Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type

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1 EXECUTIVE SUMMARY

Commercial miscellaneous electric loads (C-MELs) are generally defined as all non-main commercial building electric loads. That is, all electric loads *except* those related to main systems for heating, ventilation, cooling, water heating, and lighting. Miscellaneous electric loads account for an increasingly large portion of commercial electricity consumption.[1] Generally, the number of types of loads and the number of loads has increased. Furthermore, as commercial building main-loads and building envelopes (insulation, fenestration, etc) become more efficient, C-MELs tend to account for a larger percentage of the overall building energy.

To support its strategic planning efforts, DOE/BT contracted TIAX to characterize the current state of commercial MELs. This includes analysis of their unit energy consumption and annual electricity consumption (for 2008) based on building type, as well as an initial assessment of the energy-saving potential for MELs based on current best-available technology and practices.

Beyond its general interest in C-MEL annual electricity consumption (AEC), DOE's Building Technology Program (DOE/BT) has a goal to support the construction of cost-effective net zero-energy buildings (NZEB). Because MELs can account for the greatest portion of energy consumption in efficient commercial buildings, reducing C-MEL energy consumption is an important part of achieving net zero energy commercial buildings. Consequently, it is important for DOE/BT to understand the current C-MEL energy consumption by building type and to incorporate this information into modeling and research efforts to optimize NZEB designs.

On the other hand, reducing C-MEL energy consumption can be more challenging than reducing the energy consumed by other end uses. Countless different products fall under the broad title of C-MELs, which complicates and increases the cost of implementing measures to reduce C-MEL energy consumption. In addition, office equipment accounts for a significant portion of C-MEL energy, and these devices have, historically, evolved rapidly and had much shorter useful lives than other end uses. Fortunately, we believe that the majority of C-MEL energy can be modeled by assessing a smaller set of key loads.

Furthermore, many C-MELs differ from "conventional" building loads in that they can vary greatly between building types. For example, office equipment accounts for a significant portion of office building energy consumption, medical equipment makes a significant contribution to healthcare facilities, and vending machines have a significant impact on lodging. For this reason, this analysis breaks down the C-MEL energy consumption for nine commercial building types.

In coordination with the Department of Energy's (DOE) Building Technologies office, TIAX selected six to ten "key" loads for each of nine commercial building types. The se-

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[1] EIA, Annual Energy Outlook 2009, Mar 2009, Table A5, pp.119-120. http://www.eia.doe.gov/oiaf/archive/aeo09/pdf/0383(2009).pdf

lection process included a preliminary energy consumption estimate of a set of possible key loads. Key loads were selected based on their estimated energy consumption for each building type. Generally, the preliminary estimates showed C-MELs consume at least 1 TWh/year in building types in which they are considered key loads, although this was not used as a strict cut-off point. The preliminary energy consumption estimates for evaluating key versus non-key loads were based on an initial data collection pass from relevant literature sources for each load.

In total, TIAX selected 28 key commercial MELs for further investigation, as shown below:

Refrigeration

1. Unit Coolers
2. Central
3. Residential Type
4. Ice Machines
5. Warehouse
6. Walk-in

Consumer Electronics

7. PCs
8. Monitors
9. Other Office Equipment
10. Televisions

Other Building MELs

11. Slot Machines
12. ATMs
13. Vending Machines
14. Vertical Transport
15. Non-Road Vehicles
16. Landscape Irrigation
17. Fitness Equipment
18. Laundry
19. Fume Hoods
20. Arcade Machines

Non-Building MELs

21. Water Supply & Purification
22. Waste Water Treatment
23. Distribution Transformers
24. Mobile Phone Towers

Medical

25. Medical Imaging
26. Other Medical Equip.

27. Cooking

28. Data Center Servers

The key building MELs are those from the list of 28 that are used inside buildings. The ‘other key MELs’ include loads such as mobile phone towers or waste water treatment, which are not specifically associated with a building type, but are considered commercial MELs in this analysis.

The nine building types considered include: office, retail & service (non-food), food service, food sales, education, warehouse, healthcare, lodging, and public assembly, order, and religion (AOR). These building types are consistent with the main types defined in the Commercial Building Energy Consumption Survey (CBECS),[2] which was most recently published for 2003 by the DOE Energy Information Administration. This consistency allows for straightforward comparisons with other data sources. The CBECS definitions included three individual categories, public assembly, public order, and religious, but given their lower energy consumption, TIAX combined them to form the public AOR category.

In total, commercial buildings consume about 20% of the total U.S. primary energy (18.3 quadrillion btus (quads) per year).[3] Of the commercial, residential, and industrial sectors, the per-building and per-square foot energy use intensity, is greatest in commercial buildings. Unlike the residential sector with approximately 115 million households (BEDB, 2009), the commercial sector’s energy consumption is concentrated in 5 million buildings

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[2] Commercial Buildings Energy Consumption Survey (CBECS), Completed by the U.S. Energy Information Administration. Data available at http://www.eia.doe.gov/emeu/cbecs/. Building definitions are discussed at http://www.eia.doe.gov/emeu/cbecs/building_types.html

[3] EERE, 2009, “2009 Building Energy Data Book,” U.S. DOE. Estimate interpolated from 2006 and 2010 data, Table 1.1.3

(EIA, 2006), indicating that some energy savings measures may be more cost and time effective to implement.

The evaluated key C-MELs consume a total of 504 TWh of electric energy in commercial buildings per year, or 5.5 quads of primary energy. This is 30% of the 18.3 quads consumed by the commercial energy sector, as shown in below in Figure 1. 3.3 quads are associated with key building MELs while an additional 2.2 quads were consumed by other key loads not associated with specific building types (a.k.a., other key MELs).

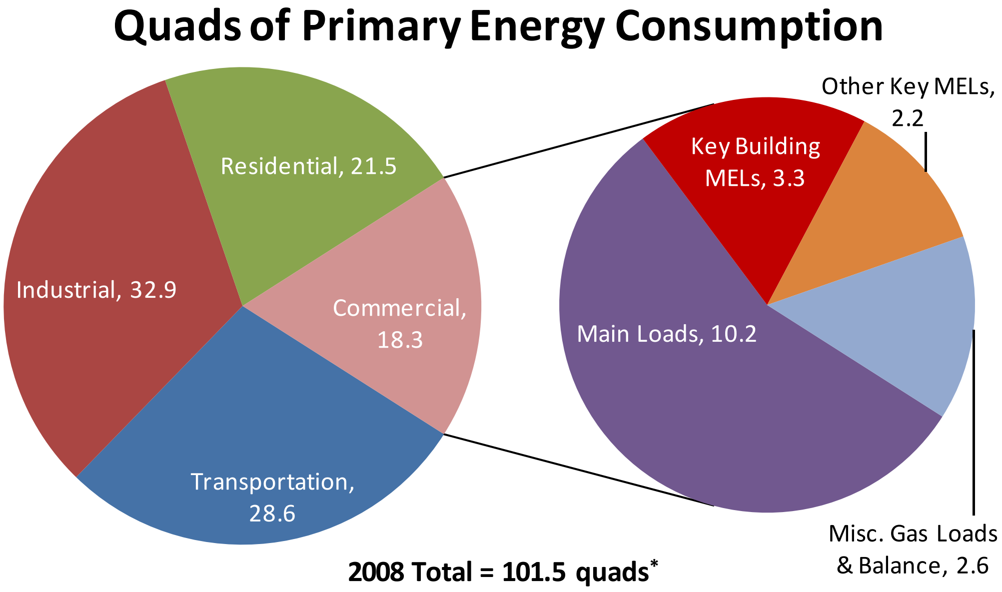

Figure 1: TIAX addressed 5.5 quads of C-MELs identified as both "Key Building MELs" and "Other Key MELs"[4]

The "miscellaneous gas loads" shown in Figure 1 include things such as gas heated laundry dryers and gas cooking. There is also a remaining "balance" after adding main loads, MELs, and miscellaneous gas loads, which may come from unaccounted for miscellaneous loads, uncertainty in the energy consumption in any category, or may be a statistical artifact resulting from summing of values from different sources.

Given that 92 TWh of site electric energy is approximately equivalent to 1 quad of primary energy, and that a 1 gigawatt power plant delivers approximately 8 TWh/yr of electricity, TIAX's key MELs consume the output of more than 11 one gigawatt power plants. They account for approximately 30% of the commercial primary energy and 5.5% of the U.S. primary energy.

In aggregate, the evaluated C-MELs consume more electric energy than any of the traditional building main loads, as shown below in Figure 2.

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[4] EERE, 2009, "2009 Building Energy Data Book," U.S. DOE. For U.S. Commercial, and main load totals

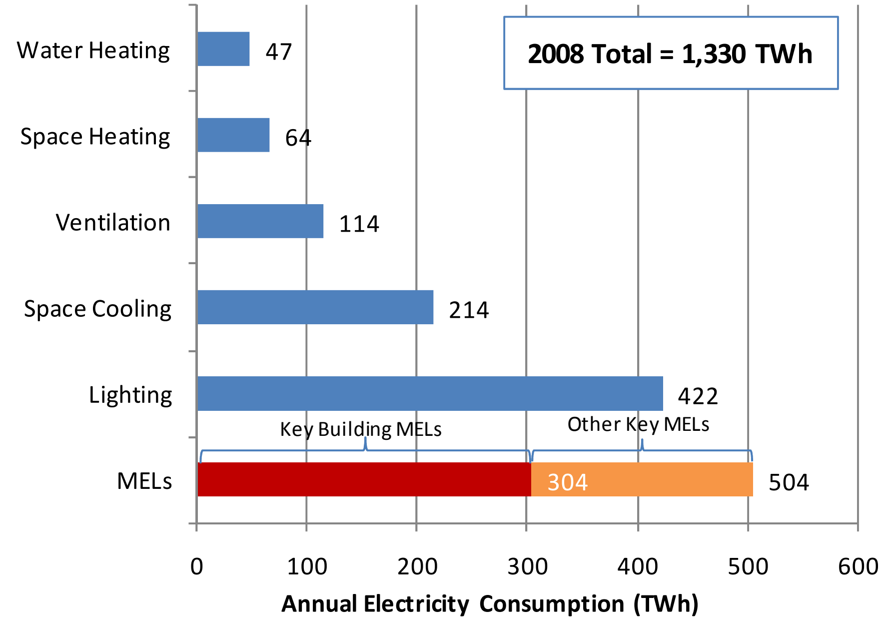

Figure 2: The U.S. Commercial Electricity Consumption, broken down by load, shows that TIAX's Key MELs are greater in aggregate than another other single load.[5]

The key building C-MELs, which consume approximately 300 TWh/yr, account for between 10% and 60% of the electric energy consumption of each building type. The breakdown between key C-MEL energy and main load energy consumption[6] by building type is shown below in Figure 3.

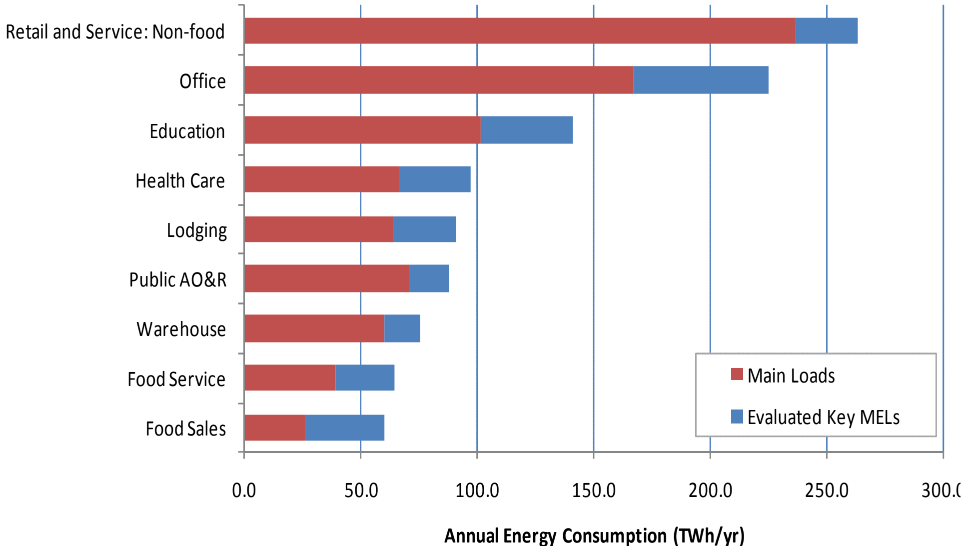

Figure 3: The key MELs are between 10% and 60% of the electric energy consumption of each building type.

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[5] EERE, 2009, "2009 Building Energy Data Book," U.S. DOE. For U.S. Commercial, and main load totals
[6] EIA, 2003, "Commercial Building Energy Consumption Survey," Main load energy from Table 5a.

Food sales buildings have a high MEL energy consumption (about 60% of the total energy) because of refrigeration loads. MELS account for 26% and 28% of office building energy and education building energy, respectively, largely because of PCs, monitors, and other office equipment.

The total energy consumption for each key C-MEL across all building types is plotted in Figure 4.

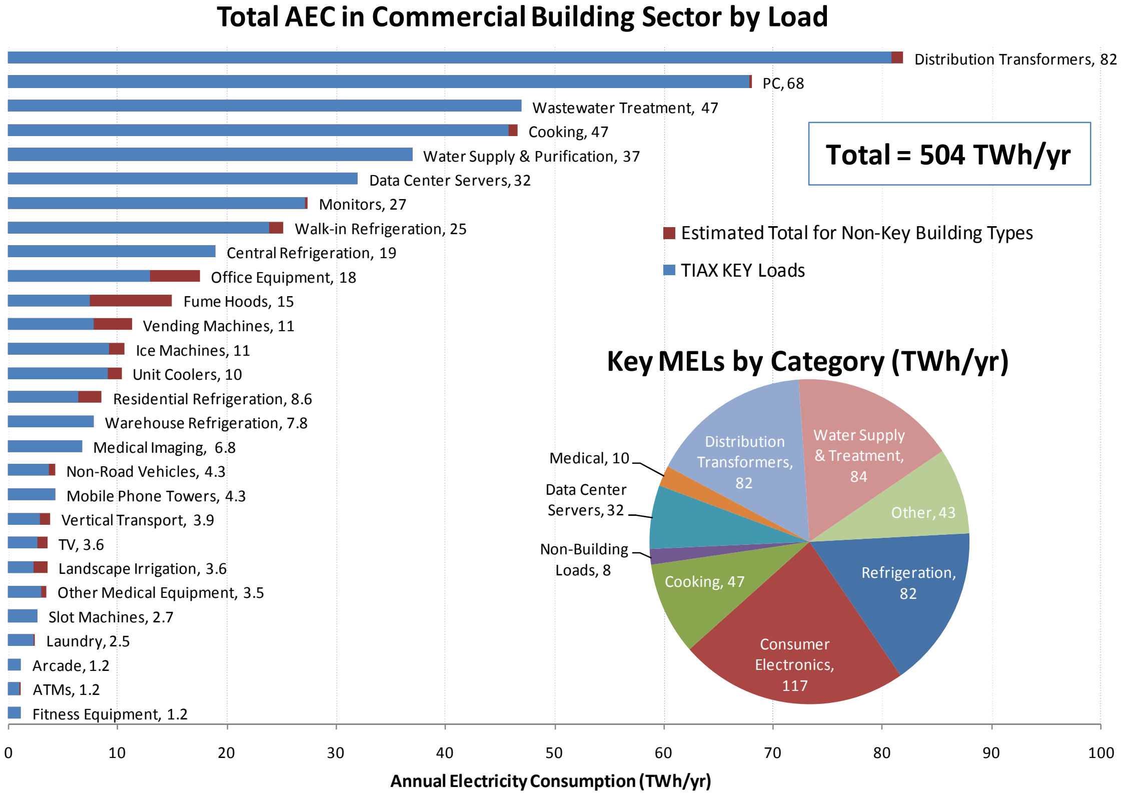

Figure 4: Consumer electronics and refrigeration, in aggregate, account for nearly 40% of the evaluated MELs.

Each bar represents the energy consumption in the commercial sector for the stated key MEL. Key C-MELs were evaluated in building types in which they represented a significant load. Bars in Figure 4 that are only blue indication that for any building type in which the load was not key, it was a negligible load. The bars that also include red sections (“estimated total for non-key building types”), are an indication that a portion of the load’s energy consumption is in building types in which it is not considered a key load, but, in aggregate, is noteworthy.

The pie chart in Figure 4 groups the key C-MELs into appropriate categories. Office electronics consume nearly 25% of the total. Refrigeration Equipment, water supply and treatment equipment (namely, pumps), and distribution transformers (both inside and outside of buildings) each used over 80 TWh in 2008, or 16% each.

In order to identify energy savings opportunities, TIAX selected or estimated “best-in-class (BIC)” models from each of the 28 selected load types. For the most part, the energy consumption associated with BIC units was derived directly from energy efficient units that are currently on the market. By comparing the BIC to the typical unit used in the baseline calculations, TIAX generated a technical “energy savings potential (ESP)” for each load. Assumptions about the market penetration and impact of emerging technologies are not addressed in this study, and therefore the ESP is not necessarily fully achievable due to many market factors, but also may be more than 100% achievable in cases where new technologies are on the horizon. It is assumed that all current units are replaced by the BIC unit. The “by load”, and “by load category” energy savings potential estimates, which include estimates for both key and non-key building types, are shown below in Figure 5. Secondary impacts on building cooling and heating loads are not addressed in this study, but, generally, reducing a building’s MEL energy consumption will result in an equal reduction in cooling loads during the cooling season. On the other hand, reducing MELs will increase the buildings heating load during the heating season, although it is generally the case that the building’s heating system is more efficient than the resistance heating provided by MELs.

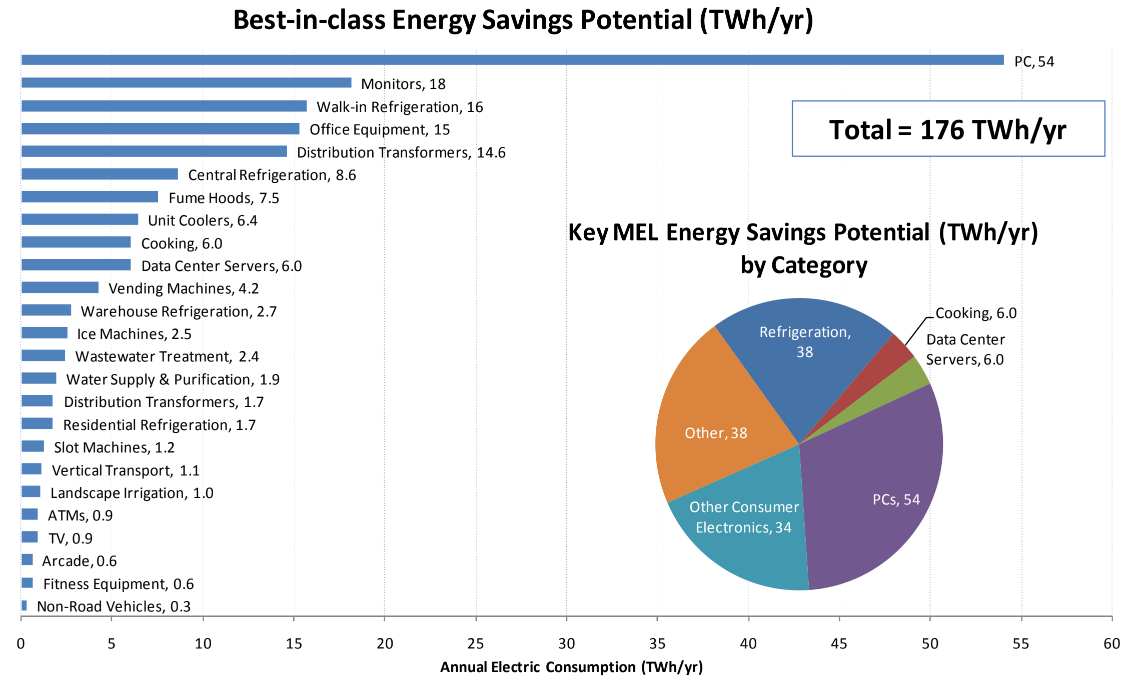

Figure 5: Achievement of this energy savings potential could reduce C-MEL energy consumption by 176 TWh/yr, thereby reducing C-MELs from approximately one third of commercial primary energy, one quarter.[7]

Overall, we have estimated a 35% (176 TWh/yr) energy savings potential by replacing the current installed base with best-in-class devices. The loads with highest savings potential include PCs, monitors, walk-in refrigeration, office equipment, and distribution transform-

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[7] Source: 2009 Buildings Energy Data Book, DOE/EERE. 2008 values interpolated from 2006 data points and 2010 projected data points – See Tables 3.14, 3.15, and 3.17.

ers. Each of these loads has the technical potential for a reduction of approximately 15 TWh/yr or greater.

Electronics (namely, PCs, monitors, and other office equipment) account for about 50% (88 TWh/yr) of the estimated energy savings potential. This energy savings potential is mainly driven by the potential impact of power management. Other key drivers for this energy savings are the transition from desktops to laptops (or at least to equivalent components and power saving design strategies in a desktop form factor), and the transition from CRT monitors to efficient LCD monitors.

Highlights and Conclusions:

- Key C-MELs in standard building types consume 300 TWh/yr
- Key C-MELs in non-standard building types and key non-building C-MELs consume 200 TWh/yr, or 40% of the key C-MEL total
- Consumer electronics make up 25%, refrigeration makes up 15%, and cooking equipment makes up 10% of the key C-MEL total
- Water supply and treatment combined consumes 15% and distribution transformers outside and inside buildings consume 15% of the key C-MEL total
- According to CBECS data, nearly 50% of building C-MEL energy is consumed in large buildings (>50,000 ft^2), which account for 5% of commercial buildings and 50% of the commercial floor area
- Data center servers, i.e., servers located in purpose-built data center buildings, account for 6% of key C-MEL energy, excluding cooling energy, and are growing rapidly
- There is a C-MEL energy savings potential of 176 TWh (2 quads) by replacing the installed devices with currently available energy efficient devices

Recommendations:

The insights gained from this characterization of commercial MELs point to several recommendations for further study. Each one is discussed separately in the following subsections.

Regular Evaluation of Rapidly Evolving MELs**:** A significant portion of the devices evaluated have – and, in many cases, continue to – undergone dramatic changes in their installed base, their usage, and their functionalities, characteristics, and underlying technologies (and, hence, their power draw by mode). This is particularly true of electronics (namely, office electronics and data servers), which have changed dramatically over the last couple of decades and tend to have much shorter average product lifetimes (i.e., on the order of a few years compared to 10 or more for white goods), but also true of some other products as well (e.g., the increased installed base of mobile phone antennas). In all cases, it has significant ramifications for DOE's goal of net zero-energy buildings (NZEB) in the future.

Consequently, we recommend performing regular (e.g., every 3-4 years) evaluations of MEL energy consumption and energy savings potential to understand how the evolution of MELs are affecting the feasibility of cost-effectively attaining DOE's building efficiency goals. Furthermore, we recommend that brief annual updates (executive summary style) be performed in order to keep installed base and UEC estimates current and statistically representative of the installed stock.

***More Refined Evaluation and Characterization of MEL Energy-Saving Opportunities*:** Our initial characterization of energy-saving opportunities for commercial MELs primarily focuses on energy savings attainable using *existing* products. Although we found that this approach can yield overall reductions in MEL energy of about 35%, it probably is not realistic to rely on a large portion of the five million commercial buildings to purchase such "best-in-class" devices to realize large-scale savings. Furthermore, it is often very challenging to reduce the building energy consumption of many MELs via other pathways (e.g., automated controls) due to the low annual energy cost savings potential for most MELs and building owners'/operators' disdain for measures that might adversely affect device utility or usability or impact business operations.

We recommend that DOE perform a study focused on a thorough characterization of commercial MEL energy savings opportunities with an emphasis on a critical assessment of the likelihood that a large portion of real buildings would accept and effectively deploy different measures. Ultimately, this could be used to develop a roadmap for credibly achieving major (e.g., 35%) reductions in MELs that identifies the technologies and policies needed to reach realize those reductions.

The initial focus should be on large (>50,000 square feet) buildings, which consume 50% of the key MEL energy, but are only 5% (~250,000) buildings. These buildings may also see appreciable reductions in operating costs from energy savings measures, and therefore may be more amenable to adopting such measures.

