Building Type (No CBECS Data)

Minnesota	Healthcare	Education	Office	Public Assembly	Warehouse
Computers/occupant	0.56	1.88	0.86	0.42	0.41
Sq. ft./Occupant	733	961	607	713	1023

It should be noted that the number of occupants of education buildings was inconsistently answered by respondents, some included students while others only counted staff. The number of computers per occupant reported for offices is lower than the value of 1.03 per occupant reported in a recent CARD study of office plug loads.[6]

Computer power management has been shown to produce energy savings of up to 30% per workstation, but good data is not available about the degree of implementation. To address this data gap, information was collected on the use of computer power management in this survey. Interestingly, while many respondents said that their computers "went to sleep," fewer knew whether they had enabled computer power management, as is shown by the fact that about 15% of the respondents did not know either way.

Table 33: Use of Computer Power Management (No CBECS Data)

	Healthcare	Education	Office	Public Assembly	Warehouse
Yes	54%	32%	35%	20%	16%
No	38%	46%	53%	47%	68%
Unknown	8%	21%	12%	33%	16%

Cooking

Cooking facilities were reported in at least 10% of each of the large building types, including virtually all K-12 education buildings (the exception being college campuses where a single building is often dedicated to food service while other buildings are exclusively classroom, office or laboratory) and most healthcare facilities. The fraction of healthcare and education buildings with cooking facilities in Minnesota is approximately double that expected based on CBECS. This was confirmed in the on-site assessments. A summary of the prevalence of different types of kitchen equipment found in each building type is included below.

[6] "Impacts of Office Plug Load Reduction Strategies: Quantifying plug load usage, the potential for reduction, and the impact on users." 2016, Hackel, S, C. Plum, C., M. Colburn, G. Marsicek, T. Rozenbergs, N Kessler, R. Carter and L. Kieffaber. Minnesota CARD Contract #87091.

Table 34: Cooking Energy End Uses (by Appliance Type)

Minnesota	Healthcare	Education	Office	Public Assembly	Warehouse
Fryers	60%	88%	26%	53%	12%
Griddles	27%	14%	2%	27%	8%
Ovens	38%	25%	4%	33%	8%
Broilers	52%	68%	12%	40%	4%
Hoods	10%	11%	0%	20%	0%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
“Energy used for cooking”	31%	31%	13%	38%	13%

Refrigeration

As with cooking, refrigeration equipment was found in all building categories. For the most part, the results agree with those in CBECS, with one notable difference: the number of walk-in coolers and freezers found in Minnesota were double those reported in CBECS in all building types except for warehouses. In warehouses they are the same in both data sets, between 12 and 20% (recall that the margin of error in the Minnesota data for warehouses is +/- 16%). The larger fraction of walk-in units was validated in our on-site assessments. For example, every K-12 school had both a walk-in refrigerator and walk-in freezer, as did all hospitals. The CBECS values for ice machines and residential type refrigerators are consistent with what was observed in the thirty on-site surveys. These values were used to determine the applicability factors of many of the commercial refrigeration measures.

Table 35: Refrigeration Equipment in Large Commercial Buildings

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Open refrigerator cases	23%	29%	2%	13%	0%
Open freezer cases	8%	9%	2%	7%	0%
Refrigerator cases with doors	35%	30%	5%	20%	0%
Freezer cases with doors	23%	14%	2%	20%	0%
Walk-in cooler	52%	71%	11%	40%	20%
Walk-in freezer	52%	70%	7%	20%	12%
Service Cooler	27%	27%	2%	40%	0%
Service Freezer	27%	20%	2%	40%	0%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Open refrigerator cases	21%	8%	2%	6%	2%
Closed refrigerator cases	36%	24%	5%	29%	12%
Walk-in units	28%	26%	9%	16%	6%
Large cold storage areas	1%	2%	0%	1%	14%
Commercial ice makers	46%	18%	9%	34%	3%
Refrigerated vending machines	52%	30%	38%	40%	44%
Full-size res. type fridge	49%	35%	35%	83%	84%

Large refrigeration systems, such as those commonly seen in grocery stores, typically have one or more centrally rack mounted compressors that serve multiple end point units (both refrigerator and freezer spaces). The energy efficiency measures for these systems are different from those for self-contained units, so data was collected on their prevalence. The rack mounted systems were found in refrigerated warehouses, hospitals, and large schools — although self-contained units were the most common in all building types except for warehouses.