***Data Gathering by Building Type to Fill Key Data Gaps*:** TIAX found a lack of current data, particularly by building type, for many C-MELs to develop accurate bottom-up estimates. We recommend that the DOE conduct power measurements by mode for a sample representative of the installed base for key C-MELs in key building types. Likewise, interviews, surveys, or actual measurements are needed to more accurately understand the usage patterns of key MELs in key building types. Obtaining real operating data can be time and budget intensive, and therefore a focused work plan is needed to fill the largest data gaps with the largest impact on energy consumption. We recommend starting with large commercial buildings (i.e., greater than 50,000 square feet).

2 INTRODUCTION

We define miscellaneous electric loads, hereafter referred to as MELs, as electricity-consuming loads that do not fall under the conventional end use categories of lighting, heating, ventilation, air conditioning, and water heating. Key types of MELs in commercial buildings, i.e., C-MELs, include consumer electronics, refrigeration, cooking, laundry, elevators, ATMs, and more.

Unlike in residences, where loads are quite similar between buildings, in the commercial sector, each set of key MELs can vary dramatically among buildings of different types. For example, office buildings exhibit high energy consumption from consumer electronics (CE) including PCs and monitors, while food sales buildings, such as supermarkets, have significantly fewer consumer electronics, and significantly more energy consumption associated refrigeration systems.

To add yet another dimension of complexity, the usage patterns across building types varies for many loads. While, for example, a residential type refrigerator generally has the same load no matter where it is located, cooking equipment loads vary significantly by building type. A restaurant may have a high concentration and usage of broilers and ranges for preparing customer meals, while a supermarket may have a high concentration and usage of ovens for baked goods.

As electricity consumption continues to grow in the United States, MELs are anticipated to increase at a disproportionately high rate. According to the 2009 Buildings Energy Data Book from the EERE/DOE, the total primary energy consumption in the commercial sector will increase by 36% to 25 quads by 2030, while the portion that constitutes C-MELs is projected to grow 78% during that period. By comparison, main loads are anticipated to grow minimally: lighting and space heating, 3%, space cooling, 1%, and ventilation, -14% (a decrease). The projected MEL growth is broken down by category in Figure 6 below.

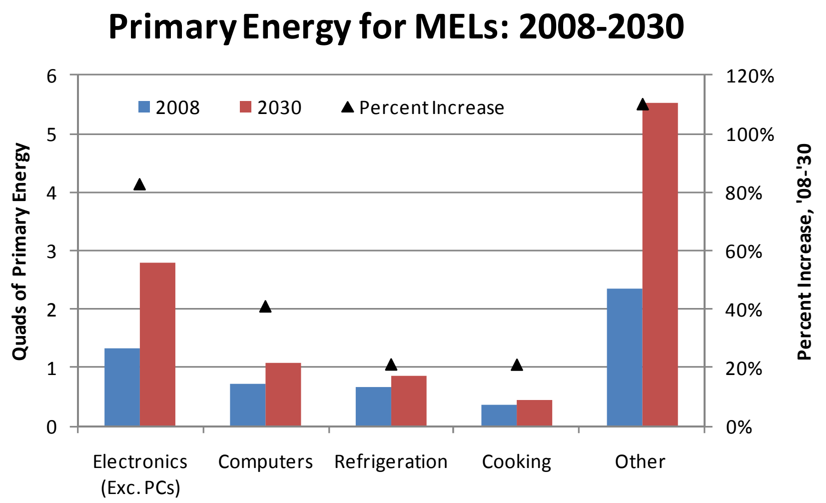

Figure 6: Primary Energy consumption for MELs in the United States is expected to increase by 78% between 2008 and 2030.[8]

Several trends (or combinations of trends) could result in this projected increase: higher installed base of existing devices, more distinct MELs within each category, greater power draw per unit, and/or greater usage per unit. PCs and other office equipment have penetrated all businesses, and all building types, creating a much larger installed base of CEs. The prices have dropped significantly allowing even the average users to purchase more units. Additionally, the number of distinct MELs within the category has grown, driven by the increased use and penetration of information and communication technologies (ICT).

Historically, the energy consumption of all miscellaneous loads has been addressed in aggregate. However, due to their relatively rapid growth over the past several decades, miscellaneous loads are now generally broken down into key groups, such as refrigeration, cooking, PCs, and office equipment. As is shown in Figure 6, there still remains a large "other" category, with a large projected growth. While more challenging, the evaluation of the current state of a larger set of key MELs provides a more accurate understanding of how buildings consume energy and helps guide energy efficiency research and prioritize the implementation of efficiency programs.

During this study, TIAX characterized the key miscellaneous loads in each of the nine key building categories. Furthermore, by comparing the typical installed unit of each MEL to the best-in-class, we established a technical savings potential that gives an indication of potential impact of implementing energy efficiency programs. We do not, however, attempt to incorporate user acceptance levels, market penetration, or other market issues into the savings potential estimates. As a result, further work is recommended to establish a realistic, achievable energy savings for the various MELs.

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[8] Source: 2009 Buildings Energy Data Book, DOE/EERE. 2008 values interpolated from 2006 data points and 2010 projected data points – See Tables 3.14, 3.15, and 3.17.

2.1 Study Approach

To support its strategic planning efforts, DOE/BT contracted TIAX to characterize commercial MELs (C-MELs), analyze their unit and annual electricity consumption (for the 2008 calendar year), and carry out an initial assessment of the energy-saving potential for C-MELs using best-available devices and practices. This study:

- Provides estimates of U.S. commercial MEL electricity consumption by commercial building type
- Provides estimates of non-traditional commercial MELs found outside (i.e., before the electric meter) of buildings (e.g., water supply, distribution transformers)
- Establishes preliminary technical energy-saving potential estimates of C-MELs using currently available, energy efficient devices and technologies
- Guides energy efficiency research and activities by aggregating the results and comparing them with main load, sector, and national energy consumption totals.

To realize these goals, TIAX and DOE/BT decided upon the following approach to the project:

1. Develop an extensive list of C-MELs for potential evaluation
2. Select six to ten key C-MELs for evaluation in each of nine building types as well as for 'other buildings and non-building' C-MELs
3. Characterize the key C-MELs by building type
4. Analyze the unit and national (U.S.) electricity consumption, and installed base of key C-MELs
5. Assess the energy savings potential for key C-MELs from existing products and technologies – a 'technical energy savings potential'
6. Present findings to DOE/BT and other relevant parties
7. Compose a final report to DOE/BT presenting the main findings and clearly explaining the methodology

This report describes the methodology, results, findings, and recommendations of the commercial miscellaneous electric load study.

2.2 Report Organization

This report has the following organization:

Section 3:	Summary of the methodology used to assess the electricity consumed by C-MELs
Section 4:	Description of the key commercial building types by which the key C-MELs were categorized
Section 5	Assessment of the energy consumption of the 28 key C-MELs and the estimate of technical energy savings potential.

Section 6	Presentation of the energy consumption of selected key C-MELs in each key building type
Section 7	Conclusions of this report and recommendations for further study

3 METHODOLOGY

3.1 Preliminary Assessment

TIAX's evaluation of C-MELS began with a brainstorm of potential loads, utilizing knowledge from our prior residential MELs study as a foundation, and adding in additional loads that are unique to commercial buildings. Potential loads were selected based on their estimated impact on commercial building energy consumption. After an initial judgment based down-selection process (i.e., removing loads that are relatively uncommon or commonly understood to consume relatively little energy), the collective group of addressed C-MELs included:

Arcade Games
ATM
Cell Phone Tower
Central Refrigeration
Coffee Maker
Cooking Equipment
Distribution Transformers
Elevator
Escalator
Fitness Equipment
Fume Hood
Gas Pump
Ice Machine
Lab Equipment
Landscape Irrigation
Medical Imaging Equipment
Microwave
Monitor
Non-Road Vehicles
Office Equipment
Other Medical Equipment
PC
Pool Pump/Heater
Residential Refrigeration
Slot Machine
Set Top Box (STB)
TVs
Unit Cooler
Vacuum
Vending Machine
Walk-in Refrigeration
Warehouse Refrigeration
Water Cooler
Water Pumping
Water Purification
Wastewater Treatment

Some of the listed loads are actually load categories (e.g., office equipment, cooking equipment) in which like devices are grouped. It serves to aggregate the load from a set of like devices when without such aggregation, some of these loads would not be considered as key loads, and may have been excluded from the study. However, given the similarities between devices, and their comparatively large energy consumption by category, it seems prudent to judge their impact in aggregate. Furthermore, energy efficiency strategies will often apply to all of the devices in the group. Examples of such C-MEL groups are as follows:

Office:	Servers, fax machines, printers, multi-function devices, etc.
Medical Imaging:	X-Ray, CT, MRI
Medical Other:	Ophthalmoscope, EKG, ultrasound, etc.
Lab:	Oscilloscope, power supply, Multi-meter, furnaces, centrifuges, etc.
Cooking:	Broiler, fryer, range, oven, steamer, griddle
Fitness:	Elliptical trainer, stair climber, treadmill, etc.

It is important to note that some of these miscellaneous loads are split between gas powered and electric powered. This evaluation did not address the loads, or portions of loads that consumed gas energy. For example, cooking in commercial buildings has a significant gas component, but TIAX only evaluated the electric cooking equipment. Other loads, like laundry, may use both simultaneously. The gas portion of the load in these cases (e.g., dryer heating) was disregarded, and only the electric motor energy consumption and electric heating were counted in the evaluation.

In order to establish which loads were to be fully assessed in this evaluation (i.e., key C-MELs), the team categorized each load by approximate annual electricity consumption (AEC) for each commercial building type. Preliminary AEC estimates were collected or calculated from relevant literature sources. Each load was 'bucketized' into one of five categories based on the preliminary estimate for AEC: < 0.5 TWh/yr, ~0.5, > 1, >5, >10, >20, >40.

Using this system, TIAX selected six to ten key C-MELs for each building type. Generally, the preliminary estimates showed C-MELs consume at least 1 TWh/year in building types in which they are considered key loads. Although this was not used as a strict cut-off point, loads that were initially found to be well above 1 TWh or well below 1 TWh were not analyzed in further detail during the down-selection process. More detail was put into loads that were estimated to be approximately 1 TWh. Final cut-off decisions were made in collaboration with DOE based on a special interest or potential energy savings opportunities for a load.

These preliminary evaluations served as starting points for deeper analysis of each "key" load. The key C-MELs that were selected based on the preliminary estimates are shown below in Table 1 for each building type.

Table 1: Selected Key MELs by Building Type

Office	Retail/Service: Non Food	Food Sales
PC	Cooking	Central Refrigeration
Monitor	PC	Walk-in Refrigeration
Office Equipment	Walk-in Refrigeration	Cooking
Cooking	Vending Machine	Unit Cooler
Residential Refrigeration	Monitor	PC
Distribution Transformer	Distribution Transformer	Ice Machine
Vending Machine	Laundry	ATMs
Vertical Transport	Unit Cooler	Monitor
Unit Cooler	TV	Distribution Transformer
	ATM	

Food Service	Education	Warehouse
Cooking	PC	Warehouse Refrigeration
Walk-in Refrigeration	Monitors	Non-Road Vehicles
Unit Cooler	Office Equipment	PC
Ice Machine	Cooking	Walk-in Refrigeration
TV	Walk-in Refrigeration	Distribution Transformer
PC	Vending Machine	Monitor
Monitor	Distribution Transformer	
	Ice Machines	
	Unit Cooler	
	Vertical Transport	

Healthcare	Public AO&R	Lodging
Cooking	Cooking	Cooking
Medical Imaging	PC	PC
PC	Landscape Irrigation	Residential Refrigeration
Other Medical Equipment	Walk-in Refrigeration	Slot Machine
Ice Machine	Fitness Equipment	Ice Machine
Monitor	Arcade	Monitor
Office Equipment	Vending Machine	Walk-in Refrigeration
Distribution Transformer	Monitor	Distribution Transformer
Walk-in Refrigeration	Non-Road Vehicles	Laundry
Vertical Transport	Unit Cooler	Vertical Transport
TV	Residential Refrigeration	TV
Unit Cooler		

Additionally, a set of ‘other building’ and ‘non-building’ C-MELs were selected for evaluation:

‘Other Building’ and ‘Non-building’ MELs
Distribution Transformer
Water Supply and Purification
Data Center Servers
Wastewater Treatment
Fume Hoods
Mobile Phone Towers

DOE had a special interest in these loads because they are generally considered commercial loads, but are overlooked during commercial building energy analyses. Data centers (containing servers) and laboratories (containing fume hoods) are buildings, but are classified in the ‘other’ category by CBECS. The non-building loads are found outside of buildings, but were of interest because of their potentially large energy consumption.

Collectively, TIAX assessed 28 different loads across 7 categories, including:

Refrigeration
- Unit Coolers
- Central Refrigeration
- Residential Type Refrigeration
- Ice Machines
- Warehouse Refrigeration
- Walk-in Refrigeration

Consumer Electronics
- PCs
- Monitors
- Other Office Equipment
- TV

Medical
- Medical Imaging
- Other Medical Equipment

Cooking

Data Servers

Other Building C-MELs
- Slot Machines
- ATMs
- Vending Machines
- Vertical Transport (Elevators & Escalators)
- Non-road Vehicles
- Landscape Irrigation
- Fitness Equipment
- Laundry
- Fume Hoods
- Arcade Machines

Non-building C-MELs
- Water Supply and Purification
- Waste Water Treatment
- Distribution Transformers
- Mobil Phone Towers

3.2 Full Load Evaluation

TIAX's assessment of the 28 different loads was approached as a bottom-up study. That is, as opposed to beginning from total energy consumption in the United States and breaking down that number step by step until each category had been filled, the team collected various pieces of data and built up the estimates from the basic components. The amount of information available varied from load to load and generally increased with greater AEC. The biggest loads are generally under greater scrutiny and are better understood on a national level.

Ideally, TIAX compiled the fundamental AEC components together to get the energy consumption for a given load: the total stock or installed base, and the power and annual usage for each relevant operating mode (e.g., active, idle, sleep, off). The method of finding the AEC using this information is laid out below in Figure 7.

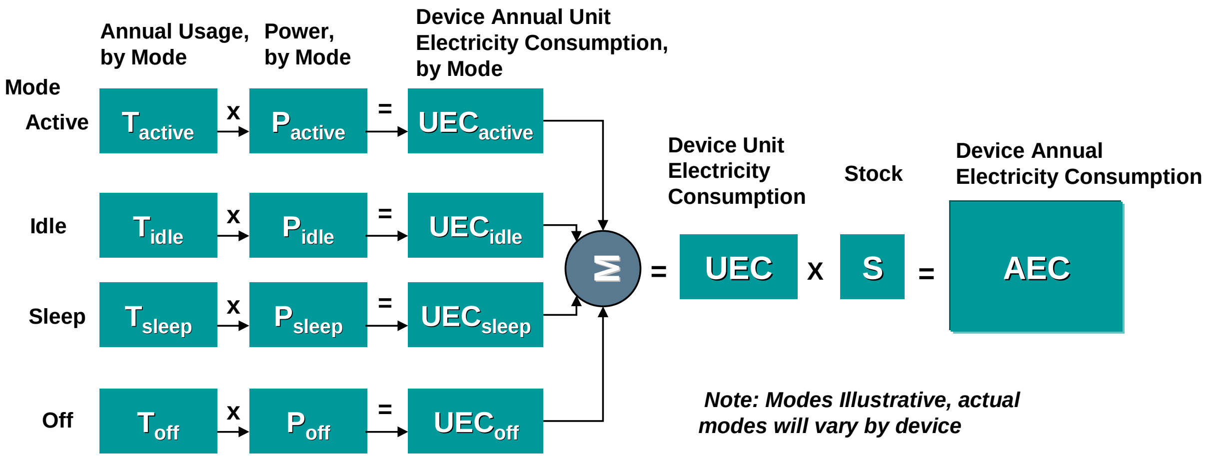

Figure 7: TIAX utilized the most detailed information available regarding usage, power, and installed base to calculate the total AEC for each load.

For PCs, for example, there is a large amount of information available which allows for calculations of each piece of data as described above. In other instances, UEC data was available, but not a breakdown of power and usage by operating mode. In the event that older data was used, adjustments were made to account for the various device trends.

In most cases, not all required pieces of the information are available, and TIAX must make assumptions based on the best available information and our general knowledge of the loads and load trends to estimate the average UEC of the load. Measurements and the collection of new data were outside the scope of this report. Rather this report is intended to serve as a broad overview of C-MELs energy consumption by building type, identify data gaps and uncertainties, and guide further focused research.

Load categories introduce further complications to the process since they may include a significant number of types of equipment. Ideally, the UECs of numerous units are averaged based on a weighting of installed base to get a representative UEC for the category. This adds another dimension of uncertainty to the UEC estimates. Often, the information available for the different devices in a category is of varied levels of detail. TIAX used the best available information to guide the assumptions made in this analysis.

The methodology and key assumptions for each load are described in Section 5.

4 BUILDING TYPES

For the purposes of the TIAX C-MELs study, commercial buildings have been broken down into ten categories (nine specific building types plus other buildings). They generally follow the principal building activity (PBA) categories as defined by the DOE/EIA Commercial Building Energy Consumption Survey (CBECS). The categories, as modified from CBECS, are described below.

It is important to note that inherent in the CBECS "principle building activity" definition is the fact that buildings are characterized by the activity that takes up the largest amount of floor space. In an extreme case, this can mean that a building has loads associated with all of the nine building types as a result of containing numerous different businesses.

4.1 Office Buildings

Office buildings are those that are used for general office space, professional offices, or administrative offices. Medical offices are included here if they do not use any type of diagnostic medical equipment (if they do, they are categorized as healthcare buildings). Examples include:

Administrative/professional office
Government office
mixed-use office
bank or other financial institution
medical office
sales office
contractor's office
non-profit or social services
research and development
city hall or city center
religious office
call center

OFFICE	Total	Admin or Profess.	Bank or financial	Gov't	Medic	Mixed Use	Other
Qty Bldgs (000)	824	442	104	84	37	84	73
Avg ft^2/bldg(000)	15	15	11	18	6	28	6
'03 Elec use (TWh)	210.6	112.5	22.5	27.3	3.0	38.4	7.0

4.2 Non-Food Retail and Service Buildings

Retail buildings are those that are used for the sale and display of goods other than food. This includes shopping malls, which are comprised of multiple connected establishments, either in an enclosed or in a strip-mall configuration. Service buildings are those in which some type of service is provided, other than food service or retail sales of goods.

Examples include:

retail store	dry cleaner or Laundromat
beer, wine, or liquor store	post office or postal center
rental center	car wash
Vehicle/boat Dealership	gas station
studio/gallery	photo processing shop
enclosed mall	beauty parlor or barber shop
strip shopping center	tanning salon
vehicle service or repair shop	copy center or printing shop
vehicle storage/ maintenance	kennel
repair shop	

RETAIL	Total	Vehicle Sales	Retail Store	Other Retail
Qty Bldgs (000)	443	50	347	47
Avg ft^2/bldg (000)	10	12	10	5
’03 Elec use (TWh)	61.8	8.0	48.7	5.1

SERVICE	Total	Post Office	Repair Shop	Vehicle Service	Vehicle Maint.	Other
Qty Bldgs (000)	622	19	76	212	176	139
Avg ft^2/bldg (000)	7	27	8	8	7	3
’03 Elec use (TWh)	43.8	13.5	5.5	11.1	8.1	5.6

MALLS	Total	Strip Malls	Enclosed Malls
Qty Bldgs (000)	213	209	4
Avg ft^2/bldg (000)	32	23	508
’03 Elec use (TWh)	153.2	113.0	40.2

CATEGORY TOTAL	Total
Qty Bldgs (000)	1,279
Avg ft^2/bldg (000)	12
’03 Elec use (TWh)	258.7

Malls are an interesting building sub-type, and it is uniquely difficult to model the energy consumption of miscellaneous loads. By definition, malls contain a number of different building types and/or sub-types, and therefore it is extremely difficult to pinpoint specific key loads. The electric load of these buildings is quite high, however, and this data cannot be overlooked. Due to the distributed nature of the load, very little detailed information is available for mall buildings. For areas of this study where specific data is not available, TIAX calculates loads based on the assumption that mall buildings consist of 10% food service and 90% non-food retail and service.

4.3 Food Sales Buildings

Food sales buildings are those that are used for retail or wholesale of food.
Examples include:

grocery store or food market
gas station convenience store
convenience store

FOOD SALES	Total	Convenience	Convenience w/gas	Grocery store / market	Other
Qty Bldgs (000)	226	57	72	86	10
Avg ft^2/bldg (000)	6	3	4	8	10
’03 Elec use (TWh)	61.1	9.5	13.9	36.0	1.7

4.4 Food Service Buildings

Food service buildings are those that are used for preparation and sale of food and beverages for consumption.
Examples include:

Fast food
Restaurant or cafeteria

FOOD SERVICE	Total	Fast Food	Restaurant Cafeteria	Other
Qty Bldgs (000)	297	78	161	58
Avg ft^2/bldg (000)	6	3	7	6
’03 Elec use (TWh)	63.5	21.1	31.1	11.2

4.5 Education Buildings

Education buildings are those that are used for academic or technical classroom instruction, such as elementary, middle, or high schools, and classroom buildings on college or university campuses. A dormitory on a college campus is not considered an education building due to its location; it is a ‘lodging’ building.
Examples include:

elementary or middle school
high school
college or university
preschool or daycare

adult education
career or vocational training
religious education

EDUCATION	Total	College	Element.	High School	Pre-school	Other
Qty Bldgs (000)	386	34	177	68	56	51
Avg ft^2/bldg (000)	26	42	27	37	8	14
’03 Elec use (TWh)	108.8	26.9	46.0	26.1	3.5	6.3

4.6 Warehouse Buildings

Warehouse buildings are those that are used to store goods, manufactured products, merchandise, raw materials, or personal belongings.

Examples include:

refrigerated warehouse
non-refrigerated warehouse
distribution or shipping center

WAREHOUSE	Total	Distribution center	Non-refrigerated	Self-storage	Refrigerated
Qty Bldgs (000)	597	155	229	198	15
Avg ft^2/bldg (000)	17	34	13	6	35
’03 Elec use (TWh)	71.6	32.2	24.6	1.8	13.1

4.7 Healthcare Buildings

Healthcare buildings are those that are used as diagnostic and treatment facilities for inpatient or outpatient care. Medical offices are included here if they use any type of diagnostic medical equipment (if they do not, they are categorized as an office building).

Examples include:

hospital
inpatient / outpatient rehabilitation
medical office
clinic
veterinarian

HEALTHCARE	Total	Diagnostic Office	Clinic	Hospital
Qty Bldgs (000)	128	54	66	8
Avg ft^2/bldg (000)	25	9	11	241
’03 Elec use (TWh)	72.6	5.8	14.5	52.3

4.8 Public Assembly, Public Order, Religious Worship (Public AOR) Buildings

Public assembly buildings are those in which people gather for religious, social, or recreational activities, whether in private or non-private meeting halls. Religious buildings include chapels, churches, mosques, synagogues, and temples. Public order buildings are those that are used for the preservation of law and order or public safety. Under CBECS, this category was broken out into three small categories. For the purpose of this TIAX study, the categories will be combined as one.

Public assembly buildings include:

social or meeting
recreation
entertainment or culture
library
funeral home
student activities center
armory
exhibition hall
broadcasting studio
transportation terminal
police station
fire station
jail, reformatory, or penitentiary
courthouse or probation office

PUBLIC AO&R	Total	Fire Police	Enter-tain	Library	Rec.	Social	Religious	Other
Qty Bldgs (000)	718	53	27	20	96	101	370	50
Avg ft^2/bldg (000)	12	7	19	28	13	12	10	27
’03 Elec use (TWh)	84.0	3.9	11.9	11.1	12.6	7.5	18.2	18.7

4.9 Lodging Buildings

Buildings used to offer multiple accommodations for short-term or long-term residents, including skilled nursing and other residential care buildings.

Examples include:

motel or inn
hotel
dormitory, fraternity, or sorority
retirement home
convent or monastery
Shelter or orphanage
halfway house
Nursing Homes

LODGING	Total	Dormitory	Hotel	Motel or Inn	Nursing Home	Other
Qty Bldgs (000)	142	16	20	70	22	16
Avg ft^2/bldg (000)	36	33	97	15	46	41
’03 Elec Use (TWh)	68.8	4.5	34.2	12.4	15.1	2.6

4.10 Other Buildings

Other buildings are those that are industrial or agricultural with some retail space; buildings having several different commercial activities that, together, comprise 50 percent or more of the floor space, but whose largest single activity is agricultural, industrial/ manufacturing, or residential; and all other miscellaneous buildings that do not fit into any other category.