Table 36: Type of Refrigeration System (Central Rack or self-contained units) (No CBECS Data)

Type	Healthcare	Education	Office	Public Assembly	Warehouse
Compressor rack	24%	21%	11%	0%	80%
Self-contained	62%	66%	67%	86%	20%
Both	7%	2%	0%	0%	0%
NA	7%	11%	22%	14%	0%

The maintenance frequency for refrigeration equipment appears to be directly related to the size and amount of equipment. In buildings with a small number of self-contained units (especially offices), maintenance is done “as needed,” while in the facilities where refrigeration is a critical component of the operation, maintenance is done multiple times per year.

Table 37: Refrigeration Maintenance Frequency (No CBECS Data)

Type	Healthcare	Education	Office	Public Assembly	Warehouse
Multiple times/year	77%	32%	33%	71%	100%
Annual	7%	19%	0%	0%	0%
As needed	13%	36%	44%	29%	0%
Unknown/NA	3%	13%	22%	0%	0%

Other energy uses in buildings

While “other” end uses represent a small percentage of total building energy use in commercial buildings, there are opportunities for efficiency measures. In particular, air compressors are the most common type of equipment not included in the standard energy end uses and they are one where significant savings through operational changes can often be realized.

Table 38: Prevalence of Other Energy End Uses

Minnesota Buildings	Healthcare	Education	Office	Public Assembly	Warehouse
Compressor	31%	30%	14%	33%	44%
Shop	15%	18%	4%	20%	16%
Other process	0%	0%	0%	0%	24%
Indoor pool	13%	13%	2%	33%	0%
Medical	23%	0%	0%	0%	0%
CBECS Midwest	**Healthcare**	**Education**	**Office**	**Public Assembly**	**Warehouse**
Process energy used	0%	1%	1%	3%	29%
Indoor pool	5%	3%	0%	5%	0%
Medical equipment	18%	0%	1%	0%	0%

The CBECS survey asked slightly different questions and did not specifically inquire about compressors, which were found in over 25% of the large Minnesota buildings, even though these buildings are not considered to have process (or manufacturing) energy use. Because air compressors offer a significant energy savings opportunity, their presence in such a large number of buildings should not be overlooked. A higher number of buildings with indoor pools was found in Minnesota buildings, than would have been expected from CBECS data (about 10% of all buildings surveyed vs. 3% expected from CBECS). A recent CARD study identified a variety of savings opportunities in public pools.[7]

[7] "Optimized Operation of Indoor Public Pool Facilities," 2017, Landry, R., D. Sui and T. Ellingson. Minnesota CARD Contract #73813.

Qualitative Results from On-Site Assessments

The thirty on-site assessments of healthcare, education and office buildings allowed more detailed information about equipment to be collected, as well as information on maintenance and other practices. Key findings are summarized here. It is important to note that these are qualitative results and should not be used as a source for quantitative values of market penetrations, for example.

Interviews of the facility managers and building operators provided information on the use of utility programs, as well as energy management, which are summarized below. A variety of methods of benchmarking energy use were found, ranging from third party databases like ENERGY STAR and Minnesota, Benchmarking and Beyond (B3) to internal benchmarking using proprietary software tools, often for a portfolio of buildings of a property management firm. While most building owners or property managers have an energy plan, only about half of the operators had a copy of the plan available, and they generally could not provide details of the plan (for example, answering that the hours of operation were defined in the plan, but they were unsure of what the weekend hours were). These results are consistent with the phone surveys regarding energy improvement projects and that operators are aware of energy efficiency at a high level, but not necessarily in detail, probably because it is not a primary driver in their decision process for undertaking projects.

Table 39: Energy Efficiency Practices from On-Site Surveys

	Education	Healthcare	Office
Uses utility funding	100%	100%	80%
Uses benchmarking	70%	70%	60%
Is ENERGY STAR	10%	0%	20%
Is LEED	10%	0%	0%
Have an energy management plan	90%	60%	30%
Hours/week spent on energy management	1.2	2.7	2.6
Has been commissioned	50%	40%	30%
Has been recommissioned	40%	10%	20%

These buildings had a variety of heating systems, with the majority being boilers, (both hot water and steam) but also furnaces in packaged roof top units, heat pump systems, and one all electric building using baseboard radiation. All buildings had redundancy in their main heating source, either through separate units (large boilers) or component parts (individual electric heating cores in a packaged electric boiler).

There was a wide range (a factor of ten) in heating and cooling system capacity: the buildings with the largest installed capacity per square foot had larger systems installed than necessary to allow for future expansion, while the buildings with the lowest installed capacity had highly efficient water loop heat pump systems. Healthcare buildings also had greater capacity both because of redundancy and standards that require a high number of air changes per hour, which increases energy consumption significantly. The average installed capacity was about 60 kbtu/square foot, with a range from 10 (highly efficient heat pump system) to over 100 (system built to allow for building expansion without adding new boilers).