Examples include:

airplane hangar
crematorium
laboratory
manufacturing or industrial with some retail space
agricultural with some retail space
data center or server farm
telephone switching

CBECS recorded 191,000 other types of buildings in the United States in 2003 that did not fit into other categories listed above. In total, these buildings consumed 30 TWh/yr of electricity.

These building classifications are based on the principal activity that takes place in the building and does not account for smaller sub-activities in a portion of a building. Therefore, a 10 story office building that has retail shops on the first floor will still be considered an office building. In addition, it must be noted that the location of a building does not necessarily influence its PBA. For example, an administration office building on a university campus is an ‘office’ building, not ‘education,’ despite being part of an academic institution. In a similar fashion, dormitories are classified as 'lodging,' not 'education.'

4.11 Building Data

TIAX collected summary information on the above building types from CBECS to give a better picture of how the building types compare in terms of numbers and square footage. The total square footage among building types is compared below in Figure 8, and the total number of buildings by building type are shown below in Figure 9.

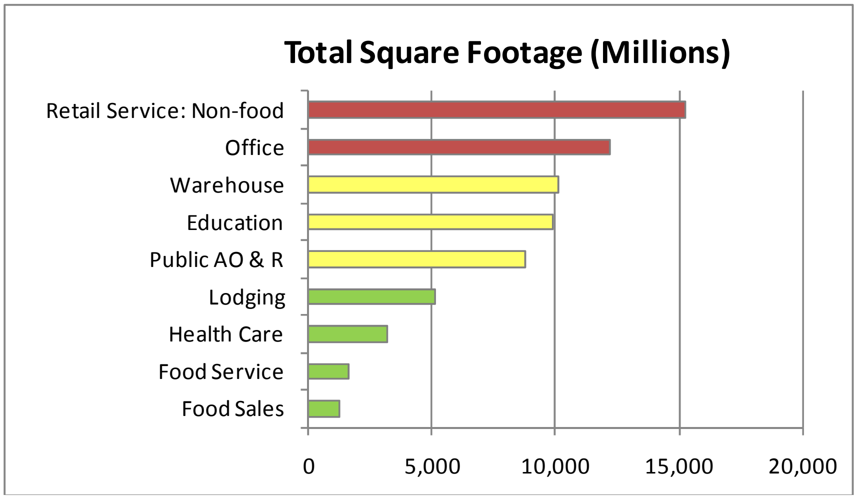

Figure 8: Building floor area broken down by building type. Coloring indicates TIAX's categorization of high, medium, low for the plotted variable.

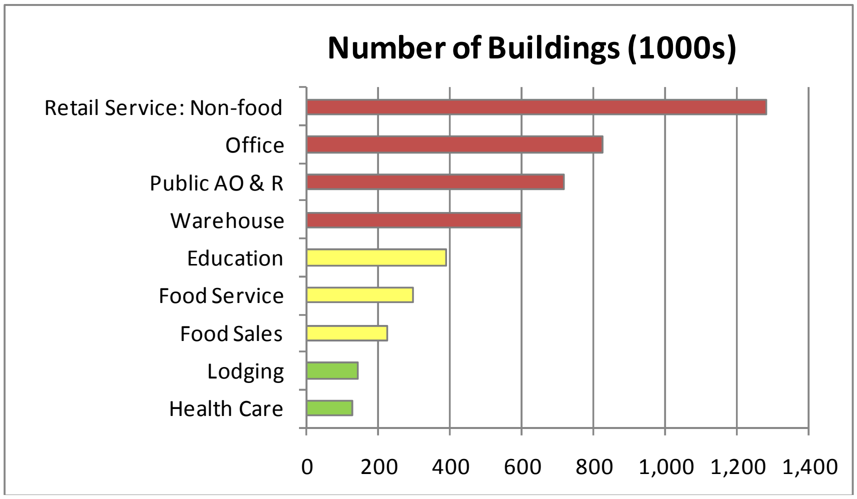

Figure 9: Number of buildings broken down by building type. Coloring indicates TIAX's categorization of high, medium, low for the plotted variable.

Additionally, Figure 10 shows that the three building types with the largest average building sizes are lodging, education, and healthcare. These numbers help to give an indication of how to prioritize energy efficiency efforts in the commercial sector as a function of concentration of consumption.

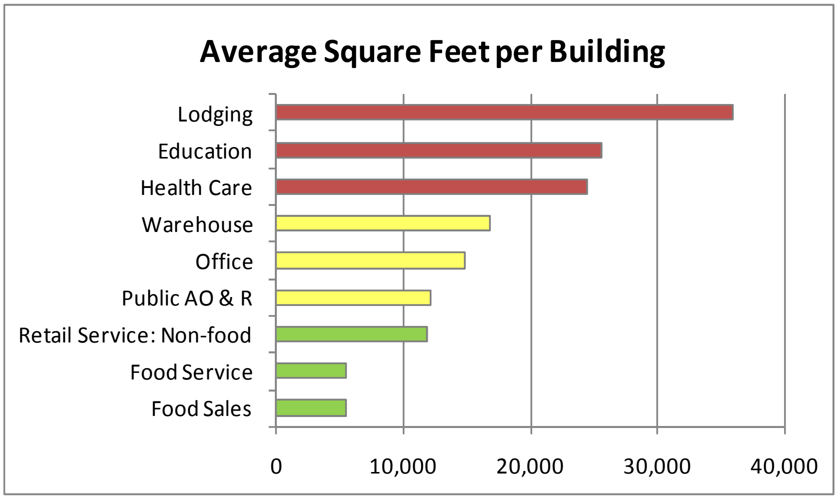

Figure 10: The average square feet per building indicates that the largest buildings are in Lodging, Education, and Healthcare.

On the other hand, the average building size does not give a full indication of the number of large buildings (i.e., greater than 50,000 square feet) for each building type. Figure 11 plots how large buildings (approximately 250,000 in total) are broken down among the different building types.

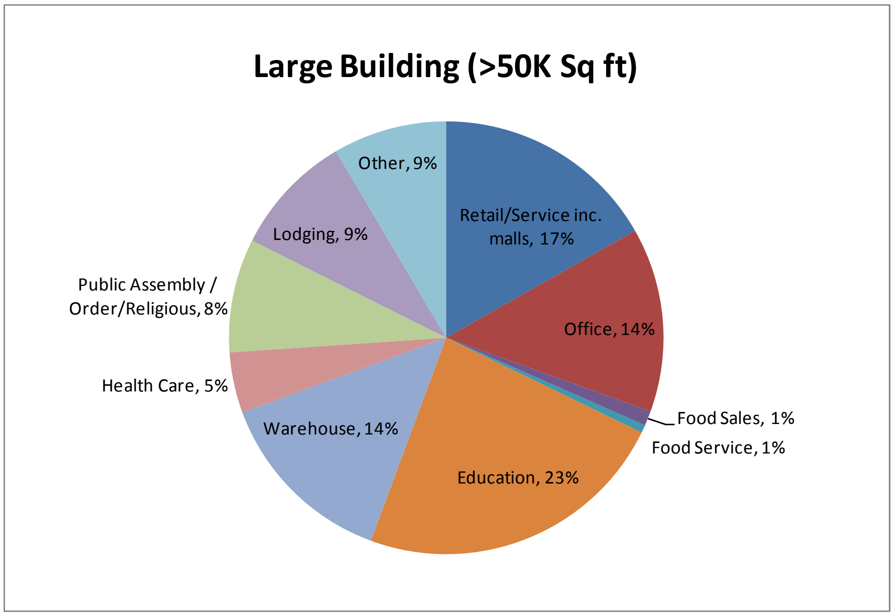

Figure 11: Total large buildings (i.e., greater than 50,000 square feet) broken down by building type (EIA 2006)

5 KEY MISCELLANEOUS ELECTRIC LOADS

5.1 Arcades

Table 2: Overview of findings for arcades in buildings for which it is a key load (details in Section 6)

	Public Assembly	Total
Total AEC (TWh/yr)	1.2	1.2
Energy Intensity (kWh /1000ft^2)	1400	1400
Installed Base (1000s)	320	320
Units / 100,000ft^2	4	4
Energy Savings Potential	50%	0.6 TWh/yr
Energy Savings Measures	Timer plugs to automate shutdown. PC-based power management such as standby mode	
Data Uncertainties	The number of arcade machines per establishment	

5.1.1 General Discussion

Arcades are coin or token-operated, electronic entertainment machines installed with various types of video games. They are predominantly found in gaming centers and theme parks and to a lesser extent in bowling centers and cinemas. Other than the aforementioned establishments, it is assumed that the number of arcades in other building types is relatively small. Their hardware components are similar to that of high-end PCs including sophisticated graphics and sound cards. In addition, a lot of the more advanced arcade games have specialized user input/control accessories, for example steering wheels, motor cycle handles, joysticks, light guns, sport bats and dancing mats as well as other specialized components that add to the user experience such as vibrations actuators or other forms of force feedback controls. The computationally-intensive nature of video games to generate and display elaborate graphics is the primary reason why arcades consume an appreciable amount of energy.

5.1.2 Energy Savings Discussion

Ensuring arcades are powered off during non-operating hours is a simple method to reducing energy consumption. Using a timer plug is one solution to facilitate and automate the shutdown of arcade gaming machines, which can save up to 1860 kWh per machine (NUS, 2009). In addition, due to arcade machines having similar hardware components as that of PCs, various levels of power management such as a “standby mode” could be utilized. Using this method the machine draws less power depending on computational load.

5.1.3 References

BMI Gamings, 2009, "Arcades Directory | Where to Play Arcade Games in the USA ," October, Available online at: http://www.bmigaming.com/arcadelocations.htm

CAPCOM, 2009 "1st Quarter Report Fiscal year ending March 31, 2009," Quarter report, March. Available online at: http://ir.capcom.co.jp/english/data/pdf/fy2009_1st_quarter_a.pdf

Encyclopedia of American Industries (EAI), 2005 "SIC 799 Bowling Centers," Industry report, Available online at: http://www.encyclopedia.com/doc/1G2-3434500956.html

Ibisworld, 2009, “Amusement & Theme Parks U.S. Industry Report,” Market report, May, Available online at: http://www.ibisworld.com/industry/retail.aspx?indid=1646&chid=1

NUS, 2009, “Reduced Energy Guide – Leisure Machines,” Downloaded in October at: http://www.nus.org.uk/PageFiles/4888/REG-5-Leisure-Machines.pdf

National Association of Theatre Owners (NATO), 2009, "U.S. Cinema Sites," Downloaded in September 2009 at: http://www.natoonline.org/statisticssites.htm

5.2 Automated Teller Machines (ATM)

Table 3: Overview of findings for ATMs in buildings for which they are a key load (details in Section 6)

	Retail & Service	Food Sales	Other	Total
Total AEC (TWh/yr)	0.5	0.5	0.2	1.2
Energy Intensity (kWh /1000ft^2)	33	400	3	16
Installed Base (1000s)	150	150	57	360
Units / 100,000 ft^2	1.0	12	<1	<1
Energy Savings Potential	80% savings per unit – based on 90% energy savings potential in stand-by mode			0.9 TWh
Energy Savings Measures	Reductions in lighting, occupancy sensed ‘sleep’ mode			
Data Uncertainties	Little information is readily available regarding the locating of standalone units, and little research has been done on by-building breakdown for installed base			

5.2.1 General Discussion

ATMs were first introduced on a commercial scale in the United States in the late 1970s. They rapidly grew in popularity as a convenient access point for customers and as an additional way to generate revenue for building owners. Growth increased at a dramatic rate to a peak of 400,000 installed units in 2005 (Kerber, 2008). At that time, two market forces combined to cause a decline in the number of unit to what it is today: saturation of the market, increased use of credit and debit cards for purchases. Installed base growth trends are shown in Figure 12.

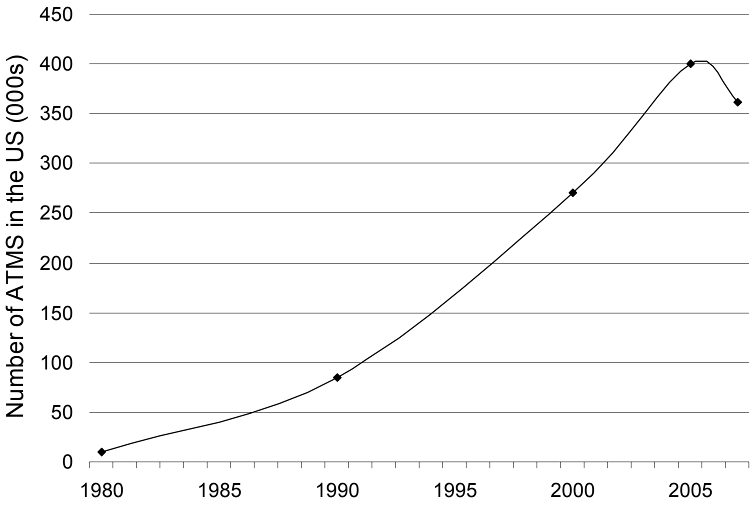

Figure 12: ATM installed base growth grew rapidly until saturation and increasing use of debit and credit cards caused a decline in 2005 (Kerber, 2008).

ATMs can either be stand-alone units or through-the-wall units (Roth, 2002). While applications vary between manufacturers, through-wall units are generally full service financial units, while stand-alone units are generally for cash dispensing only. The through-wall type is what would be found in a bank branch, while stand alone units are more commonly found in retail areas of buildings.

While TIAX assumes that ATM energy consumption is only key in food sales and retail and service buildings, ATMs are found in a wide variety of locations. They are placed in any space that may facilitate consumer spending, including some bars (food service), hotel bars or lobbies (lodging), stadiums, theatres, bowling allies, or other recreational buildings (public assembly), and retail areas in offices.

5.2.2 Energy Savings Discussion

Based on approximate savings potential of individual ATM components, TIAX estimates that each unit has an 80% energy savings potential. This assumes a 20% savings during active use (based on best-in-class active mode energy consumption), as well as a 90% savings in stand-by, or idle mode. The extreme savings during non-active use is based on PC and LCD display energy savings during sleep mode (~95%). Given that ATMs require always-active security measures, such as cameras, and potentially occupancy sensors, TIAX adjusted the potential savings accordingly. This 80% savings corresponds to a UEC of 610 kWh/yr.

5.2.3 References

ADL, 1993, *"Characterization of Commercial building Appliances"* June, 1993 by Arthur D. Little for DOE.

Kerber, 2008, *"Withdrawing from the ATM Habit,"* Boston Globe (online), February 19, 2008. Downloaded on September 30, 2009 from http://www.boston.com/business/personalfinance/articles/2008/02/19/withdrawing_from_the_atm_habit/

Roth et. al., 2002 *"Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings,"* January, 2002, Arthur D Little for DOE.

5.3 Cooking Equipment

Table 4: Overview of findings for Cooking Equipment for buildings in which it is a key load (details in Section 6)

	Office	Retail & Services	Food Sales	Food Service	Education	Health-care	Public AOR	Lodging	Other	Total
Total AEC (TWh/yr)	5.1	5.9	3.6	9.5	2.6	7.7	3	8.4	0.8	47
Energy Intensity (kWh /1000ft^2)	420	390	2900	5700	260	2400	340	1600	56	650
Installed Base (1000s)	920	460	220	780	1000	410	110	610	180	4700
Units / 100,000ft^2	8	3	18	47	10	13	1	12	1	7
Energy Savings Potential	14% savings per unit									6.5 TWh
Energy Savings Measures	Zone control through modularity. Resistive type elements in different configurations to improve heat transfer. Air impingement technology. Insulation gaskets and seals, insulated lids, covers and doors. Double sided griddles to increase throughput									
Data Uncertainties	Usage pattern among different building types can vary substantially. Appreciable uncertainty in ADL (1993) estimates of number of cooking equipment per establishment, which were used to infer the installed base in each building type.									

Table 5: Breakdown of Cooking Equipment for buildings in which it is a key load

		Office	Retail & Service	Food Sales	Food Service	Education	Health-care	Lodging
Broilers	**AEC** (TWh/yr)	0.4	0.5	n/a	0.8	0.1	0.3	0.4
	Installed Base (1000s)	0.37	18	n/a	27	17	12	13
Fryers	**AEC** (TWh/yr)	0.4	0.6	0.7	1.8	0.2	0.2	0.9
	Installed Base (1000s)	170	86	95	250	160	54	120
Griddles	**AEC** (TWh/yr)	0.8	1.1	n/a	1.6	0.3	0.7	0.8
	Installed Base (1000s)	210	100	n/a	150	190	65	71
Ovens	**AEC** (TWh/yr)	1.6	1.9	2.5	2.7	1.3	4.4	3.9
	Installed Base (1000s)	190	92	100	130	250	170	190
Ranges	**AEC** (TWh/yr)	0.2	0.3	0.5	0.4	0.1	0.4	0.4
	Installed Base (1000s)	37	19	20	27	35	23	26
Steamers	**AEC** (TWh/yr)	1.7	1.5	n/a	2.2	0.7	1.6	2.1
	Installed Base (1000s)	280	140	n/a	200	260	86	190

5.3.1 General Discussion

Since this study focuses solely on electric loads, it is important to note that estimates and discussion in this section are based on electrical cooking equipment only and do not include gas-fired models, which have a higher installed base. The cooking equipment being considered includes the following:

- Broilers (free-standing, Salamanders, charbroilers, convey broilers)
- Fryers
- Griddles
- Ovens (convection, deck ovens, range ovens)
- Ranges
- Steamers

High AEC values for cooking equipments are primarily attributed to their high power consumption and usage patterns. A lot of equipment in the commercial sector, particularly in the food service & fast food industry, experience heavy standby energy loss due to the need to leave equipment on between use periods to expedite the cooking of food and/or to keep food warm. The breakdown of how each type of cooking equipment contributes to the total AEC is shown in Figure 2. Ovens are by far the largest load, due to their high installed base compared to other cooking equipment.

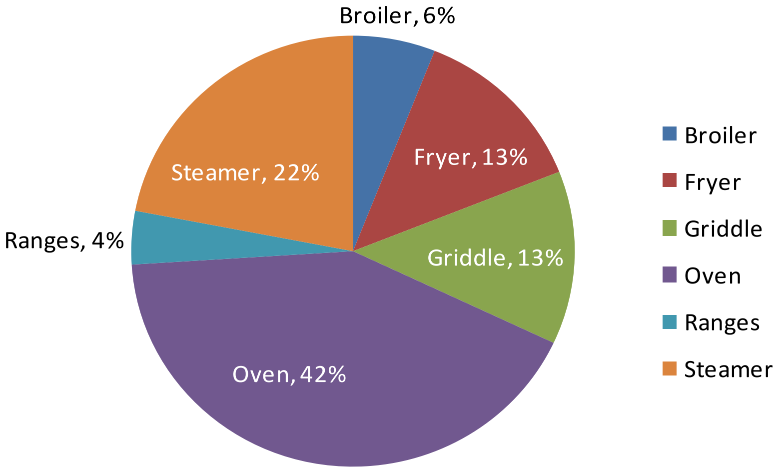

Figure 13: Ovens contribute over 40% of the electric load of cooking equipment.

An ADL (1992) report solicited industry expert feedback and used survey data to estimate the number of cooking equipment inventory by building type as well as their typical sizes and respective hours of operation. In addition, their estimate of typical rated capacities was obtained from catalogs of manufacturers such as Garland Commercial Industries, Vulcan Corporation, Cleveland Range, Frymaster, Beverage Air and Middleby Marshall. Capitalizing on the information from the ADL (1992), TIAX used the number of establishments by building type obtained from CBECS (EIA, 2006) to estimate cooking equipment installed base and AEC for each building type.

As mentioned, electrical cooking equipment has a smaller installed based than gas-fired equipment. However, there are currently no Energy Star ratings for cooking equipment and no mandated minimum efficiency standards, or even industry-wide uniform testing procedures. ADL (1993) proposed a “first principles” analysis for calculating cooking efficiency defined as the theoretical amount of energy required to cook the food consisting of sensible, latent and endothermic heats of reaction divided by the total energy input to the system:

$\eta_{cooking}$ = Cooking efficiency

Where:

$$\eta_{cooking} = \frac{Q_{food}}{Q_{in}}$$

Q_{food} = Heat required by the food

Q_{in} = Total input energy

Where:

$$Q_{in} = \frac{(M_{food})(\Delta H_{cooking})}{\eta_{SS}} + Q_{SB} t_{SB}$$

M_{food} = Mass of Food (lb)

$\Delta H_{cooking}$ = Theoretical amount of energy require to cook the food (200- 700 Btw/lb depending on application)

η_{SS} = Steady state cooking efficiency (50%–60% on average for most cooking equipment)

Q_{SB} = Standby energy loss rate

t_{SB} = Standby time

It is important to note that the actual operating efficiency will always be less than the steady state cooking efficiency due to the fact that cooking equipment is sized for the peak usage; idle (stand-by) and part load usage generates significant energy losses.
From the above equation, cooking efficiency can be theoretically increased by:

- Increasing the steady state cooking efficiency
- Reducing the standby energy losses

5.3.2 Energy Savings Discussion

Summarized in the table below, currently available technologies can potentially save energy across all cooking equipment. In addition to the technologies mentioned, there are others which can augment existing technologies at saving energy in cooking equipment. Examples include:

- Reduced diameter
- Energy management system
- Oil-less cooking
- Inductive cooking
- Microwave assist

Some of the technologies mentioned are applicable to certain types of equipment due to the nature of their operation and the industry in which they are predominantly installed. For example double sided griddles in the fast food industry can reduce energy consumption by increasing product throughput during hours of operating. Commercial service steamers may have achieved some efficiency gains by implementing efficient residential steam boiler designs developed in response to the DOE minimum efficiency standards program, although it is unclear the level at which this technology transfer has occurred.

Table 6: Energy saving technologies for cooking equipment (ADL, 1993)

Technology	Applies to Equipment Type	% Energy Reduction
Zone control through modularity	All except ranges	10
Reduce thermal mass	Griddles only	5
Resistive type elements in different configurations to improve heat transfer	All except steamers	10
Conveyorized broilers to increase throughput	Broilers only	3
Air impingement technology	Broilers, ovens and steamers	15
Insulation gaskets and seals, insulated lids, covers and doors	All except griddles and ranges	10
Double sided griddles to increase throughput	Griddles only	5

Given the older vintage of the available data, there is considerable uncertainty in the level to which these efficient technologies have been implemented in the current installed base.

5.3.3 References

ADL, 1993, “Characterization of Commercial Building Appliances,” Final Report to the Building Equipment Division Office of Building Technologies, U.S. Department of Energy, June.

EIA, 2006, “2003 Commercial Buildings Energy Consumption Survey (CBECS),” Public Use Microdata Files," Download from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html on August 2009.

5.4 Distribution Transformers

Table 7: Overview of findings for distribution transformers for buildings in which they are a key load (details in Section 6)

	Office	Retail & Services	Food Sales	Education	Warehouse	Healthcare	Lodging	Other	Utility owned	Total
Total AEC (TWh/yr)	2	2.1	0.2	1.1	0.8	0.9	0.7	1.1	73	82
Energy Intensity (kWh /1000ft^2)	160	140	160	110	79	290	140	75	N/A	1100
Installed Base (1000s)	1200	1400	100	690	490	570	440	730	46000	52000
Units / 100,000ft^2	9.8	9.2	8.0	7.0	4.9	18.0	8.6	5	N/A	73
Energy Savings Potential	20% savings per unit									16 TWh/yr
Energy Savings Measures	Improve efficiency in dry-type transformers, Promote TP-1 minimum efficiency standard, Promote the adoption of transformer efficiency labeling standard such those from Energy Star and TP-3									
Data Uncertainties	Installed base unclear in each building type since a uniform UEC was assumed									

5.4.1 General Discussion

Distribution transformers are devices that transform electric utility power distribution line voltages (4-35 kilovolts) to lower secondary voltages (120-480 volts) suitable for customer equipment. This voltage transformation can occur in multiple stages, depending on application, but all electrical energy used in the US passes through at least one distribution transformer before being used in end-use equipment. There are two basic types of distribution transformers, and they are defined by their insulation: liquid-immersed or dry-type. However, they can be further categorized in the following ways: Number of phases - single or three phase; voltage class (for dry-type) - low or medium; basic impulse - insulation level (BIL) for medium-voltage, dry-type.

Liquid-immersed transformers rely on oil or other liquid circulating around the coils for cooling. Dry-type transformers on the other hand only use natural convection of air for insulation and cooling. Liquid-immersed transformers are generally more efficient than dry-type due to more effective heat transfer in liquid cooled systems. Generally speaking, distribution transformers are reliable and efficient devices, with no moving parts and average life spans of more than 30 years. There are, however, various factors that affect the overall efficiency of distribution transformers. There is a continuous core loss as a result of being constantly energized and ready to serve a needed load. In addition, there is winding loss associated with temperature and the average load on transformers, which is expressed in terms of percentage of transformer capacity. The figures below, taken from Cadmus Group (1999) study, depict the wattage loss and as result transformer efficiency with respect to load for a 75 kVA transformer model.

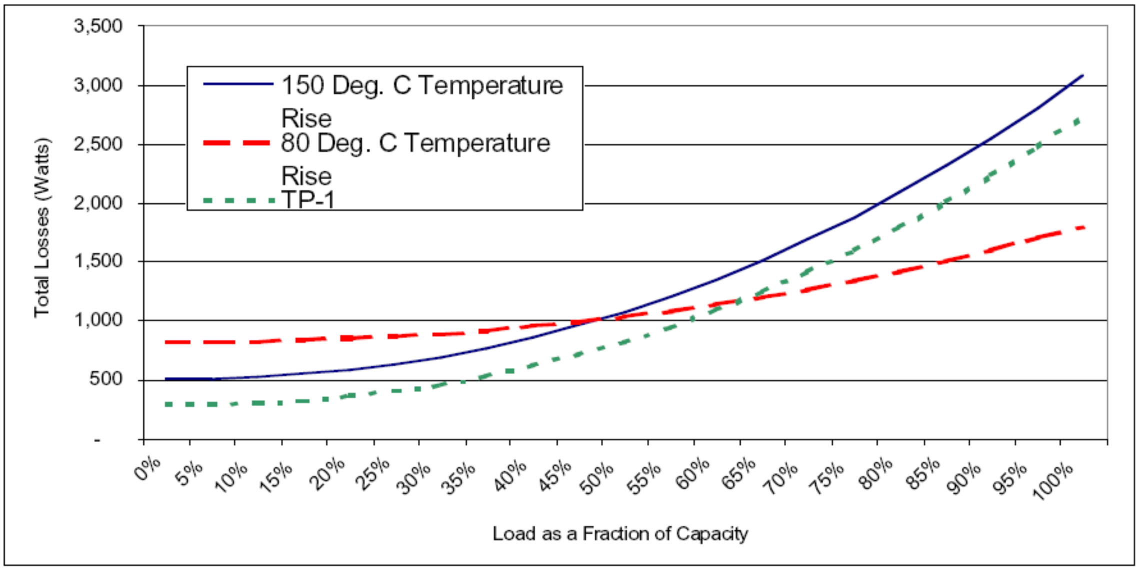

Figure 14: Total Losses versus Load for Three Representative 75kVA Transformer Models (Cadmus Group, 1999)

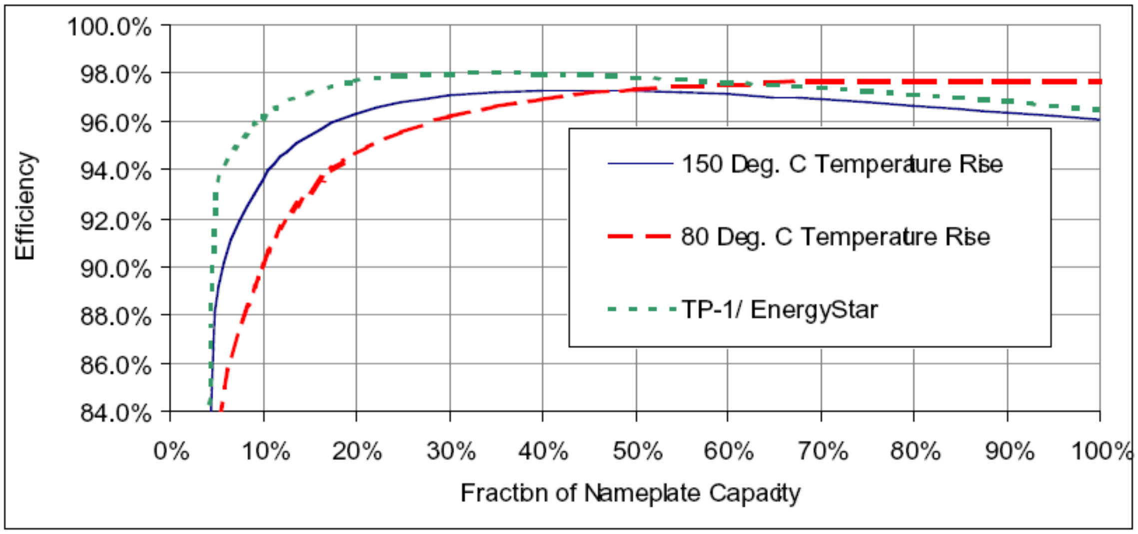

Figure 15: Efficiency versus load for three representative 75kVA models (Cadmus Group, 1999)

It is also important to note from the Cadmus Group (1999) study that the average transformer loads varied little across building types with an RMS average load of 15.9%. The surveyed buildings were universities, healthcare facilities, manufacturing facilities, office buildings, and retail facilities. Each building had an average floor area of roughly 100,000 square feet since most transformers in the commercial sector are in large buildings. The consistent average load across building types implies that there is generally a consistent transformer efficiency value. Typically, distribution transformer efficiencies are in the range of 97% to 99.5% (LBNL's Energy Efficiency Standards, 2009). For this study, TIAX calculated energy loss associated with distribution transformers in the various building types using an efficiency value of 98.5% applied to electrical energy going into buildings of over 50,000 square feet for each building type. This energy loss comes from inefficiencies in distribution transformers that are on the customer side of the electric meter.

TIAX estimates an additional aggregate energy loss of 73 TWh from transformers that are owned by utilities and thus are not associated with any building type. This value was derived by scaling from the transformer energy consumption 1996 to 2008, based on the growth in overall electric energy consumption during that period, or approximately 20%. ORNL (1996) estimated the annual energy lost in the delivery of electricity from distribution transformers used by utilities was approximately 61 TWh in 1996. Around 90% of all liquid-immersed transformers are owned by electric utilities while the remaining systems are owned by commercial and industrial customers (ORNL, 1996). Conversely, more than 90% of the total dry-type market is non-utility (i.e., commercial and industrial sector). (ORNL, 1996)

5.4.2 Energy Savings Discussions

Because all electric energy passes through one or more distribution transformers, energy savings associated could prove to be significant even if there is a slight incremental improvement in the efficiency. Dry-type transformers are less efficient than liquid-immersed and are primarily purchased on the basis of first cost and local availability rather than efficiency. As a result, they pose an appreciable untapped opportunity for efficiency improvements. Application of energy-efficient equipment can reduce transformer losses by about 20%, substantially cutting a facility's total electricity bill and offering a typical payback of less than three years (deLaski et al., 1998). The 20% reduction in energy loss is also consistent with the study from ORNL (1996).

To address these losses and encourage the purchase of more efficient transformers, the National Electrical Manufacturers Association (NEMA) developed and published the voluntary industry standard TP-1-1996, *Guide to Determining Energy Efficiency for Distribution Transformers* (NEMA, 1996, deLaski et. al. 1998). The standard addresses both dry and liquid-filled transformers. Furthermore, it covers low-voltage general purpose dry-type specialty transformers. In addition to TP-1, NEMA has developed and issued TP-2, a test method for transformer efficiency, and is in the process of developing TP-3, a labeling standard to identify transformers that meet TP-1 (Hinge et al., 2000). Lastly, working with NEMA, the Consortium for Energy Efficiency (CEE), and others, the EPA launched the ENERGY STAR commercial and industrial (C&I) transformers labeling program, which is also based on the TP-1 standard for low-voltage dry-type transformers, making it simpler to identify efficient transformers in the market place (Hinge et al., 2000).

5.4.3 References

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DeLaski, A., J. Gauthier, J. Shugars, M. Suozzo, and S. Thigpen. "Transforming the Market for Commercial and Industrial Distribution Transformers: A Government, Manufacturer, and Utility Collaboration.: In Proceedings of the 1998 ACEEE

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5.5 Fitness Equipment

Table 8: Overview of findings for Fitness Equipments in buildings for which it is a key load (details in Section 6)

	Public AOR	Other	Total
Total AEC (TWh/yr)	1.2	n/a	1.2
Energy Intensity (kWh /1000ft^2)	140	n/a	140
Installed Base (1000s)	820	n/a	820
Units / 100,000ft^2	9	n/a	9
Energy Savings Potential	50% savings per unit		0.6 TWh/yr
Energy Savings Measures	Rely more on mechanical mechanism to create resistance. Utilizing Woodway's patented frictionless drive system.		
Data Uncertainties	Installed base of fitness equipment in building types other than public assembly, ratio of treadmills and other fitness equipments, average UEC.		

5.5.1 General Discussion

Fitness equipment is predominantly found in gyms and fitness centers. It is important to note that for this study, buildings that house gyms and fitness centers are considered public assembly buildings, even if those buildings are a part of academic institutions.

Fitness equipment comes in a variety of types and models. The devices that consume the largest amount of energy are primarily those used for stationary cardiovascular exercises such as treadmills, elliptical trainers, stationary bicycles, stair-steppers and rowing machines. Out of the various types of fitness equipment, treadmills draw the most power as a result of their internal electric motors that are used to drive moving conveyor belt platforms. Users can control the speed of the belt as well as the inclination of the platform to increase the intensity of the workout. Energy consumption from other electrical components common to treadmills and other fitness equipment are considered relatively negligible. These include small computer consoles and sometime monitors to calculate, control and display workout duration, levels, heart rates, calories burnt and other exercise parameters.

Unlike treadmills, the majority of other aforementioned fitness equipment relies on the user's motion to generate electricity. As a result, the electrical energy consumption is generally much less than treadmills due to the absence of motors. Exercise intensity is adjusted using various forms of both electrical and mechanical resistance mechanisms such as magnets, electromagnets and fans. Electrical consumption is primarily attributed to these resistance mechanisms. The average power draw for elliptical machines is about 200 Watts (Smooth Fitness, 2009), which is a quarter of that of treadmills (Woodway 2009).

5.5.2 Energy Savings Discussion

For fitness equipment other than treadmills, relying more on mechanical mechanisms to create resistance as well as servicing equipment are good ways to reduce energy consumption. For treadmills, Woodway has come up with a patented technology for a near frictionless drive system which allows treadmill running surfaces to glide on smooth rolling ball bearings. This allows for a much smaller drive motor that Woodway claims to consume 50% less electricity. According to Woodway (2009), friction is the biggest detriment to conventional treadmills. Each time a user takes a step they literally push down the nylon belt onto the deck, requiring the motor to work much harder to overcome friction. This results in a power surge and increased power draw. Woodway's frictionless drive system technology essentially eliminates these power surges as depicted by the figure below from Woodway (2009).

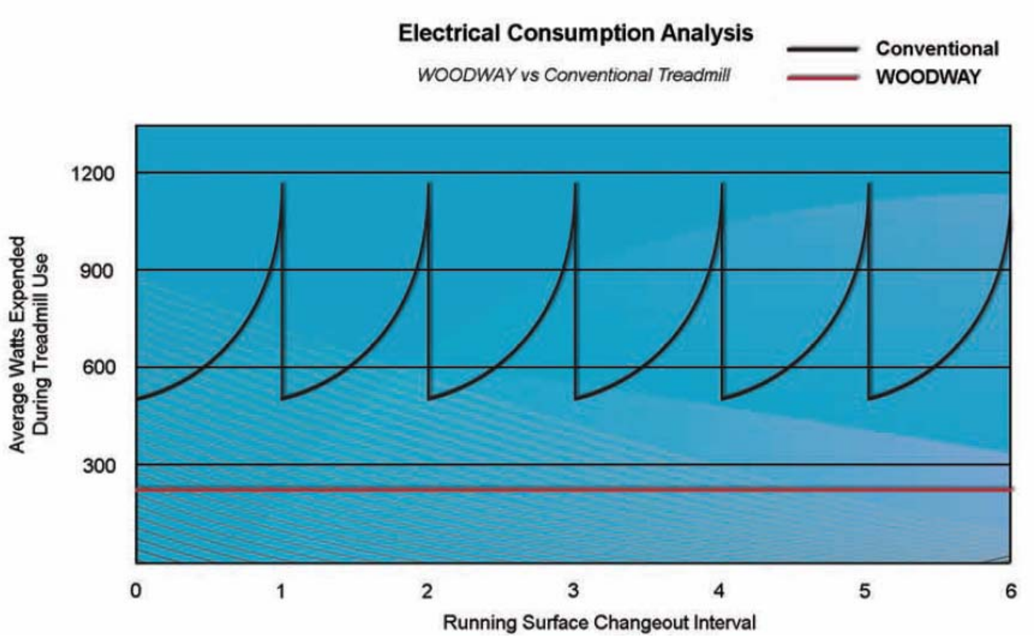

Figure 16: Average Power Consumption comparison between Woodway and Conventional Treadmills. Source: www.woodway.com[9]

5.5.3 References

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[9] Photo source: http://www.woodway.com/begreenrunclean/begreenruncleanwoodway.pdf

5.6 Fume Hoods

Table 9: Overview of findings for fume hoods in buildings for which it is a key load (details in Section 6)

	Laboratories	Other (Office/Education)	Total
Total AEC (TWh/yr)	7.5	7.5	15
Energy Intensity (kWh /1000ft^2)	N/A	340	N/A
Installed Base (1000s)	375	375	750
Units / 100,000ft^2	N/A	170	N/A
Energy Savings Potential	50%		7.5 TWh/yr
Energy Savings Measures	Dampers, variable speed ventilation, and minimal face opening to vary air volume while maintaining constant face velocity, Berkeley Lab's hood design concept, tempered outdoor air near the face of the hood (space conditioning savings)		
Data Uncertainties	Distribution of fume hoods across building types		

5.6.1 General Discussion

Fume hoods are local ventilation chambers found predominantly in laboratory environments and are used to protect workers from exposure to gases, fumes and small particles that could be generated from the substances that are being handled or stored. They work by drawing fresh air from the front opening and expelling the contaminated air from inside the hoods via ducts to the exterior of the building. In specialized systems, the air is recycled via a filtration system. Due to their large power draw and predominantly 24-hour usage, fume hoods are one of the biggest energy consumers of any laboratory equipment. Other laboratory equipment such as those that have electric heating elements including ovens, furnaces, incubators, refractory, autoclaves also consume a significant amount of energy, but have been left out of this study due to insufficient data and very minimal energy savings potential. To be consistent with the MEL-centric nature of this study, TIAX addressed only the energy consumption of the air-handling components of fume hoods, i.e. the energy used to drive ventilation fans. The energy used for conditioning of replacement air in fume hoods is not considered.

There is an appreciable amount of uncertainty in how fume hoods are distributed between building types. They are concentrated in laboratory environments, but this includes both dedicated laboratory buildings and buildings which contain lab space but primarily functions as offices or education buildings. There are many examples of buildings that primarily serve as offices or class room buildings but contain laboratories. The best estimates indicate there is a 50% split in distribution of fume hoods in laboratory buildings versus being in a laboratory that is a minority part of another, non-key building type (mainly offices and education buildings).

5.6.2 Energy Savings Discussion

Fume hoods pose a significant opportunity for energy savings among laboratory equipment. According to LBNL (2003) report, an estimated 50% energy reduction can be achieved for each fume hood through a variety of methods, including:

- Use of a combination of dampers, variable speed ventilation, and digital controls to vary air volume while maintaining constant face velocity
- Restriction of the hood's face opening area while maintaining a constant airflow
- Introduction of tempered outdoor air near the face of the hood (space conditioning savings)
- Use of Berkeley Lab's hood design concept of using a "push-pull" approach to contain fumes and exhaust them from the hood. Small supply fans located at the top and bottom of the hood's "face," gently push air in low velocity into the hood (see figure below) creating an "air divider" that separates the fume hood's interior from the exterior. As a result, the need to expel large amount of air from the hood is reduced unlike conventional hoods which use higher velocity airflow.

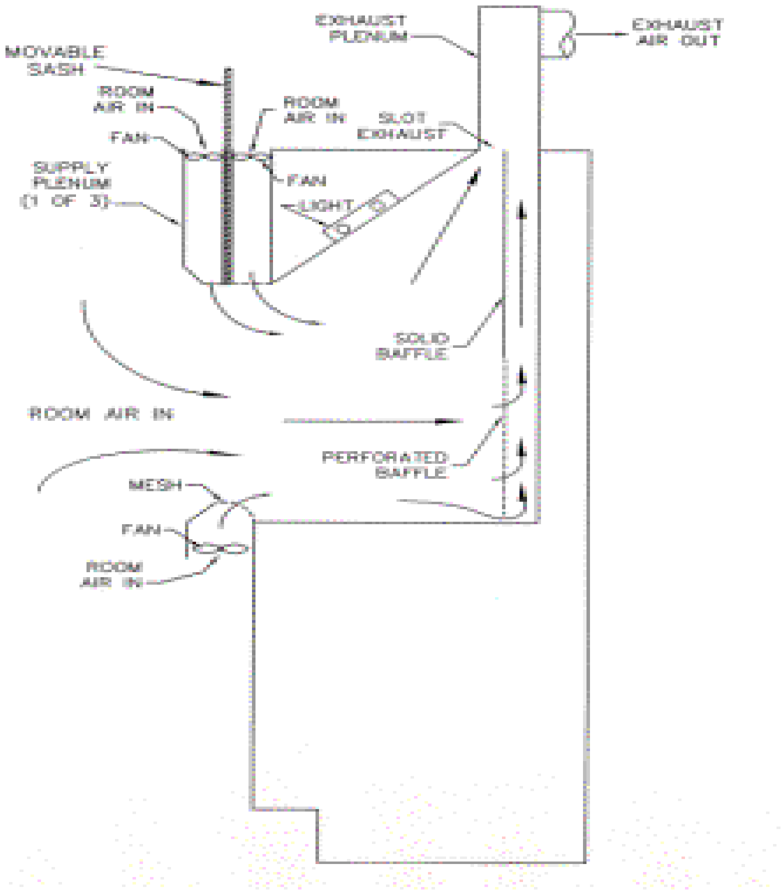

Figure 1: (Bell et al., 2002)[10]

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[10] Source: http://ateam.lbl.gov/hightech/fumehood/fhood.html

5.6.3 References

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5.7 Ice Machines

Table 10: Overview of findings for ice machines in buildings for which it is a key load (details in Section 6)

	Food Sales	Food Service	Education	Healthcare	Lodging	Other	Total
Total AEC (TWh/yr)	0.5	2.8	0.6	2.8	2.6	1.5	11
Energy Intensity (kWh /1000ft^2)	380	1,700	60	880	500	30	150
Installed Base (1000s)	58	340	140	650	1100	320	2,600
Units / 100,000 ft^2	4.6	21	1.4	21	22	0.6	3.6
Energy Savings Potential	24% - Based on ADL estimates for cumulative savings potential for six different measures						2.6 TWh/yr
Energy Savings Measures	High efficiency compressors, fan motors, and fan blades, thicker insulation, reduced evaporator cycling, and reduced harvest melt						
Data Uncertainties	Further research is required on recent trends for analysis of which energy savings measures have the least barriers to implementation. Additionally, little information is available on current installed base. The base data point for this assessment is 1991 ADL.						

5.7.1 General Discussion

Ice is made through traditional vapor-compression refrigeration. A water pump provides steady flow of water over the evaporator plate where the ice accumulates. When sufficient ice has accumulated (generally sensed by thickness or weight), a condenser bypass valve diverts flow directly from the compressor to the evaporator, thereby heating up the plate surface enough to melt the ice and let it fall. In some systems, a mechanical mechanism assists the gravity harvesting system.

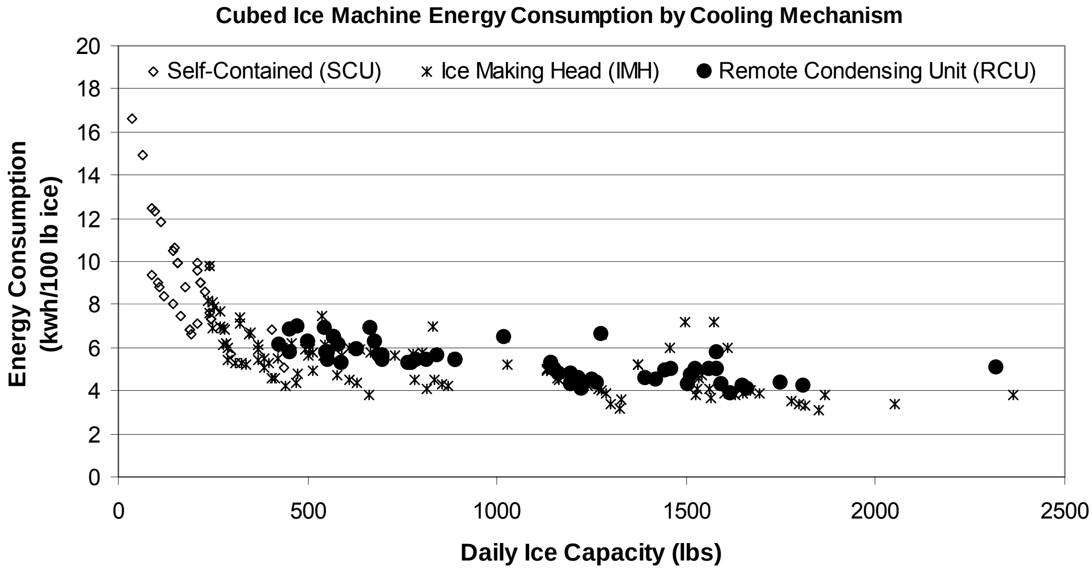

Figure 17: SCUs are generally used for low capacity ice production (<250 lbs per day), whereas IMH and RCU are used for higher production installations.

There are five general types of ice machines based on both configuration and cooling type. These include air and water cooled ice making heads (IMH) that are combined with various size storage bins, air-cooled remote condensing units (RCU), and water and air cooled self-contained units (SCU). The energy consumption (by configuration) of 200 AHRI certified units is shown in Figure 17. In general, SCUs are generally the smallest, with capacities ranging up to 450 lbs per day. Beyond that size, there is a fairly even mix of RCU and IMH units.

In looking at the same data by cooling mechanism, one can see that water-cooled systems generally use slightly less energy, and that they are evenly spread across the size categories. ADL estimates that in 1996, 80% of ice machines had air-cooled integrated condensers (IMH or SCU). The graph in Figure 18 shows the energy consumption of AHRI certified units.

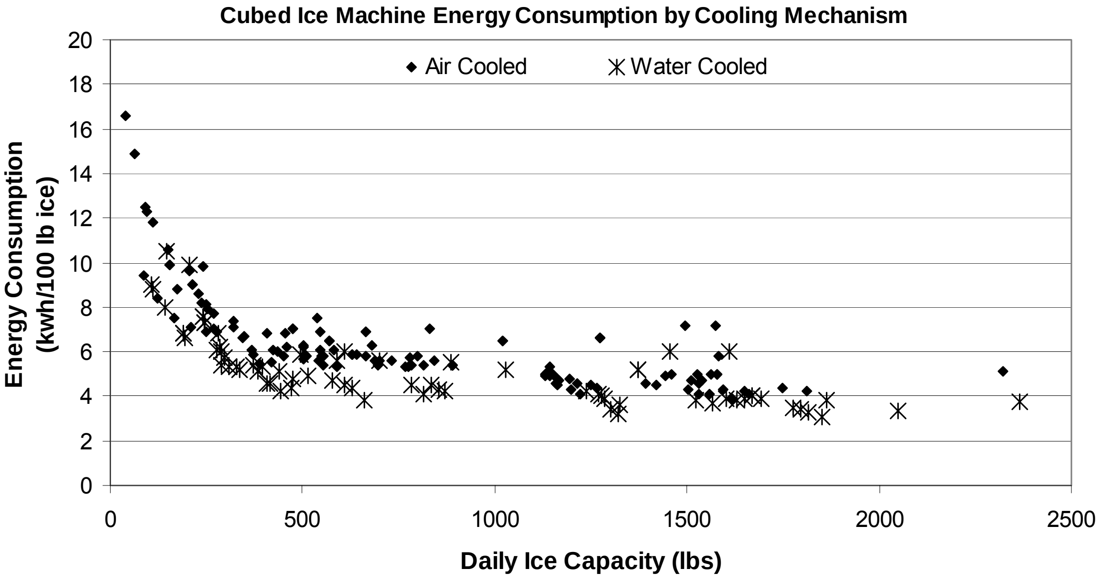

Figure 18: Energy Consumption (per 100 lbs of ice) of AHRI certified ice makers

The AHRI uses a testing environment that is 90 degree inlet air and 70 degree inlet water; depending on the location of use, this may turn out to be higher temperatures and corresponding energy consumption than may actually be exhibited.