The high average age of the systems primarily reflects the active maintenance practices in these large buildings. Original equipment that is well maintained remains in place for a long time, in part because the majority of working components are actually much newer than the core system. The average efficiency of heating systems of 79 to 86% is driven by the fact that boilers make up the largest fraction of total energy capacity of the systems. The average operating hours reflect building schedules, and show differences by building type: education buildings tend to frequently schedule their systems based on occupied hours, while healthcare facilities (even including clinics that close over night and on weekends) usually run in occupied mode 24 hours a day. The healthcare facilities were also less likely to use energy savings control features such as outdoor reset of boiler water temperatures.

Table 40: Heating Systems Characteristics in On-Site Surveys

Heating Systems (averages)	Education	Healthcare	Office
Year installed	1991	1988	1990
Age (years)	26	29	27
Number of heating sources	4.3	3.8	3.5
Total capacity (Million Btu/hr)	7.9	29.4	1.3
Efficiency (AFUE)	86	79	79
Weekly System operating hours	73	140	102
Outdoor reset control	80%	40%	70%

Cooling equipment is slightly newer than heating equipment. Although 100% of the building space we assessed was heated, not all of it was cooled (the buildings with less than 100% cooling were mostly older education buildings). The range of cooling capacity was 0.4 to 4.4 Tons/1,000 sq. ft with an average of 2 tons per 1,000 square feet.

Table 41: Cooling Systems Characteristics in On-Site Surveys

Cooling Equipment (averages)	Education	Healthcare	Office
Year installed	2008	1999	1998
Age (years)	9	18	19
Cooling equipment capacity (tons)	233	1078	169
Efficiency (EER)	10.2	13.1	12.0
Use of outdoor reset control for chiller	60%	20%	60%

The differences in Energy Efficiency Rating (EER) are primarily due to the cooling technology used, as shown in the table below. Only the largest buildings (including hospitals which accounts for the higher efficiency of Healthcare buildings) used water cooled chillers, which have the highest energy efficiency, but also the highest initial cost.

Table 42: Cooling Systems in On-Site Surveys

Number	Type	EER	Age (Years)
7	Air cooled chiller	10.1	12
9	Packaged units	10.3	16
2	Heat pumps, water loop	14.5	4
4	Water cooled chiller	16.5	26

All of the buildings had active ventilation systems; the majority had one or more air handler units, and most of the rest were ventilated by roof top units[8]. While variable air volume systems were found in almost all the buildings, some still had areas served by constant volume systems as well. Only two of

[8] See the recent CARD study, "Commercial Roof-top Units in Minnesota: Characteristics and Energy Performance" available at: CARD RTU Final Report for more information on Roof Top Units in Minnesota.

the thirty buildings had areas served by dedicated outdoor air systems (DOAS) and no underfloor air distribution or demand control ventilation systems were seen.

The size of a typical heating zone was consistent within each building type, but varied greatly across the three building types as shown in Table 42. Healthcare has the smallest zones (775 square feet per zone) and educational buildings having slightly larger average zone sizes (3,204 square feet) than offices (2,517 square feet). Pneumatic controls were still used in parts of almost half of the buildings; these were most likely to be seen in hospitals and clinics (where energy saving temperature setup and setback strategies were least likely to be used). Thus while the healthcare buildings appear to have the greatest potential for energy savings through scheduling of set point changes; the lack of full digital controls may be a barrier to achieving maximum savings.

Table 43: HVAC Distribution Systems in On-Site Surveys

Distribution	Education	Healthcare	Office
Central Air Handlers	80%	100%	30%
VAV system (any)	90%	90%	90%
Constant volume system (any)	30%	20%	20%
Perimeter radiation	40%	30%	30%
Number of zones	55	412	109
Square feet per zone	3,204	775	2,517
Ducts sealed	60%	40%	10%

Significant opportunities for hot water energy savings exist based on the relatively low penetration of low-flow faucet aerators. In addition, 75% of these buildings have circulating hot water systems, and most could install energy saving circulation controls.[9] On the other hand, we found that the majority of hot water storage tanks were well insulated, although the hot water piping was often not full insulated, or the insulation that was present was only in fair or poor condition. The lack of pipe insulation caused us to extend this measure, previously only included for the residential sector to all commercial buildings.

[9] Ben Schoenbauer circulating DHW