In general, and especially at lower capacities, the air-cooled units are more energy intensive. When it comes to actual usage costs however, water-cooled units have the potential to be much more expensive. All units are recommended to use 24 gallons or less for 100 lbs (12 gallons is the minimum feasible), but in addition, water cooled units are recommended to use 215 gallons of condenser cooling water per 100 lbs of ice. In total, that is more than 1075 gallons, or 1.4 ccf (hundreds of cubic feet) per day. Depending on specific commercial water and sewage rates for a given region or utility, this can become a majority of the usage costs.

5.7.2 Energy Savings Discussion

A big, often overlooked benefit of water-cooled units and all RCU ice machines is that the heat from the ice making process is discharged outside, thereby preventing an increase in air-conditioning load. For air-cooled units, the heat is discharged inside at the expense of the air conditioner and the owner (EERE/DOE, 2009).

The ADL study from 1996 on “Energy Savings Potential for Commercial Refrigeration Equipment” outlines six different measures that could be taken to improve energy efficiency. The total potential savings from these six measures is 1200 kWh/yr for a unit with a 500 lb/day capacity. These measures include (ADL 1996):

- High-Efficiency compressor (280 kWh/yr potential reduction) – For a small price premium, ADL estimates that compressors could be used that are 5 to 10% more efficient

- ECM Condenser Fan Motor (271 kWh/yr potential reduction) – Replacing the 100W shaded pole motor that is most commonly used with an ECM motor would saving nearly 66% of the condenser fan energy.
- Thicker Insulation (150 kWh/yr potential reduction) – Doubling the thickness of the insulation is estimated to save 3% on energy costs
- Reduced melting during harvest (230 kWh/yr potential reduction) – Approximately 15% of the ice can melt during ice harvest. ADL estimates that by adding in a mechanical mechanism to assist the heating process, the melt during harvest could be cut by more than 50% for a reduction in cycle consumption of 5%.
- Reduced evaporator thermal cycling (210 kWh/yr potential reduction) – approximately 9% of the compressor energy during the freeze cycle is due to evaporator cycling. ADL assumes that the thermal mass could be reduced by a factor of two, which would reduce the energy consumption by 4 to 5%.
- High-efficiency fan blades (61 kWh/yr potential Reduction) – Optimized ice blades could provide 15% savings on fan energy consumption.

If all of these measures are used, each unit has the potential to save 24% on annual energy consumption. For the purposes of Energy Saving Potential calculations, TIAX uses this mark as the ‘Best-In-Class’ model.

5.7.3 References

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5.8 Irrigation

Table 11: Overview of findings for Irrigation systems for buildings in which it is a key load (details in Section 6)

	Public Assembly	Other	Total
AEC (TWh/yr)	2.4	1.2	3.6
Energy Intensity (kWh /1000 acres)	n/a	n/a	n/a
Total area to irrigate (1000 acres)	2,600	1,200	3,800
Units per 100,000ft^2	n/a	n/a	n/a
Energy Savings Potential	30%		1.1 TWh/yr
Energy Savings Measures	Use of efficient hardware (e.g. NEMA Premium efficiency-rated motors for the pumping systems, optimized water usage for reduced pumping, use of novel technologies such as wireless sensors, variable frequency drive and solar powered irrigation systems.		

	Public Assembly	Other	Total
Data Uncertainties	Energy consumption pertaining to commercial landscape irrigation and how it is distributed among building types		

5.8.1 General Discussion

The Irrigation Association reports that of all fresh water used in the U.S. for the purpose of irrigation, 79.6% is for agricultural purposes, 2.9% is in landscaping, 1.5% is for golf courses, and the remaining 16% is consumed by humans, animals or industry (Zoldoske, 2003). Since this study is limited to commercial buildings, the focus is on irrigation pertaining to golf courses and landscaping since they are the two major contributors to water usage that lie within the commercial sector. For landscaping, there is little data on how much energy is directed towards commercial irrigation but TIAX assumes 25% i.e. substantially less than residential irrigation since nearly 50% of all water withdrawn for public supply is used solely to water residential lawns (FDEP, 2009).

Golf course irrigation is estimated to use more than 476 billion gallons of water annually in the U.S. (Zoldoske, 2003). According to Staples (2009b), a typical golf course uses 250,0000 to 500,000 kWh per year and around 25% to 50% of the electricity consumed by golf courses is used to power pumping systems for water distribution throughout the course. Rarely are pumping systems' efficiencies explicitly known and may often produce 10% to 20% less than they should due wear and tear over time (Staples, 2009b).

5.8.2 Energy Savings Discussion

Many opportunities exist for saving energy in commercial irrigation. Some of easiest available savings come from the following methods:

- Installing more efficient hardware such as National Electrical Manufacturers Association (NEMA) premium efficiency-rated motors for the pumping systems.
- Optimizing water usage to reducing pumping. There are various methods described by MDE (2009) such as using only low-water use plant material in non-turf areas; automating irrigation systems monitored by moisture probes (i.e., tensiometers); design dual watering system with sprinklers for turf and low-volume irrigation for plants, trees, and shrubs; operate sprinkler system before sunrise and after sunset since the amount of irrigation can be determined by the evapotranspiration rate.
- Taking advantage of novel technologies such as the following, which can lead of to 30% in energy savings (Sciencedaily, 2009), Environmental Leader, 2006):
    - Wireless sensors described by Sciencedaily (2009), which optimizes current irrigation systems by measuring and calculating the correct water requirements in real time using information gathered by small electronic devices distributed along the golf course forming a sensor network. These nodes allow for the sprinklers to be activated and deactivated efficiently.
    - Variable frequency drive, which enables a pumping system to adjust itself to demand, and new software for more precise system control, can significantly reduce both energy and water consumption (Environmental Leader, 2006).

5.8.3 References

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5.9 Laundry Equipment (Washers and Dryers)

Table 12: Overview of findings for laundry equipment by key building type (details in Section 6)

	Retail & Services	Lodging	Estimated Total for Non-key Building Types	Total
Total AEC (Twh/yr)	0.8	0.5	0.1	1.4
Energy Intensity (kWh/1,000 ft^2)	52	100	0	20
Installed Base (1000s)	3800	300	60	4,100

	Retail & Services	Lodging	Estimated Total for Non-key Building Types	Total
Units/100,000 ft^2	25	6	0	6
Energy Savings Potential (TWh/yr)	0.2	0.1	0	0.3
Energy Savings Measures	Moisture sensors in dryers, efficient motors, high performance washers (may use more electricity, but save on hot water and by requiring less dryer time)			
Data Uncertainties	Usage profiles (including power draw) by building type, installed base by building type			

5.9.1 General Discussion

Laundry equipment in commercial buildings generally consists of washing machines, dryers, and dry cleaning equipment. This study is only evaluating electric energy consumption, and the majority of commercial dryer are gas powered. Therefore, the majority of the energy consumed by commercial dryers is not considered here. Likewise, the majority of the energy consumed for commercial clothes washer is actually consumed by water heaters to heat the water used in the process. The energy considered in this study is the electric energy used by washer and dryer motors and controls.

About 85% of commercial laundry equipment is found in non-food service buildings (e.g., coin and route operations). Laundry equipment is also considered to be a key MEL in lodging buildings (e.g., hotels, motels, nursing homes, and dormitories). CBECS data suggests that approximately 65% of lodging buildings (72% of lodging square footage) and 80% of nursing homes have on-site laundry equipment. (EIA, 2006). On the other hand, 80% of hospitals do not have on-site laundry, and therefore the energy is consumed in non-food service buildings.

The average unit energy consumption is approximately 330 kWh/yr, but the average for specific commercial building types varies based on the assumed usage pattern.

5.9.2 Energy Savings Discussion

Federal standards were initiated for residential-style commercial washer energy and water usage in 2007. The modified energy factor (MEF) sets the amount of energy that can be consumed for the sum of water heating energy, operation energy, and post wash drying energy per load capacity. Additionally, a water factor (WF) sets the maximum amount of water that can be consumed during a wash per load capacity. Tax incentives such as EPACT 2005 have also helped to promote the penetration of more efficient wash equipment. Generally, the electric energy consumption of laundry equipment is reduced by reducing wash agitator energy or by reducing dryer time. The Energy Star commercial washer energy calculator indicates that efficient commercial equipment (with a gas dryer) consumes about 25% less electric energy than conventional equipment.

5.9.3 References

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5.10 Medical Equipment

5.10.1 Medical Imaging Equipment

Table 13: Overview of findings for medical imaging equipment in buildings for which it is a key load (details in Section 6)

	Healthcare	Total
Total AEC (Twh/yr)	6.8	6.8
Energy Intensity (kWh/1,000 ft^2)	2,150	100
Installed Base (1000s)	200	200
Units/100,000 ft^2	6	0.3
Energy Savings Potential (TWh/yr)	0.3	0.3
Energy Savings Measures	Power management, low power mode, efficient cooling technology	
Data Uncertainties	Usage by mode, energy consumption of ultrasound imaging equipment, energy consumption of dental X-ray equipment	

5.10.1.1 General Discussion

Medical imaging equipment consists primarily of X-ray, magnetic resonance imaging (MRI), and computed tomography (CT). As expected, this equipment is found almost exclusively in healthcare buildings. The data in Table 13 represents a weighted average of these three key medical imaging equipment types. Ultrasound imaging equipment is not included due to the lack of reliable data, and the anticipated lower energy consumption.

In 2008, there were approximately 170 thousand medical X-ray machines in the U.S. and 16 thousand CT scanners. The installed base was estimated based on data from state health departments for California, Texas, Florida, New York, and Pennsylvania, the most populated states, which track the equipment that emit radiation. The installed base was scaled nationally based on population. The installed base of MRI equipment in 2008 was approximately 9 thousand (Bell 2004, Bell 2006).

In general, the unit energy consumption of medical imaging equipment is increasing. Higher resolution equipment typically consumes more energy. Additionally, the installed base of medical equipment is increasing, adding to the growth in annual energy consumption of this C-MEL.

5.10.1.2 Energy Savings Discussion

Energy efficiency has not generally been a key parameter for medical imaging equipment, although it seems that manufacturers are becoming more aware of the concerns with healthcare building energy consumption. One manufacturer now promotes a 1.5 T MRI system that consumes 40% less energy than conventional systems, claiming efficient gradient and electronics design and more efficient cooling technology. We have applied these savings to MRI equipment in our energy savings potential calculation, but it is unclear to what extent power management and other energy savings measure could reduce medical imaging equipment energy consumption.

5.10.2 Other Medical Equipment

Table 14: Summary for other medical equipment for buildings in which it is a key load

	Healthcare	Total
Total AEC (Twh/yr)	3	3
Energy Intensity (kWh/1,000 sqft)	950	45
Energy Savings Potential (TWh/yr)	unclear	unclear
Energy Savings Measures	Power management, energy efficient design practices	
Data Uncertainties	Estimate based on energy consumption per floor area in sample medical buildings (LBNL 2004), there is very high uncertainty in these estimates due to the large range of devices included and the lack of available data.	

5.10.2.1 General Discussion

In addition to large medical imaging equipment, there are other medical imaging technologies not accounted for above. Ultrasound, dental x-ray, mammography, and fluoroscopy equipment, for example, are not included. Furthermore, there is an abundance of other medical equipment that consumes energy. Heart rate monitors, oto-ophthalmoscopes, hospital beds, exam tables, exam lights, sterilizers, defibrillators, IV carts, etc. are all found in healthcare buildings.

It does not appear that any one device consumes a significant amount of energy, but LBNL (2004) found that miscellaneous medical equipment consumed approximately 1,000 kWh per 1,000 square feet of floor area for a small sample of healthcare buildings. This scales to approximately 3 TWh per year for all healthcare buildings, assuming approximately 3 billion square feet for healthcare buildings. If the buildings sampled by LBNL (2004) are representative of healthcare buildings in the U.S., there may be an installed base of over 30 million miscellaneous medical devices. This installed base is not very meaningful given the large number of device types it could incorporate. Further investigation is needed to find the medical devices which consume the bulk of the energy in the sub-category.

There is a high degree of uncertainty in the estimates for ‘other’ medical equipment due to the large number of device types and the lack of available data. The estimates provided should be considered as preliminary.

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New York State Department of Health Bureau of Environmental Radiation Protection, 2006, X-ray Equipment Inventory, Received upon request.

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5.11 Mobile Phone Towers

Table 15: Overview of findings for mobile phone towers

	Estimated Total for Non-key Building Types
Total AEC (TWh/yr)	4.4
Energy Intensity (kWh /1000ft^2)	N/A
Installed Base (1000s)	175
Units / 100,000 ft^2	N/A
Energy Savings Potential	unclear
Energy Savings Measures	On-site wind or solar power generation, power management
Data Uncertainties	Installed base, average site power draw

5.11.1 General Discussion

TIAX calculated a preliminary estimate of the energy consumption of mobile phone towers (a.k.a., base transceiver stations, cell sites), due to the relatively rapid increase in installed base. Mobile phone towers are generally not associated with building energy consumption, but may be considered a commercial miscellaneous electric load. We have assumed that towers installed on top of buildings have their own electric meters, and are therefore independent of the building energy consumption. Also, the term “tower” is used loosely, since antennas installed on buildings may not require an actual tower. Furthermore, a single site (e.g., tower or building roof) may have multiple antennas from multiple wireless carriers. The antennas and other communications equipment for each carrier, or tenant, generally have separate utilities installed, and therefore should be considered as separate units. However, we do not have data to support this level of granularity, and our installed base estimate is likely for individual sites, which may or may not have equipment from multiple carriers. There are an estimated 175,000 cell sites in the U.S., which consume approximately 4.4 TWh/yr.

Towers are equipped with antennas, transmitters, and other electronics to support the mobile phone infrastructure. There is little public information regarding the power draw and usage of the current installed base. However, through discussions with an industry expert, we were able to define the UEC range to be 6,600 kWh/yr for low traffic towers to 43,000 kWh/yr for high traffic towers. Assuming a normal distribution of low and high traffic towers, the average UEC was calculated to be approximately 24,900 kWh/yr.

Mobile phone towers will have a power draw profile that follows call traffic. We do not have information regarding the power profile, but have estimated the average power draw to be 2.8 kW, which assumes that installed towers are active all the time.

There is a high degree of uncertainty in the estimates for mobile phone towers due to the lack of available data. The estimates provided should be considered as preliminary.

5.11.2 Energy Savings Discussion

The energy savings potential for mobile phone towers is unclear. There are opportunities to install onsite wind or solar power generation to partially or completely offset the electric energy requirement from the grid. There are examples of both solar and wind powered mobile phone towers in industry for rural or secluded sites. Furthermore, there may be power management techniques that could reduce energy consumption during off-peak periods. However, it is not known what power management methods are already being implemented. We have not calculated an energy savings potential for mobile phone towers in this study. Further analysis is necessary to understand the applicability of different energy savings measures.

5.11.3 References

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5.12 Monitors

Table 16: Overview of findings for Monitors in buildings for which it is a key load (details in Section 6)

	Office	Retail & Services	Food Sales	Food Service	Educa-tion	Ware house	Health care	POA &R	Lodging	Other	Total
Total AEC (TWh/yr)	11	2.7	0.5	0.5	6.7	0.8	1.9	1.1	2	0.2	27
Energy Intensity (kWh /1000ft^2)	900	180	400	300	680	79	600	130	390	46	380
Installed Base (1000s)	63,000	15,000	3,000	3,000	38,000	4,400	11,000	6,000	11,000	1,200	160,000
Units / 100,000ft^2	520	98	240	180	390	44	350	68	220	28	220
Energy Savings Potential	66% savings per unit										18 TWh/yr
Energy Savings Measures	Greater penetration of LCDs (vs. CRTs), Higher efficiency LCD backlighting, Adoption of organic light emitting diode (OLED) displays, Increasing PM-enable rates via factory installation, user, PC-automated PM										
Data Uncertainties	PM-enabled rates, Usage patterns										

5.12.1 General Discussion

Monitors are electrical equipment that display images generated by PCs, mostly desktop PCs. Laptops, which have their own monitors, are sometime connected to docking stations which utilize external monitors. The installed base of monitors comprises of primarily three types of display technology which include: liquid crystal display (LCD), cathode ray tube (CRT), and plasma (PDP). Once dominated by CRT displays, the monitor market has transitioned to liquid crystal displays (LCDs). Plasma has not gained a substantial market share due to its relative high cost compared to the other two technologies. The popularity of LCD monitors is attributed to their compact size, minimal screen flicker and competitive price. It is also the most energy efficient, consuming significantly lower energy compared with CRTs.

In this report, we have estimated monitor usage patterns in three key building types (offices, education and healthcare) based on the LBNL (2007) study where sixteen buildings in three cities were surveyed. According to LBNL (2007), 75% of the U.S. installed base of computers is found among the three aforementioned building types, which is where highest concentration of monitors will be located as well.

5.12.2 Energy Saving Discussion

Similar to PCs, increasing the PM-enabled rates will have a substantial impact on monitor UEC and AEC. Table 5 lists the power draw by mode for best in class monitors according to data gathered by Energy Star (2005).

Table 17: Best in Class UEC from Energy Star Monitors Product List (EPA, 2005)

	Active [W]	Sleep [W]	Off [W]	Brand and Model
CRT – 17”	37	2	1	Lanix LN710S
LCD – 15”	14	0.7	0.5	NEC AccuSync LCD52V Mitsubishi DiamondPoint V51LCD Philips 150B6
LCD – 17”	15	2	1	Lanix 700P Lanix AL170
LCD – 19”	23	0.9	0.7	AccuSync LCD92V Mitsubishi DiamondPoint V91LCD

An appreciable reduction in energy consumption can be attained as more LCD replace older CRT monitors. The bulk of the energy savings comes from lower active mode power draw. Furthermore, energy savings could be achieved through the implementation of automatic brightness control (ABC), although the potential savings from ABC have not been determined in this study.

Future technologies such as LCDs with high efficiency backlights and organic light emitting diode (OLED) displays could offer further significant reductions in unit electricity consumption. OLEDs have many advantages such as greater range of colors, brightness, contrast and viewing angle compared to LCDs. In addition, LCDs use a backlight and cannot show true black, while an off OLED element produces no light and consumes no power. Energy is also lost in LCDs because they require polarizers that filter out about half of the light emitted by the backlight.

5.12.3 References

EIA, 2006, “2003 Commercial Buildings Energy Consumption Survey (CBECS),” Public Use Microdata Files, Downloaded from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html on August 2009.

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5.13 Non-road Vehicles

Table 18: Overview of findings for non-road vehicles in buildings for which they are a key load (details in Section 6)

	Warehouse	Public AOR	Estimated Total for Non-key Building Types	Total
Total AEC (Twh/yr)	2.7	1.0	0.6	4.3
Energy Intensity (kWh/1,000 ft^2)	271	110	12	64
Installed Base (1000s)	580	980	890	2,400
Units/100,000 ft^2	5.7	11	2	4
Energy Savings Potential (TWh/yr)	0	0.3	0	0.3
Energy Savings Measures	Solar powered golf carts (~33% savings), reduced battery charge leakage, efficient batteries			
Data Uncertainties	Energy consumption of floor burnishers			

5.13.1 General Discussion

The category of non-road electric vehicles consists of lift trucks (a.k.a., fork lifts), golf carts, and electric burnishers. There are approximately 575 thousand electric lift trucks in the U.S., the majority of which are assumed to be found in warehouses. There are approximately 975 thousand electric golf carts in the U.S., and golf courses are considered to be public assembly buildings. Electric burnishers are assumed to be generally evenly distributed among large buildings, and do not make a significant energy contribution to any one building type.

Forklifts are divided into classes. Class 1 and 2 forklifts tend to have a much higher unit energy consumption than motorized hand lifts (class 3). The growth in the installed base is approximately 3% per year, while the UEC does not appear to be changing with time. Internal combustion engine (ICE) forklifts are also common in the commercial sector, but their energy consumption is not considered here (see ITA 2005, EPRI 1996).

65% of golf carts are electric, with an increasing percentage trend. Overall, the stock of electric golf carts increases by approximately 2% per year.

Electric burnishers are estimated to be fairly evenly distributed among building types, perhaps as a function of floor area. Their energy consumption is not considered to be significant in any one building type, and therefore the estimated 0.6 TWh/yr is grouped in the total energy for non-key building types.

5.13.2 Energy Savings Discussion

The energy savings potential for non-road vehicles comes from either improving the battery efficacy, or by recharging using renewable energy sources. Non-road vehicles generally use deep-cycle batteries which are generally selected based on durability. Some deep discharge batteries may offer a lower self-discharge rate, which could be captured as energy savings potential, but may not offer the same battery life. It is unclear what the practical energy savings potential is for similarly performing batteries suited for the application.

Similar deep discharge batteries are used for both forklifts and golf carts, and therefore battery technology improvements could impact the energy consumption of both. Additionally, for golf cards, we have assumed that best in class units use solar panels to offset the electric energy requirement from the building. Products are available that use this technology, and one reference suggests that the energy savings is approximately 33%. (Cruise Car 2009) We have applied this factor as the energy savings potential for golf carts, shown as energy savings potential in public assembly buildings.

5.13.3 References

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5.14 Office Equipment

Table 19: Overview of findings for Office Equipment in buildings for which it is a key load (details in Section 6)

	Office	Education	Healthcare	Other	Total
Total AEC (TWh/yr)	7.2	4.5	1.3	4.8	18
Energy Intensity (kWh /1000ft^2)	590	460	410	100	250
Installed Base (1000s)	22,000	14,000	3,800	14,000	54,000
Units / 100,000ft^2	180	140	120	30	75

	Office	Education	Healthcare	Other	Total
Energy Savings Potential	85% savings per unit				15 TWh/yr
Energy Savings Measures	Increasing PM enable rates for equipment types that have PM via user awareness, network, PC. For servers, scale microprocessors operating voltage/clock frequency in response to server demand. Utilizing smart power strip				
Data Uncertainties	Usage patterns are unclear due to the vast number/variety/diffuse nature of equipment. Mode of operations varies among types of office equipment. TIAX estimates of office equipment usage patterns as well as their installed base in the context of various commercial building types were deduced from the LBNL (2007) study. For this study, LBNL conducted an after-hours power status survey of over 500 office equipment units in sixteen commercial buildings in three cities. Please refer to Section 6.1.4 for further details.				

Table 20: Breakdown of Printers in buildings for which it is a key load

		Office	Education	Healthcare	Other	Total
Printers	**AEC** (TWh/yr)	4.7	2.8	0.8	2.9	11
	Installed Base (1000s)	14,000	8,500	2,400	8,700	34,000
Copiers	**AEC** (TWh/yr)	1.1	0.7	0.2	0.7	2.7
	Installed Base (1000s)	1,500	940	270	950	3,700
MultiFunction Devices	**AEC** (TWh/yr)	0.2	0.1	0.03	0.1	0.4
	Installed Base (1000s)	2,500	1,500	430	1,600	6,000
Scanners	**AEC** (TWh/yr)	0.05	0.03	0.01	0.03	0.1
	Installed Base (1000s)	1,500	890	250	930	3,600
Fax Machines	**AEC** (TWh/yr)	0.1	0.1	0.02	0.08	0.3
	Installed Base (1000s)	2,300	1,400	390	1,400	5,500
Servers	**AEC** (TWh/yr)	1.1	0.8	0.2	3.0	5.1
	Installed Base (1000s)	490	380	100	340	1,300

5.14.1 General Discussions

Office equipment is a sizeable load in commercial buildings and is present in most work environments. The highest concentration is in office, education and healthcare buildings where the largest numbers of PCs are found. Approximately 74% of the PCs in the US can be in these three building types (LBNL, 2007). This report defines office equipment as the following devices:

- Printers (impact, inkjet, laser)
- Copiers
- Multi-function devices – provide printing (inkjet and laser), copying & scanning services
- Scanners
- Fax machine (inkjet, laser, thermal)
- Servers

Although PCs and monitors are conventionally known and are defined as office equipment in other studies sited in this report, they are broken out individually in this study since they are significant and growing loads.

As depicted in the figure below, this study shows that printers account for the most energy consumption (over half) of office equipment across the three key building types followed by servers and copiers.

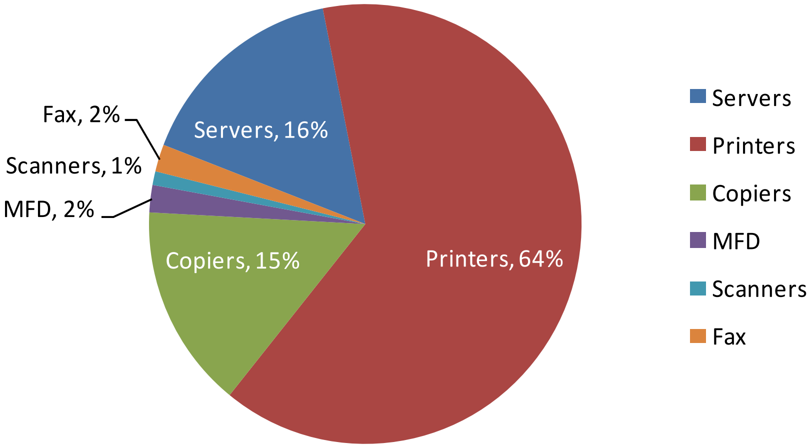

Figure 19: Energy Consumption breakdown for Office Equipment

The large percentage of energy consumption by printers is due to both the high installed base and the relatively high average power draw of up to 77W for laser printers in standby mode (ADL 2002). Being the primary means to generate hardcopy documents from computers, printers are an integral part in the office environment. The vast majority of printers in commercial buildings are laser printers which account for about 75% of printers (ADL 2002) with the remaining being primarily inkjets and impact printers. Typically, laser printers are shared resources between multiple users in a computer network, whereas inkjet printers may serve as personal printers and thus are more commonly found in small office environments. The primary difference among the various types of printers is the mechanism in which images are generated. Laser printer consume significantly more energy then other printers (almost twice as much) due to the need for fuser rolls to be held at high temperatures to bond the toner to the paper. With other types of printers, energy is primarily used to move and operate mechanical components such as the inkjet in inkjet printers.

Copiers are similar to laser printers in terms of energy consumption in that they are also required to maintain high fuser roll temperatures and thus have high stand-by power draws. Reheating cooled fuser roll can take some time which is the main reason they consume more power during start up.

Another large consumer of energy among office equipment is servers, which are computers that provide various services such as storage, database and other shared applications across a network. Servers vary in size, computation capabilities and power draw but the majority of servers in commercial buildings are workhouse and mid-range server computers running business applications and databases (ADL, 2002).

An estimated 9% of the electricity consumed by commercial buildings is from office equipment (TIAX, 2002). This equipment is often shared in the office environment and most often connected to company networks. As a result, network connectivity has been found to induce energy use in equipment by remaining fully powered-up continuously even when not in active use due to the need to respond to network protocol messages. To mitigate this situation, implementing a power management proxy as described in Klamra et al. (2005) is a via solution to have connected devices enter and remain in a sleep state and wake up on when their services are needed based on a Wake-on-LAN packet trigger. The basis of the approach relies on a proxy server within the networked devices that manages the replaying of network protocol messages and act as an entity on behalf of the sleeping devices to maintain their network presence. Currently one of the major technical challenges facing power management proxy is to accurately determine if a sleeping device has left the network. Nevertheless, the energy savings from office equipment could be substantial if proxy network receives wide spread penetration. Klamra et al. (2005) estimates that if up to 25% of devices are enabled with power management proxy, around 4TWh can be saved.

5.14.2 Energy Savings Discussion

Energy savings approaches for office equipment are highest impact if focused on power saving features for printers, servers and copiers, which constitute the majority of energy consumed in office equipment. Currently Energy Star performance criteria for most IT and office equipment have focused primarily on having equipment enter low-power modes after a period of inactivity as well as capping power draw values for different equipment types in low-power mode. Increasing PM-enable rates can be facilitated by network software which provides a means to centralized power management across a range of equipment interconnected via a network.

Beyond power management and being more active about turning off devices, there are other methods to achieving energy savings. In the case of printers and in particular laser printers, maintaining fuser rolls at an elevated temperature could significantly reduce total laser printer as well as copier energy consumption by almost 50% (TIAX, 2004). Therefore any advances in fuser systems, including toner materials with lower melting temperature can contribute to energy savings in these devices during the stand-by mode.

In addition, since most office equipment is centered on PCs, automating device shut-down or low power mode based on PCs inactivity using smart power strips creates significant savings potential. The Smart Strip Power Strip works to switch devices on and off automatically based on a "master" PC. For example when a computer that is connected to the smart power strip goes into sleep mode, all of the peripherals (printer, monitor, etc.) will also turn off. Other models of the smart power strip also include a timer switch which shuts off connected peripherals based on the time of day.

Servers, unlike PCs, do not use power management to reduce energy consumption during periods of reduced usage. However, energy savings potential exists in powering down a significant number of servers based on computation load, particular during nights and weekends when workloads decrease. Strategies that power down certain server hardware components (such a hard drives) or scale server microprocessors operating voltage/clock frequency in response to server demand can reduce energy consumption by servers in many scenarios. These strategies, however, would be most beneficial in servers exhibiting large variations in load and might not be appropriate for servers that run applications that continuously process data.

5.14.3 References

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5.15 Personal Computers (PCs)

Table 21: Overview of findings for PCs (desktops & notebooks) in buildings for which they are a key load (details in Section 6)

	Office	Retail & Services	Food Sales	Food Service	Education	Ware house	Healthcare	Public AOR	Lodging	Other	Total
Total AEC (TWh/yr)	25.5	5.4	1.3	1.3	19.4	2	5.3	2.7	4.9	0.2	68
Energy Intensity (kWh /1000ft^2)	2,100	350	1,000	790	2,000	200	1,700	310	960	46	950
Installed Base (1000s)	57,000	11,500	3,000	3,000	44,000	4,500	12,000	5,500	1,100	500	150,000
Units / 100,000ft^2	470	75	240	180	450	45	380	63	22	12	210
Energy Savings Potential	79% savings per unit										54 TWh/yr
Energy Savings Measures	Turn off PC when not in use, More efficient power supplies, Enable PM via factory default setting, user, network. PM enabling can be automated via network.										
Data Uncertainties	PC PM-enabled rates and usage patterns. Much of the estimates are based on LBNL (2004) data which surveyed 12 buildings in three states and has an accurate breakdown of PC usage pattern based on building types. Values from on LBNL (2004) in addition to those from CBECS (2003) to project values up to 2008 as well as to obtain PC energy consumption values in building types that were not surveyed in LBNL (2004). LBNL (2004) recorded the number of computers in each buildings as well as the power state during after-hours. Please refer to Section 6.1.5 for further details.										

5.15.1 General Discussion

Personal computers (PCs) play a vital role in today's work environment. They come in two main form factors commonly referred to as desktops and notebooks with the former making up a majority of the installed base. This is primarily due to the higher cost of notebook PCs. Both form factors share similar physical components, including a central processing unit (CPU), power supply, motherboard, memory card, hard disk, video card, monitor, keyboard, pointing device such as a mouse and optical disk usually in the form of CD-ROM/Writer or DVD-ROM/Writer. Furthermore, the PC's hardware capabilities can frequently be expanded by means of hardware expansion slots such as PCI and ISA in the case of desktops, PCMCIA on laptops, and Universal Serial Bus (USB) devices which can be found in both desktops and notebooks. The latter is becoming increasing commonplace as a means to connect additional peripherals such external drives, webcams and other human-interface devices with the PC. The digital resources of a PC are managed by an operating system (OS), which serves as the interface between the hardware and the user.

In addition to being relatively low cost and high in processing power, there is a vast array of software programs written for the PC which makes it a versatile tool capable of serving the needs of a wide range of applications in various industries and occupations. As a result, PCs can be found in most work environments and thus in all building types. Generally speaking however, PCs are most abundant in settings where common PC applications are used, including: word-processors, browsers, email clients, multimedia programs, databases and spreadsheets. This is indicative of why the AEC of 25.2 TWh and installed base of PCs are highest in offices. Education and healthcare buildings are the other building types in which the aforementioned PC applications are concentrated. In 1999, 74% of computers in the U.S. were found among office, education and healthcare buildings (LBNL, 2004)

In terms of power consumption, notebooks consume considerably less compared to desktops due to the need to converse battery life. According to EPA Energy Star (2005b) and Roberson et al. (2002) a desktop can consume on average up to 75W while a notebook consumes around 25W in active mode. The hardware components that make up for the majority of the energy consumption come from the power supply losses, graphics card, and CPU. To provide some perspective, Figure 20 presents Intel's estimates of the overall power shares of the major components of a personal computer.

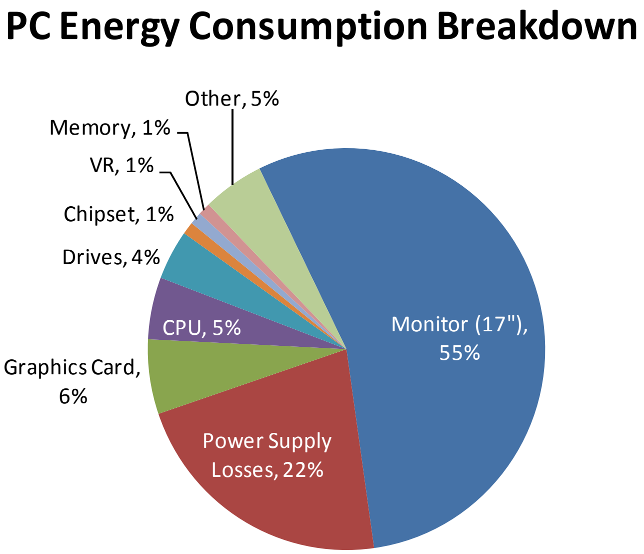

Figure 20: Estimated Power Budget for Personal Computer. *Source Intel 2003*

5.15.2 Energy Savings Discussion

Currently, PCs reduce their energy consumption primarily through power management (PM). Under an industry standard specification called Advanced Configuration and Power Interface (ACPI), current operating systems provide interfaces for users to configure when and under what condition(s) their PCs go into a lower power mode. Such conditions can be a period of inactivity or when the monitors are shut-down as in the case with notebooks. Power management reduces the energy consumption of PCs by controlling the operating voltage and/or clock frequency in response to computational load obtained from the operating system. Almost all PCs possess power management with many having PM factory enabled. However, according to Korn et al. (2004) there are several reasons why an appreciable amount of PCs in commercial sector are not power managed which includes the following: historical problems with PM reliability, software incompatibility, a lack of awareness of PM, and prior myths about PM that decrease its use. Christensen et al. (2004) note that PCs often lose network connectivity when they enter a low-power mode. Many users may not accept the inconvenience of losing connectivity and, thus, disable power management to avoid this problem. It is widely known that notebook users tend to see more value in power management because it can play a vital role in prolonging battery life, as well as alleviating the potential for overheating, especially in fan-less PCs. There is an appreciable amount of uncertainty of how many PC users in the commercial sector have PM disabled.

A network-based collection of data regarding usage patterns and PM enable rates would be beneficial in yielding more detail data over longer periods of time. It is estimated that 9% of the electricity consumed by commercial buildings is from office equipment – much of it is attributed to network connected PCs (TIAX, 2002). With the increased reliance of the Internet in addition to accessing information on company networks, PCs in commercial buildings most often connected to networks. Maintaining network connectivity requires active participation on part of the host PCs. In fact, it is estimated that billions of dollars worth of electricity every year are used to keep network hosts fully powered on at all times only for the purpose of maintain network presences (Nordman et al., 2007). According a survey by Webber (2006), around 60% of office desktop PCs are left on continuously. Another source estimates that 80% and 60% of desktop and notebook PCs, respectively, have PM disabled (CCAP 2005). Network connected PCs could be asleep and saving energy a majority of the time if not for the need to maintain connectivity. To mitigate this problem, the advent of Network Connectivity Proxy (NCP) has recently been introduced, which allows idle host PCs to enter a low-power sleep state and still maintain network presence. NCP, by definition, encapsulates the intelligence for maintaining network presence in an entity other than the core of the networked devices – an NCP is that entity which maintains full network presence for sleeping network hosts (Jimeno et al., 2008). In recent years, NCP have only started to penetrate into commercial buildings. Certain technical challenges still remain such as the ability to preserve existing TCP connections when a network host goes to low power mode as well as the issue of accurately determining which network packets received by a sleeping can be ignored, which require immediate reply and which can be buffered for later processing. Currently estimating the exact cost and energy savings of network connectivity poses an appreciable amount of uncertainty. According to PC Energy Report (2007), an estimate of around 17 TWh of energy can be saved from office PCs alone using NCP.

Enabling PC power management and turning machines off particularly during nights and weekends can achieve extensive energy savings. Increasing consumer awareness of the benefit of power management will help significantly since consumer demand for desktops is currently centered on high performance processors rather than conserving PC power. Beyond power management, more efficient power supplies can reduce PC power draw (TIAX, 2004) and the aforementioned draft version of a new Energy Star specification for PCs also includes minimum power supply efficiencies for both internal and external ac-dc power supplies.

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5.16 Refrigeration

5.16.1 Overview Discussion

Refrigeration in this study will cover two categories: commercial and residential (found in commercial spaces). Commercial units are discussed in sections 5.16.2 through 5.16.5, and residential units are covered in detail in Section 5.16.6.

Commercial refrigeration is broken down into classes of equipment by the equipment family, condensing unit configuration, and the rating temperature. These categories include:

Equipment Families (EERE, 2009)

VOP	Vertical without Doors
SVO	Semi-Vertical without Doors
HZO	Horizontal without Doors
SOC	Service Over Counter
VCT	Vertical with Transparent Doors

HCT	Horizontal with Transparent Doors
VCS	Vertical with Solid Doors
HCS	Horizontal with Solid Doors

Condensing Unit Configuration

RC	Remote Condensing Unit
SC	Self-Contained Condensing Unit

Rating Temperature

M	Refrigerator (“Medium Temperature”), 38 °F
L	Freezer (“Low Temperature”), 0 °F
I	Ice Cream Freezer (“Ice Cream Temperature”), 15 °F

For example, HZO.RC.L is a horizontal unit without doors that uses a remote condensing unit and is rated for low temperatures. For the purposes of this study, TIAX used definitions that centered on the condensing unit configuration. “warehouse” and “central” refrigeration both use remote condensing units, while “commercial units” use self-contained condensing units. “Walk-in” refrigeration does not fit in the above class definitions, and is broken out separately in this study. A summary of refrigeration is shown below in Figure 22. Starred table entries (*) indicate that the specific load was not studied in depth because it was not believed to be a key load for a given building type. It does not necessarily indicate a value of zero.

Table 22: Refrigeration Annual Energy Consumption (TWh/yr) for key sub-types across all building types.

Building Types	Office	Retail & Service	Food Sales	Food Service	Education	Warehouse	Healthcare	Public AOR	Lodging
Residential	2.8	*	*	*	*	*	*	0.7	2.9
Central	*	*	19	*	*	*	*	*	*
Unit Coolers	0.3	1.4	2.8	2.9	0.6	*	0.2	0.9	*
Walk-in	*	3.4	5.9	7.2	2.1	1.4	0.7	1.7	1.5
Warehouse	*	*	*	*	*	7.8	*	*	*

5.16.2 *Central Refrigeration*

Table 23: Overview of findings for central refrigeration in buildings for which it is a key load

	Food Sales
Total AEC (TWh/yr)	19 (assume 95% of refrigeration load is from central)
Energy Intensity (kWh /1000ft^2)	26,000
Installed Base (1000s)	28 (CBECS - assume all grocery stores have one system)
Units / 100,000 ft^2	NA
Energy Savings Potential	46% over conventional systems – 8.6 TWh/yr total

	Food Sales
Energy Savings Measures	low-charge multiplex systems, evaporative condensers, distributed compressor systems, more
Data Uncertainties	Highly varying descriptions of “typical” system size – wide range of estimates for avg store size and avg UEC. Unlike many data sources, TIAX includes small grocery stores in calculations – UEC is much smaller as a result

5.16.2.1 General Discussion

Typical supermarket central refrigeration systems can consume as much as 1-1.5 million kWh per year, which is generally about half of the energy consumption of the entire building (Baxter, ORNL). Of the total refrigeration load, 60-70% is for condensers and evaporators, and the remainder is for fans, lighting, defrosting, and anti-sweat heaters (Baxter, ORNL). Unlike other types of refrigeration, central refrigeration is unique to food sales buildings as defined by CBECS. Specifically this includes markets and grocery stores – convenience stores are generally not large enough to make central refrigeration economically viable. As defined by the Food Marketing Institute (FMI, 2008), a supermarket has greater than $2MM in annual sales (~35,400 in the US as of 2008). While convenience stores may also clear $2MM in annual sales, they often do so by selling gasoline as their primary product – their grocery selections are often limited to high-convenience items.

For years supermarkets have been designing high efficiency systems. The extreme costs of refrigeration on such a large scale motivates larger capital expenditures during building construction to minimize the impact of electricity costs on profits for years to come (ADL, 2002)

In 2002, ADL described a typical full size supermarket with a multiplex refrigeration system as follows:

- Average full service store is 60,000 square feet
- Average design loads:
    - low temperature - 330,000 Btu/hr, average 80 horsepower
    - medium temperature - 1,150,000 Btu/hr, average 175 horsepower
- Average electric load is 440 kW, 55%-57% of which (245 kW) is used to operate refrigeration equipment
- 1.2 million kWh/year is consumed by refrigeration equipment
- The average compressor duty cycle is 85% for low temperature and 55% for medium temperature (ADL, 2002)

In 2008, NREL updated this assessment:

- Average full service store is 42,000 sq ft
- Compressor-racks consisting of: two low-temp racks for frozen foods, ice cream, and walk-in freezers, and two medium-temp racks for meat, dairy, and deli cases and walk-in units (Hale, 2008).
- Breakdown of refrigeration units as shown in Table 24

Table 24: Typical supermarket breakdown of units by type

Case/Walk-in Type	Total Length (ft)	Percentage
Island single deck meat	108	8.6%
Multi-deck Dairy/Deli	264	20.9%
Vertical Frozen Food with Doors	270	21.4%
Island Single Deck Ice Cream	120	9.5%
Walk-In Cooler (Med-Temp)	375	29.7%
Walk-in Freezer (Low-Temp)	125	9.9%

As Figure 21 shows, the vast majority of food sales buildings are less than 5000 sq ft in size. However, the energy consumption for refrigeration increases dramatically as size increases. So while there are numerous stores that are greater than 100,000 sq ft that consume close to two million kWh for their refrigeration needs every year, the average is significantly less.

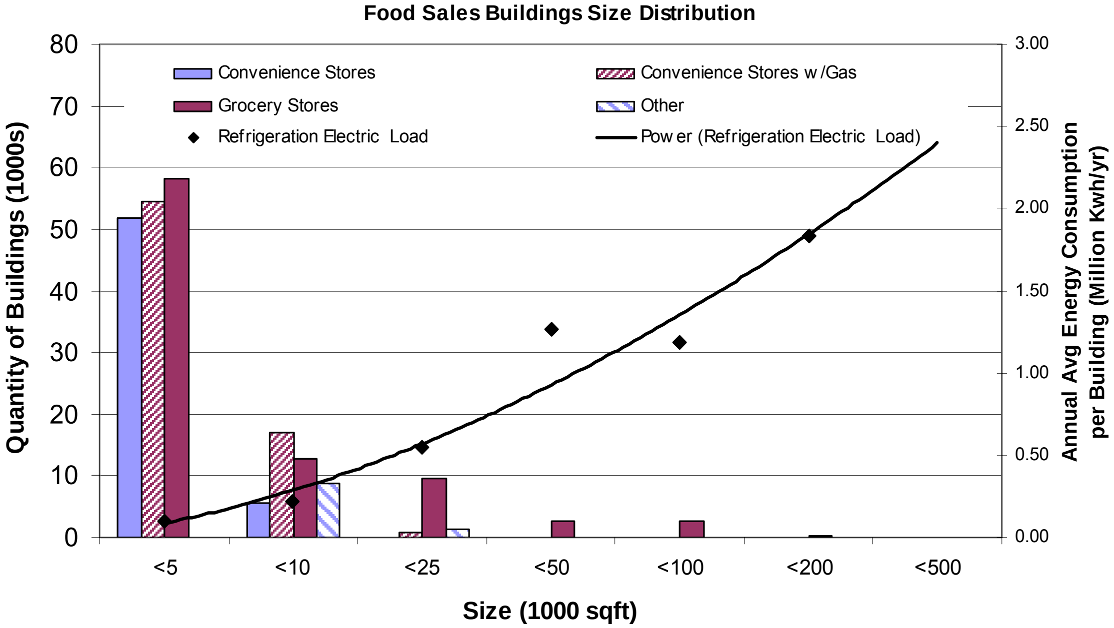

Figure 21: The vast majority of food sales buildings are less than 5000 sq ft in size, and the only subgroup of any significance at larger sizes is grocery stores (EIA, 2006).

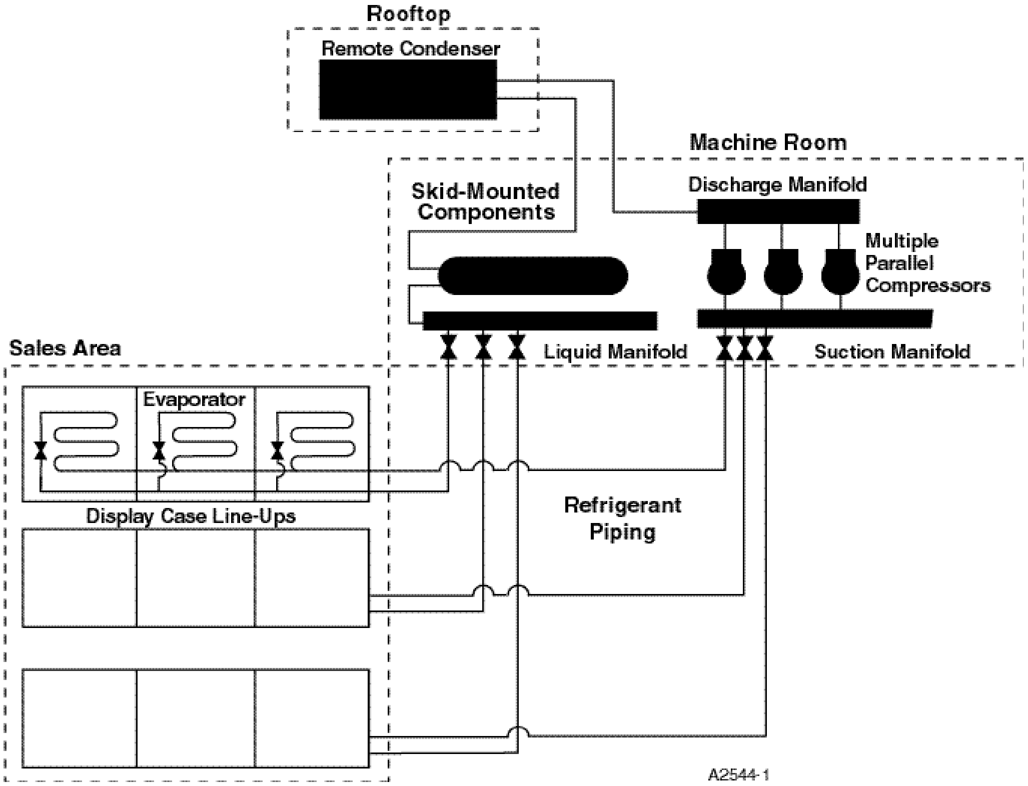

Figure 22: Layout of a typical multiplex refrigeration system in a supermarket (Walker, Foster-Miller).

A multiplexed refrigeration system is the standard type of system in a supermarket. The general layout, as shown in Figure 22, consists of a remote machine room where racks of compressors are mounted in parallel. This configuration allows for greater load control for varying system needs, and consistent cycling of all compressors. The refrigerant flows through hundreds of feet of piping to evaporators located in each of the refrigerated units on the sales floor. Heat is rejected though remote (often rooftop) condenser units after passing through hundreds of additional feet of piping. Generally the condenser units are air-cooled because of the low up front capital investment required.

For the purposes of this study, TIAX assumes that convenience stores, though they may have significant electricity loads for refrigeration, do not use central refrigeration systems. These buildings tend to have most refrigerated beverages in merchandiser units and potentially a few units for dairy products including refrigerated items like milk, and frozen items like ice cream. This refrigeration is generally done with unit coolers/freezers or walk-in units with outward facing merchandiser doors (see Section 5.16.4).

5.16.2.2 Energy Savings Discussion

The use of evaporative condensers instead of air-cooled condensers can provide an 8.2% savings on energy consumption (Baxter, ORNL). The evaporation causes the water temperature to approach the air's wet bulb temperature which is significantly lower than the dry bulb temperature. As a result of a lower heat sink temperature, the systems head pressure can be lowered, increasing efficiency, or the condenser size can be decreased, lowering system costs (ADL, 1996)

Distributed compressor systems also provide room for efficiency gains. Instead of using a centralized compressor stage, this type of system uses individual compressors in each unit. Scroll compressors are often utilized to reduce noise and vibration (Baxter, ORNL). While they are slightly less efficient in refrigeration applications, the fact that scroll compressors have no valves in them allows for lower condensing temperatures, thereby boosting the overall efficiency of the system.

Heat is rejected in this system through each unit's own liquid cooled condenser. The heat rejection fluid loop connects all the units in the building to a centralized chiller. Because the heat rejection loop can be glycol or another fluid, a major benefit of this system is a 50% reduction in charge size assuming liquid-cooled condensing is used. Overall, a distributed compressor system can reduce electricity consumption by 11-12% (Baxter, ORNL and Walker, Foster-Miller).

ORNL's analysis of advanced energy saving techniques in supermarket refrigeration also discusses low-charge multiplex systems, and secondary loop systems. These systems, when coupled with evaporative condensers, were able to achieve 11.6% and 10.4% energy savings, respectively.

In addition to high level system design improvements, there are several smaller energy saving measures that are more targeted at improvements at the component level. While generally more associated with stand-alone commercial or residential units, they apply to central systems as well. In their recent NREL study, Hale describes many of these measures, including:

- High-efficiency fans
- Reduced lighting power (LED and CFL)
- Anti-sweat heater controls
- High-efficiency anti-sweat heaters
- Alternative defrost systems
- Addition of night-covers or doors to open cases

By incorporating the above features, Hale concludes that load can be reduced for a specific unit as follows:

Based on the breakdown of units from Figure 24 and the potential savings from Figure 25, TIAX estimates that these measures could reduce the system's energy consumption by 15%.

Table 25: Central refrigeration energy savings potential by unit type (Hale, 2008)

Unit type	Savings Potential	
	With listed measures	Replace with vertical, closed door unit
Low-temperature, vertical unit with doors	40%	-
Multi-deck dairy/deli case	14%	82%
Single-deck ice cream case	36%	54%

The most effective method for achieving high efficiency at the unit level is to switch out all open cases to high-efficiency vertical cases with doors. This however comes with certain usability changes that some stores may be less inclined to accept (Hale, 2008).

In its analysis of energy savings potential, ADL provides a breakdown by specific technologies (see Table 26). Taking into account various competing technologies and the percentage of applicable supermarkets based on size and type, the total potential savings becomes 24%.

Table 26: Incorporating various factors of supermarkets across the country, the total potential energy savings for the average supermarket refrigeration system is 24%.

Technology	Load reduction	% of supermarkets	Actual national impact
Evaporative Condenser	3.1%	96%	2.98%
Floating Head Pressure	3.1%	38%	1.18%
Ambient Subcooling	0.5%	63%	0.32%
Mechanical Subcooling	1.4%	35%	0.49%
Hot Gas Defrost	3.1%	31%	0.96%
Liquid Suction Heat Exchanger Low Temp.	2.4%	50%	1.20%
Liquid Suction Heat Exchanger Med. Temp.	1.8%	75%	1.35%
High-Efficiency Lighting	2%	100%	2.00%
ECM Evap Fan Motors	8.1%	100%	8.10%
Antisweat Heater Controls	5.7%	25%	1.43%
Improved Insulation	0.3%	100%	0.30%
Defrost Control	0.5%	100%	0.50%
High-Efficiency Fan Blades	3.2%	100%	3.20%
		TOTAL:	**24%**

In combining system level improvement from the ADL study, and the benefits gained from replacing various open units with high-efficiency reach-in units with doors, TIAX estimates a total savings potential of 46%. This includes:

- 24% savings estimate from ADL system-level improvements
- 17% savings by replacement of Multi-deck dairy/deli units (82% savings on 21% of units – See Table 24 and Table 25)
- 5% savings by replacement of Single-deck ice cream units (54% savings on 9.5% of units – See Table 24 and Table 25)

TIAX does not include savings achieved by adding strip curtains (24 hr/day impact) or night covering shields (impact only when store is closed) to open units because the savings is less that what could be achieved by replacing the open units with high-efficiency closed units (SCE, 1997 and Energy Star Building Manual, 2009).

For the purposes of this study, a ‘Best-in-class’ unit will not be a specific unit, but rather a generic system that is 46% better than the current typical unit that is used today.

5.16.2.3 References

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5.16.3 *Warehouse Refrigeration*

Table 27: Overview of findings for warehouse refrigeration in buildings for which it is a key load

	Warehouse
Total AEC (TWh/yr)	7.8
Energy Intensity (kWh /1000ft^2)	770
Installed Base (1000s)	15
Units / 100,000 ft^2	NA
Energy Savings Potential	35% (PG&E, 2009 Estimate) – 2.7 TWh/yr Total
Energy Savings Measures	Evaporative condensing, improved lighting and insulation, sensor controlled doors, and more
Data Uncertainties	Due to scale, warehouse efficiency is a high priority, but most data are broad and cover general efficiency. Also, UEC and applicability of various savings measures varies significantly from system to system.

5.16.3.1 General Discussion

Warehouse refrigeration systems are similar to supermarket "central" systems in their scale, but instead of piping refrigerant to various units throughout the building, the warehouse refrigeration cools an entire building or a portion of a building.

It is common for different goods to need different storage temperatures; for example, ice cream is frequently stored at 15°F, while other frozen goods are stored at 0°F, and refrigerated items are as high as 38 to 40°F. The incredible energy intensity of these buildings is more akin to large scale HVAC in both concept and implementation than to other refrigeration systems.

An Alaska Sea Grant study points out that the design temperatures are important to energy consumption beyond the direct costs for electricity; for many goods, including seafood, the colder the temperature, the longer the storage life (Cole, 2004). It is therefore vital to appropriately balance the increased costs of decreasing the set point temperature with the increased revenue potential associated with increased storage life.

5.16.3.2 Energy Savings Discussion

Lekov et al., in a 2009 study estimated the potential savings breakdown by system components, including the condenser, evaporator, compressor, and the building shell (insulation, doors, etc). The results are shown below in Figure 23.

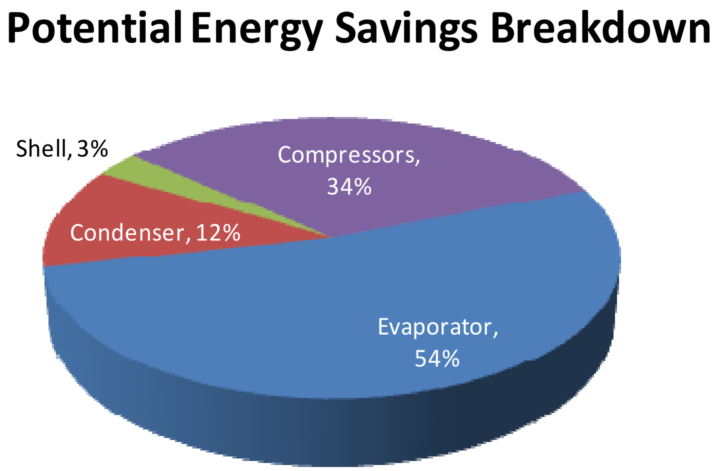

Figure 23: Advances in evaporators are estimated to account for 54% of all energy savings in warehouse refrigeration.

In 2008, a PIER study for the CEC surveyed California refrigerated warehouses in part to understand energy consumption and the various measures being used to reduce the consumption. They asked about the use of 11 different energy saving measures

- Upgraded insulation (UI)
- Cool roofs (CR)
- Efficient lighting technology (ELT)
- Aggressive evaporative condenser (AEC)
- Thermo siphon oil cooling (TSC)
- Computer control (CC)
- Compressor variable frequency drive (Comp VFD)
- Condenser variable frequency drive (Cond VFD)
- Evaporator variable frequency drive (Evap VFD)
- Floating head pressure (FHP)
- Sensor controlled doors (SCD)

Only five of the 11 measures were found in more than 50% of buildings, indicating that there is significant room for improvement in energy consumption. The percentage of surveyed buildings that contained each energy savings measure is shown below in Figure 24.

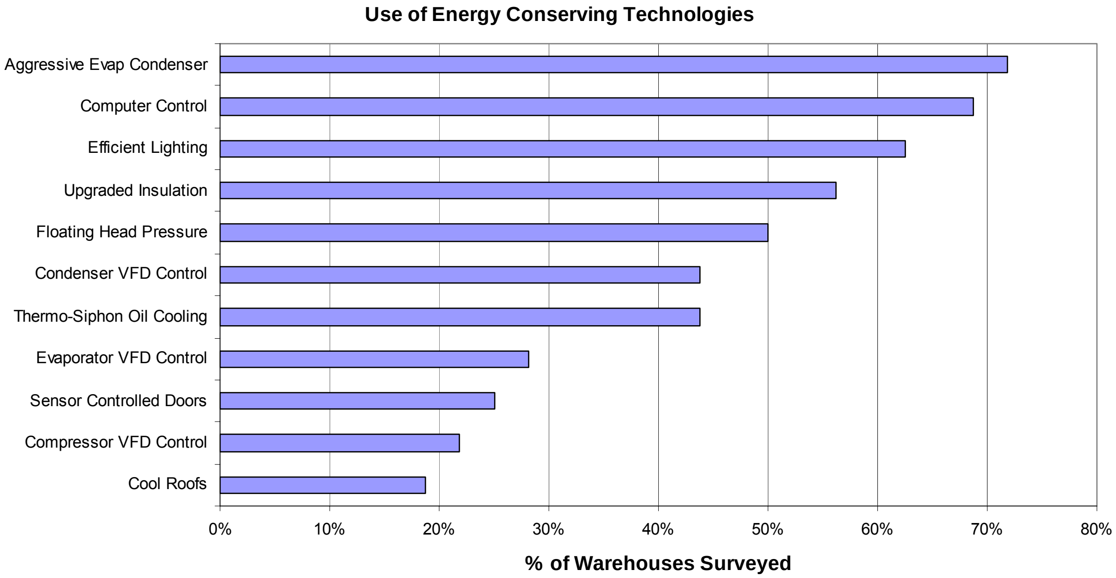

Figure 24: PIER study findings on use of energy saving technologies in refrigerated warehouses

Lekov et al, discusses additional energy saving measures, but does not estimate potential savings. These include Fast-Acting Doors for reducing air infiltration, improved defrost control, improved part-load performance, and load-shedding or duty cycling which allows the system to be shut off when the temperature is within a specific range around the set point (Lekov, 2009) (Black, 2008).

While the PIER study does not analyze a "best-in-class" system or give a potential energy savings, estimates from other sources indicate a 35% potential decrease in refrigeration load with implementation of the various available technologies (PG&E, 2009). ADL's 1996 study of commercial refrigeration gives an even more optimistic view on warehouse refrigeration (ADL, 1996). The study does not specifically discuss warehouse refrigeration, but given the similarities to walk-in refrigeration, one can get an idea of the energy saving measures that might be available if the system were scaled to warehouse size. TIAX assumes however that the PG&E estimate is more realistic at this time because in the years since the ADL study, many of these measures have already been implemented in refrigerated warehouses (lowering applicability of savings measures to a 'typical' unit). The energy consumption is so large in these situations that companies tend to upgrade their systems sooner than the owner of a walk-in unit would do. The potential economic impact creates an incentive to upgrade to energy saving technologies very quickly.

For the purposes of this study, TIAX assumes that a best in class warehouse refrigeration system has a 35% lower electric load than a typical unit.

5.16.3.3 References

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5.16.4 Walk-in Refrigeration

Table 28: Overview of findings for walk-in refrigeration in buildings for which it is a key load

	Retail Service	Food Sales	Food Service	Education	Warehouse	Health care	Public AOR	Lodging	Other	Total
Total AEC (TWh/yr)	3.4	5.9	7.2	2.1	1.4	0.7	1.7	1.5	1.3	25
Energy Intensity (kWh /1000ft^2)	220	4,700	4,400	210	140	230	190	290	80	350
Installed Base (1000s)	180	310	380	110	74	39	87	77	69	1,300
Units/100,000 ft^2	1.2	25	23	1.1	0.7	1.2	1.0	1.5	0.4	1.8
Energy Savings Potential	62% per unit over conventional systems (ADL, 1996)									16 TWh/yr
Energy Savings Measures	Thick insulation, Economizer Cooling, floating head pressure, high efficiency lighting and fans, and advanced defrost and anti-sweat systems									
Data Uncertainties	Walk-in refrigeration in Mall is very sparse and what exists is difficult to accurately assess due to the varied use of space. Best UEC data are from 1997 which is likely to be on the high side.									

5.16.4.1 General Discussion

Walk-in refrigeration is commonly used in the food sales and service industries. Their large capacity is useful for short term storage of perishable goods before shelving in a store or prior to preparation in a restaurant. Typical units used in food sales and service are approximately 160 square feet in floor space (ADL, 1996).

In food sales, another configuration is also often used where one side of the walk-in unit contains display cases that face outwards. These combination units help store owners with little floor space to make good use of their square footage by combining refrigeration units together. Additionally, it reduces shelf stocking time and keeps aisles from being blocked since all stocking is done from the rear with products that are presumably already very close at hand. Though it can be an efficient use of the area, the loads can fluctuate more frequently as doors are opened on an irregular and potentially frequent basis by customers.

While Walk-in units are not exclusive to food industry buildings, it is generally exclusive to the food industry itself. That is, even though small percentages of all non-food related building types have walk-in refrigeration (see data below in Figure 25), the use is almost always for restaurants, cafés, convenience stores, or other food related businesses that reside in the building.

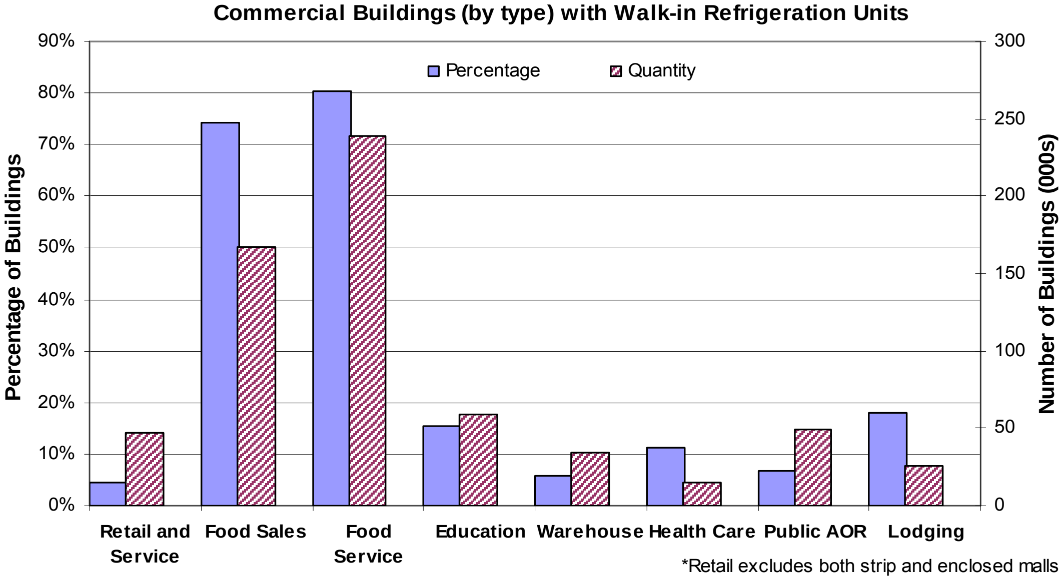

Figure 25: Walk-in refrigeration is most common in buildings in the food industry.

As shown in Figure 25, greater than 70% of food sales and service buildings have walk-in refrigeration, accounting for greater than 60% of the commercial buildings in the US with walk-in refrigeration, and 55% of the total US installed base.

5.16.4.2 Energy Savings Discussion

ADL outlines a number of energy saving measures at various stages of market penetration, including: Thick insulation, Economizer Cooling, floating head pressure, high efficiency lighting and fans, and advanced defrost and anti-sweat systems (ADL, 1996). Some of the most applicable ones include:

- High Efficiency Fans and lighting – The use of ECM evaporator/condenser fan motors and electronic ballasted fluorescent lights, as with many forms of refrigeration, can provide important savings.
- Floating head pressure – With floating head pressure, the pressure ratio is significantly lower for a good portion of the year while still providing the same reliable service. While it is standard to then run the condenser fan continuously

with this setup, the tradeoff of lower compressor energy consumption more than counters this energy consumption.

- Economizer Cooling – by utilizing cold outdoor air in northern climates to reduce cooling load, ADL estimates that compressor electricity can be reduced by up to 26% (based on a unit in Minneapolis)
- External Heat Rejection – By locating the condenser (or entire condensing unit) outside in cold environments, the compressor duty cycle can be reduced. In addition, during warmer times of year, this can also provide additional savings through reduced space conditioning loads.

Table 29: Energy Efficiency measures for walk-in coolers and freezers

Energy Efficiency Measure	Cooler Energy Reduction	Freezer Energy Reduction
Floating Head Pressure	18%	-
External Heat Rejection	-	9
Ambient Sub-cooling	9	9
Economizer Cooling	8	-
Anti-Sweat Heat Controls	2	6
Thicker Insulation	0.4	4
Evaporator Fan Shutdown	4	4
ECM Evaporator Fan Motor	8	14
ECM Condenser Fan Motor	2	7
Electronic Light Ballasts	1	-
High Efficiency Fan Blades	6	5
Non-electric Anti-sweat	6	13
Hot Gas Defrost	-	4
Defrost Controls	-	2
TOTAL	**32%**	**33%**

Based on ADL's analysis, walk-in refrigeration units have the potential to save up to 33% on annual energy consumption by implementing various energy saving measures. Their analysis weighed the applicability of each technology for the two different temperature levels as well its usage in combination with other technologies.

5.16.4.3 References

ADL, 1996, *"Energy Savings Potential for Commercial Refrigeration Equipment,"* Arthur D. Little for DOE/OBT, June, 1996.

Energy Center of Wisconsin, 1999, *"Cutting Energy Waste in Large Refrigeration Systems,"* Downloaded on September 16, 2009 from http://www.irc.wisc.edu/file.php?id=33.

5.16.5 Commercial Unit Coolers and Freezers

Table 30: Overview of findings for commercial unit coolers and freezers in buildings for which it is a key load

	Office	Retail / Service	Food Sales	Food Service	Educa-tion	Health-care	Public AOR	Other	Total
Total AEC (TWh/yr)	0.3	1.4	2.8	2.9	0.6	0.2	0.9	1.3	10
Energy Intensity (kWh /1000ft^2)	24	92	2,200	1,700	63	69	98	65	150
Installed Base (1000s)	74	360	720	740	160	56	220	320	2,700
Units / 100,000 ft^2	0.6	2.4	57	45	1.6	1.8	2.5	1.6	3.8
Energy Savings Potential	62% per unit over conventional systems								6.4 TWh/yr
Energy Savings Measures	ECM fan motors, high efficiency lighting and compressors, hot gas defrost and anti-sweat heaters, better insulation, more								
Data Uncertainties	Many comprehensive inventory studies are now out of date. Sources vary in definition of ‘commercial units’								

5.16.5.1 General Discussion

Energy of commercial refrigerators varies significantly depending on the intended application; a common, typical unit is approximately 44 to 48 cu ft, has two doors, and is a reach-in style unit (ACEEE, 2004). Pacific Gas and Electric Company’s Food Service Technology Center (FSTC) for example, tested a typical unit that had 44 cu ft of usable space (FSTC, 1999).

In this self-contained commercial refrigerator category there are many configurations: there are roll-in units which have floors that are flush to the ground for rolling carts into, pass-through units which have doors on opposing sides, glass-door and mixed door units that allow people to see the contents, and beverage merchandisers which are designed specifically for holding cold beverages for sale.

Commercial refrigeration units are used in a wide variety of buildings. They are concentrated in the food industry, but since restaurants and cafes are routinely located in a variety of buildings, so are commercial refrigerator and freezer units. CBECS gives some insight into where they are used with the data in Figure 26. The highest numbers are in food related buildings and the least are in offices and warehouses.

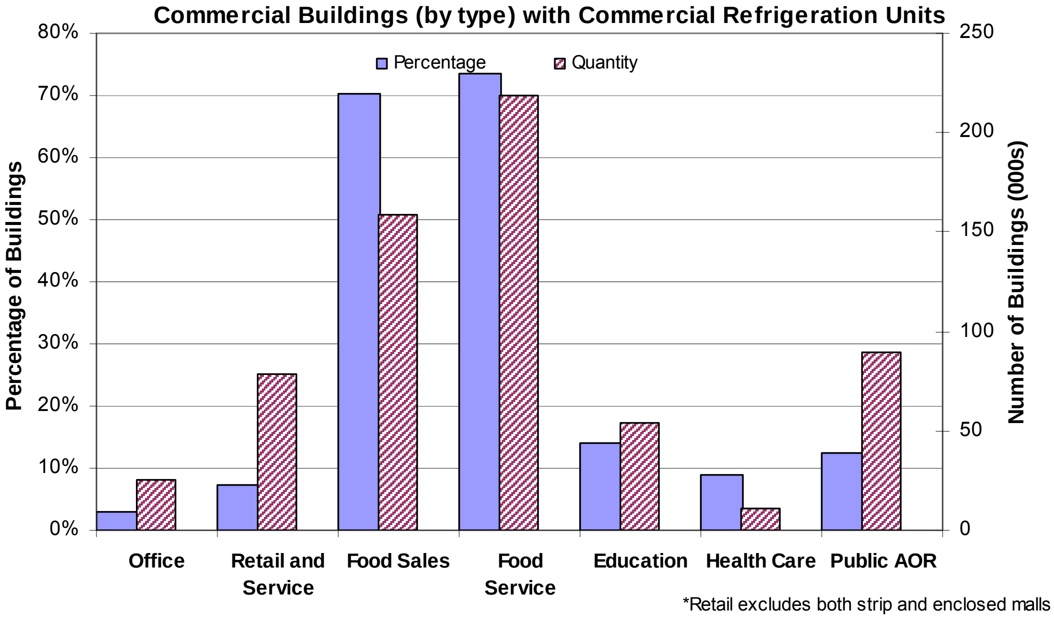

Figure 26: Food related buildings have the most commercial refrigeration units, but retail and service and public AOR buildings are also notable in terms of quantity.

5.16.5.2 Energy Savings Discussion

Energy Star V1.0 criteria (shown below in Table 31) for solid-door only commercial refrigerators is currently in effect. V2.0 will go into effect starting on January 1, 2010. As an early exception, glass-door and mixed-door units which could never before be certified can now be tested to meet the new criteria. This began on April 1, 2009.

Table 31: The current, V1.0 criteria for Energy Star certification of commercial refrigerators

Product Type	Energy Star Criteria
Refrigerators	<= 0.10V + 2.04 kWh/day
Freezers	<= 0.40V + 1.38 kWh/day
Refrigerator-Freezers	<= 0.27AV - 0.71 kWh/day
Ice Cream Freezers	<= 0.39V + 0.82 kWh/day

Where AV = Adjusted volume = (1.63 x freezer volume in ft^3) + refrigerator volume in ft^3

The V2.0 criteria are shown below in Table 32.

Table 32: The new criteria, v2.0 for Energy Star certification of commercial refrigerators went info effect on April 1, 2009 for glass door units, and will go into effect on January 1, 2010 for solid door units.

Product Volume (in cubic feet)	Refrigerator	Freezer
Vertical Configuration		
Solid Door Cabinets		
0 < V < 15	≤ 0.089V + 1.411	≤ 0.250V + 1.250
15 ≤ V < 30	≤ 0.037V + 2.200	≤ 0.400V – 1.000
30 ≤ V < 50	≤ 0.056V + 1.635	≤ 0.163V + 6.125
50 ≤ V	≤ 0.060V + 1.416	≤ 0.158V + 6.333
Glass Door Cabinets		
0 < V < 15	≤ 0.118V + 1.382	≤ 0.607V + 0.893
15 ≤ V < 30	≤ 0.140V + 1.050	≤ 0.733V – 1.000
30 ≤ V < 50	≤ 0.088V + 2.625	≤ 0.250V + 13.500
50 ≤ V	≤ 0.110V + 1.500	≤ 0.450V + 3.500
Chest Configuration		
Solid or Glass Door Cabinets	≤ 0.125V + 0.475	≤ 0.270V + 0.130

The best energy star compliant refrigerators are achieving such low levels of energy consumption through a variety of methods (COEE, 2009):

- *Hot gas anti-sweat heater* – frequently, commercial units use electric resistance anti-sweat heaters to reduce surface condensation build-up around the door, but using hot gas heaters which use excess heat output from the compressor to service the same purpose are far more energy efficient.
- *High efficiency ECM evaporator and condenser fan motors* – Permanent magnet, electronically-commutated motors (ECM) are both more efficient and run cooler, thereby reducing overall unit energy consumption by reducing the cooling load. Additionally more efficient blades can be employed to improve efficacy of the unit.
- *High efficiency compressors* – newer scroll and linear compressors can improve efficiency over traditional refrigeration compressors.
- *High efficiency lighting* – Incandescent bulbs give off large amounts of heat and thereby force the refrigerator to work harder to maintain its temperature. Instead, use compact fluorescent bulbs which will reduce electricity consumption for lighting by up to 75% (Energy Star CFL, 2009), and will last 10 times longer than the incandescent bulb.
- *Improved defrosting designs* –
    - Hot-gas defrost, like hot gas anti-sweat heaters is a new technology that uses hot compressor gas for the defrosting process
    - Improved defrost cycle monitoring can improve efficiency by only defrosting when necessary, and for optimal periods of time. This can be achieved by monitoring variables including the cumulative amount of time the door is open and the number of times it is opened.

    - Hot-gas activated evaporation of condensate eliminates the need for high power heaters. This feature eliminates the need to attach the unit to a drain during installation.
- *Improved insulation* –
    - Wall insulation is commonly ~1.5 inches thick, but new more efficient units are going as thick as 2.5 inches.
    - Alternative varieties of insulation, such as foamed-in-place insulation
    - Improved glass doors are available that utilize low-E, multi layer glass and multiple glazing layers to reduce heat loss.

While purchasing an Energy Star compliant unit is important, the energy consumption relies heavily on the usage of the unit. Many important things can be done to ensure the refrigerator or freezer operates at or below the specified energy consumption:

- *Buy appropriate size for a given application* – If the unit is oversized for a user's needs, it will use more energy than necessary, since it must cool a larger volume. The empty space is rapidly warmed with each opening of the door, resulting in greater energy consumption and more temperature fluctuations.
- *Buy solid-door units if possible* – While glass-door units are preferable in many retail situations to allow customers to see all the products, they are not as energy efficient, and should be avoided if it is not necessary.
- *Maintain seals appropriately* – Well maintained seals ensure that heat is not exchanged through gaps in the seals. This is a cost-effective method for maintaining like-new performance in older units.
- *Locate unit for max efficiency* – Refrigerator units located next to hot stoves or ovens or even located in direct sunlight are forced to consume more energy to maintain the desired internal temperature.

Best in Class

Since commercial refrigerator and freezer efficiency depends so much on volume, specifying a single Best in Class (BIC) unit does not incorporate the variation. In analyzing the Energy Star qualifying commercial refrigerator units, TIAX found that the top tier units were able to achieve UECs as low as 50% better than the Energy Star (ES) qualifying value. Table 27, below, shows the full spectrum of Energy Star refrigerators, as well as the ES limit and the region that encompasses the top tier units (>45% improvement over ES).

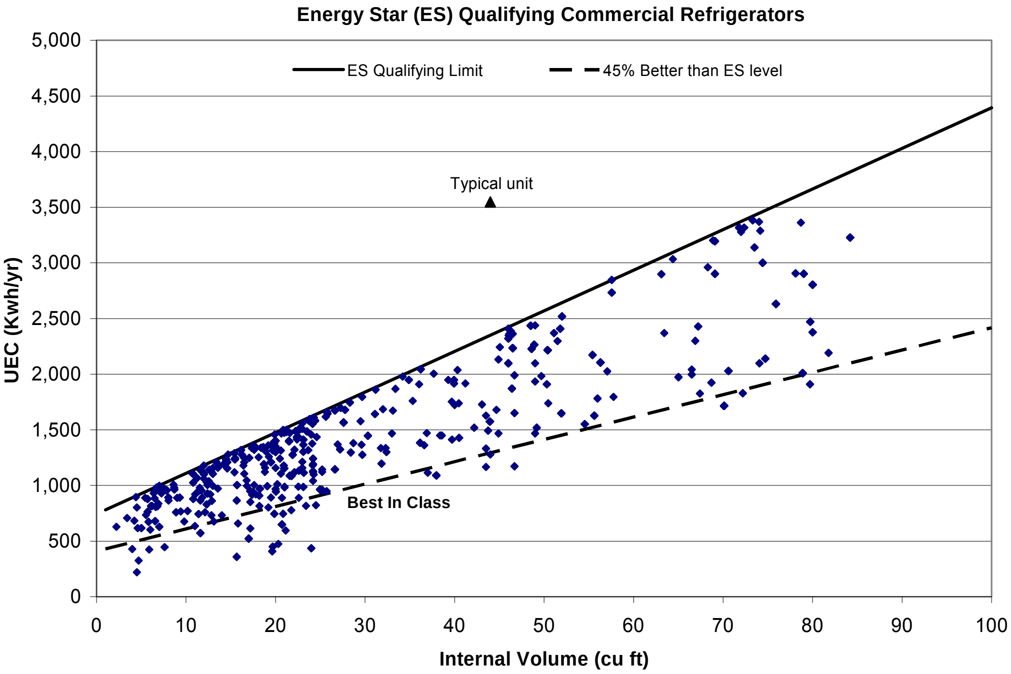

Figure 27: The ‘Best in Class’ region marks the most energy efficient units on the market across all sizes. The BIC is assumed to be 50% better than the Energy Star qualifying limit.

Similarly, Table 28 shows ES qualifying commercial freezers, the ES qualifying limit, and highlights the top tier units (>40% improvement over ES). In this case, the best units are approximately 45% better than the base ES unit.

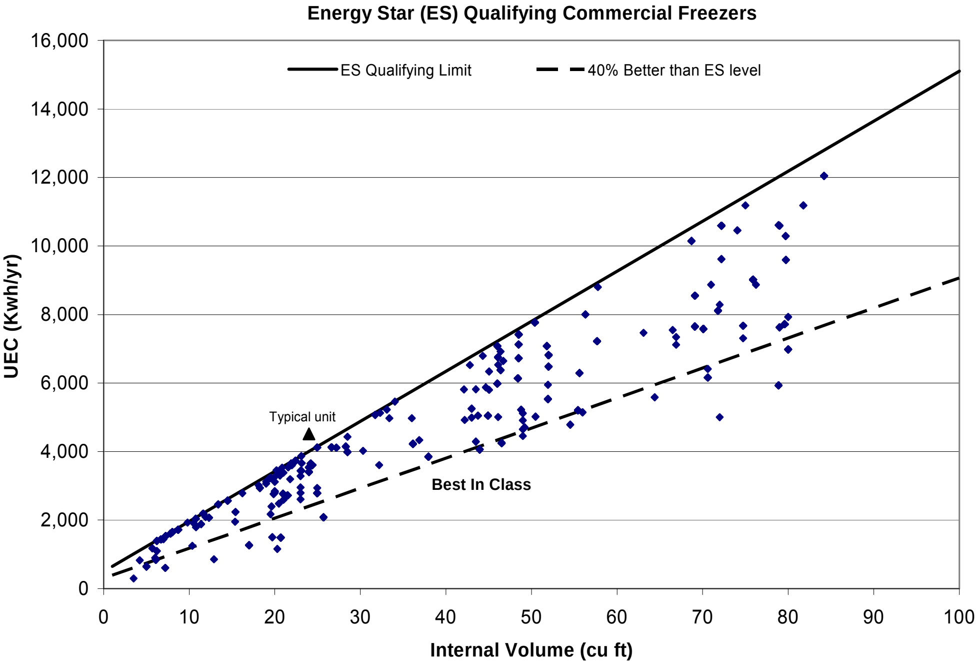

Figure 28: The most efficient commercial freezers achieve 45% better UEC than the base Energy Star Unit.

According to Energy Star, the best in class unit has 38 cu ft of space, and only uses 1088 kWh of electricity in a year, which is almost 50% less than the Energy Star rating of 2130 kWh/yr. To do this, it utilizes many of the previously described technologies, including: high efficiency defrost system, fluorescent lighting, and condensate elimination with a hot gas system.

TIAX assumes that the BIC commercial refrigerator unit is 62% more efficient than the baseline conventional unit. This takes into account the BIC refrigerator and freezer from the Energy Star qualified listing (ES Commercial list, 2009) by taking weighted averages based on the associated installed base. The BIC refrigerators and freezers are 67% and 56% more efficient, respectively, than the conventional units. Combining this value using the installed base split of 60% refrigerators and 40% freezers gives a total savings of 62%.

5.16.5.3 References

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Delfield Specification, 2009. *"Delfield Specification Line: Self-Contained Sliding Door Two Section Shallow Reach-In Refrigerator,"* Downloaded on Aug 27, 2009 from http://www.delfield.com/docs/uploaded/del/specsheets/DSSSRS-SL.pdf.

5.16.6 Residential Refrigerators

Table 33: Overview of findings for residential refrigeration in buildings for which it is a key load

	Office	Public AOR	Lodging	Other	Total
Total AEC (TWh/yr)	2.8	0.7	2.9	2.3	8.7
Energy Intensity (kWh /1000ft^2)	230	84	570	50	120
Installed Base (1000s)	7,300	1,400	6,800	4,100	20,000
Units / 100,000 ft^2	60	16	133	9	28
Energy Savings Potential	30% on each full size unit and BIC UEC of 300 kWh/yr (8.3% savings) for compact units				1.7 TWh/yr

Energy Savings Measures	Top mounted freezer instead of side-by-side, no in-door ice, improved insulation and seals, optimal locating of unit, more
Data Uncertainties	Little concrete data are available for compact refrigeration and the existing data varies between sources.

5.16.6.1 General Discussion

Full Size Units

There are numerous styles of residential refrigerators, freezers, and combination refrigerator-freezers. Out of the eighteen styles as specified by NAECA and as used in Energy Star, the Canadian Office of Energy Efficiency (COEE) studies and other organizations, the seven most common are shown below in Table 34 along with each style's associated Energy star rating. These categories are based on three variables: configuration (i.e. freezer on top, freezer on the side, etc), automatic or manual defrost, and whether or not it has through-the-door ice service.

Table 34: Energy star standards for seven types of residential refrigerator-freezers (ES ratings, 2009)

Style category	Style Category Description	UEC (kWh/yr)
1	Manual Defrost Refrigerators	407
2	Partial Automatic Defrost Refrigerators	407
3	Top Mount Freezer without through-the-door ice	452
4	Side Mount Freezer without through-the-door ice	541
5	Bottom Mount Freezer without through-the-door ice	492
6	Top Mount Freezer with through-the-door ice	529
7	Side Mount Freezer with through-the-door ice	570

While significant sales are represented by all seven categories, a 2007 COEE study found that almost two thirds of refrigerators sold in 2005 are type three (3), that is, they have "automatic defrost and top-mounted freezer, but [do not have] through-the-door ice service." (Lindia, 2007).

The energy consumption of this type of refrigerator is ~450 kWh/yr. Not only is this amongst the lowest of all types of refrigerators, it also indicates that most of these units are at or below the Energy Star standard consumption level.

Unfortunately, trends over the last 20 years have shown dramatic increases in sales of units with higher energy consumption, namely the side by side refrigerator-freezers with automatic defrost, and through-the-door ice service (Lindia, 2007). These units can consume 600+ kWh/yr, or more than 33% more than units with top-mounted freezers and no ice service. Overall, however, the energy consumption trends are decreasing consistently every year. Lindia reported that both the unit types above reduced energy consumption by approximately half between 1990 and 2005.

It is important to note that while energy consumption of the new units is quite good, the life of a refrigerator can be close to two decades and therefore the average unit currently being used actually has much higher energy consumption than those currently on the market. While industry estimates vary for the life expectancy of refrigerators, the numbers in Table 35, below, from the Association of Home Appliance Manufacturers is believe to be a good approximation.

Table 35: Approximate Life Expectancy of Refrigerators by type (AHAM, 1996)

Type	Life (yrs)
Side By Side	14
Top Mount	14
Bottom Mount	17
One Door	19
Built In	14
Compact	5
Chest Freezer	18
Upright Freezer	15

Lindia found that since 1990, the average UEC of residential refrigerators has fallen by 50% or more in almost every category. Figure 29, below, shows the Unit Energy Consumption of Types 3, 5 and 7 between 1990 and 2005 to show the significant improvements in efficiency.

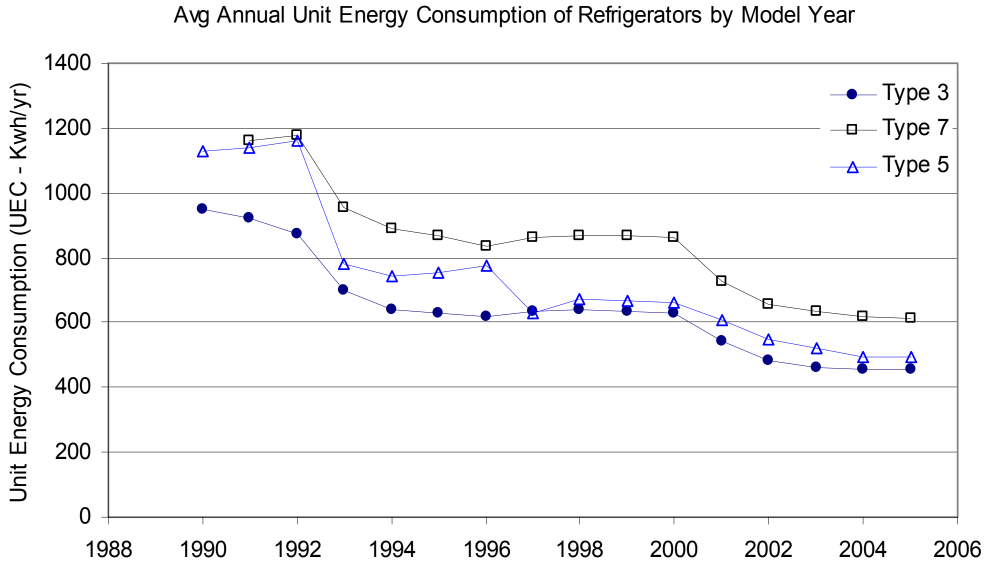

Figure 29: The energy consumption of the 3 most common types of residential refrigerators have dropped by almost half since 1990 (Lindia, 2007).

Over the last two decades, sales have gradually trended towards larger units. The most common size group, 16.5 cu ft to 18.4 cu ft is still the most popular group, but sales of those smaller have decreased, and sales of those larger have increased. Figure 30, below, shows this trend using data from all residential refrigerator sales, including both those for commercial and residential use. TIAX assumes for this study that the typical size of full size units is the same for all sectors.

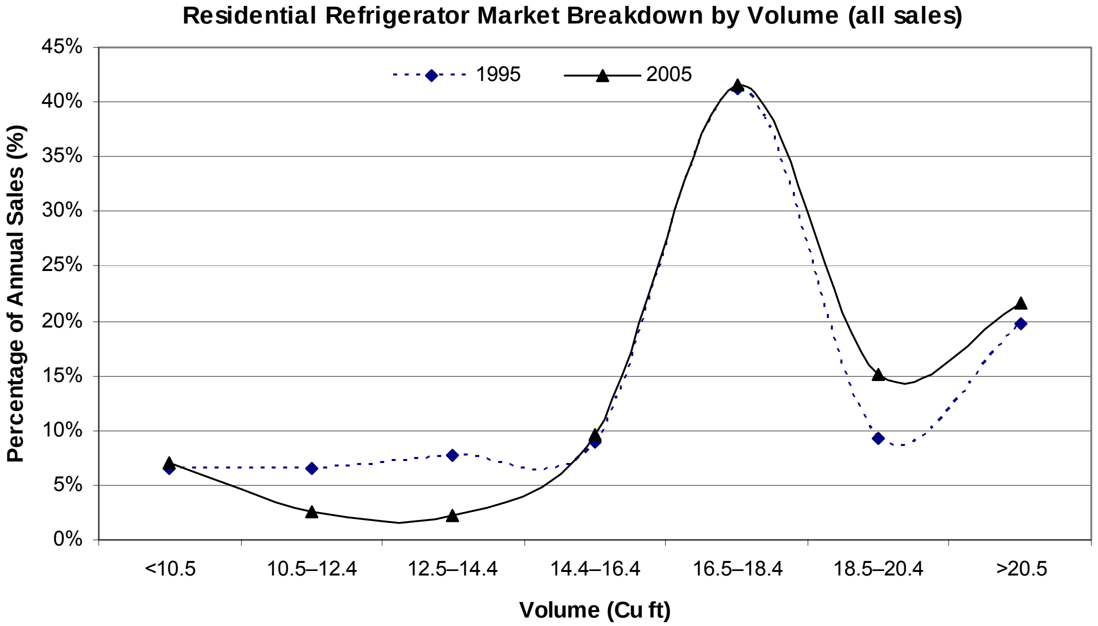

Figure 30: Of all Residential Refrigerators, the most common sizes are between 16.5 and 18.4 cubic feet in volume (Lindia, 2007).

Compact Units

A compact unit is defined as one that has less than 7.75 cu ft adjusted capacity and is less than 36" tall (ES calculations, 2009). Given their size, compact residential refrigerators are common in the workplace for storing lunch or other small items. Their usage varies significantly by building type however, since many commercial areas, such as retail stores are not conducive to storing of employee food.

In comparison to full size refrigerators, compact units are fairly inefficient on a by-volume basis. There is, to a certain extent, an economy of scale with refrigerators, meaning that size is not linearly proportional to energy consumption.

While full size refrigerators have advanced significantly in the last 20 years, compact units have by in large remained the same in terms of efficiency (Lindia, 2007). Figure 31 shows a comparison of the UEC of compact units to that of the average of all units over the last two decades. This is partially due to the fact that their overall impact is much lower due to their lower UEC. Appliance manufacturers and regulatory bodies have focused on areas with the most potential for energy savings and compact refrigerators are less likely to have as significant of a net impact. Additionally, due to their sizes, compact refrigerators often have more limited features and therefore efficiency gains can only come from a few restricted areas: better compressors and heat exchanger technology or better insulation and door sealing methods.

For compact refrigerators, the vast majority are NAECA Type 11 (Lindia, 2007).

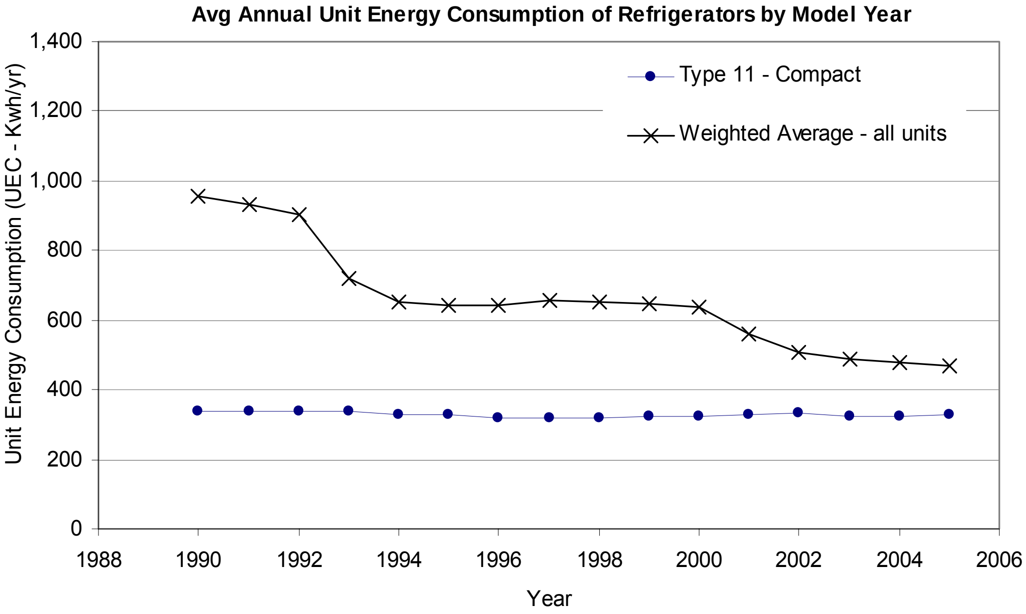

Figure 31: While the energy consumption of the average residential refrigerator has decreased significantly in recent decades, the compact refrigerators have stayed relatively the same.

The COEE estimates that compact units are only 6.4% of the total (residential and commercial) market (Lindia, 2007). In commercial settings however, it is significantly higher due to very different usage patterns between work and home environments.

5.16.6.2 Energy Savings Discussion

Energy Star standards for full size refrigerators and freezers are calculated as 20% less than the National Appliance Energy Conservation Act (NAECA) standard. Since these standards vary by unit type (i.e. configuration types 1-15), achieving the actual target UEC often appears to be a compromise between functionality and energy consumption. By providing multiple standards, Energy Star has recognized that one feature set does not match up with the needs of all consumers.

NAECA standards are calculated by using the "adjusted volume" in a set formula for each configuration:

Adjusted Volume (AV)

For refrigerators - AV = (Fresh Volume) + 1.63 x (Freezer Volume)

For freezers - AV = 1.73 x (Freezer Volume)

where "Fresh Volume" is the total volume of the main refrigerator compartment, and "Freezer Volume" is the total volume of the freezer compartment. (ES Standards, 2009)
Energy Star standard calculates the UEC energy consumption for a type 3 unit as follows (NAECA 2009):

$$UEC = (1-0.20) *(9.80*AV+276)$$

Best in Class

Many brands have units that do 30+% better than the most lenient Energy Star standard for energy consumption (Type 7 standard - side by side refrigerator/freezer units with through-door ice). Figure 32 shows a plot of all Energy Star qualifying units and highlights the top tier units that can achieve 30+% less energy consumption than the most lenient Energy star standard.

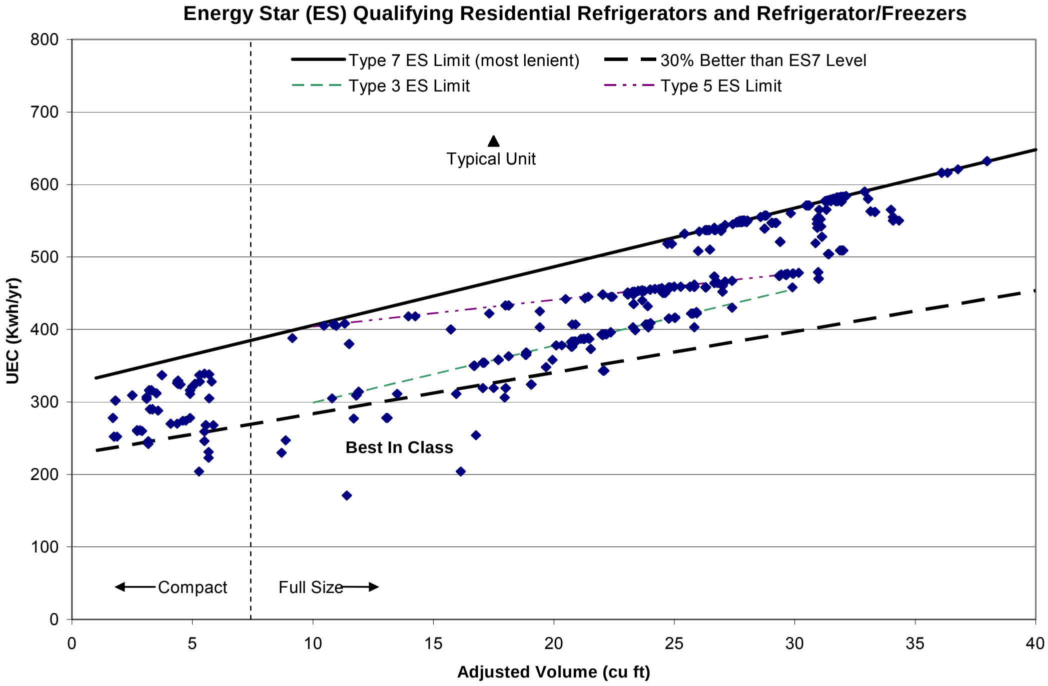

Figure 32: Energy consumption of Energy star qualifying residential refrigerators

The key features for best in class include:

- Improved insulation
- Improved seals and maintenance of seals
- Location of unit - not in sun, not next to stove, enough space for hot air to escape
- No through-door ice service
- Top mounted freezer, not side by side
- Reasonable size (<20 cu ft is best)

For best in class energy consumption, TIAX assumes 462 kWh/yr for full size units and 300 kWh/yr for compact units.

5.16.6.3 References

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5.17 Servers in Data Centers

Table 36: Overview of findings for Servers in Data Centers

	Data Centers ("Other" Building category)
Total AEC (TWh/yr)	32

	Data Centers ("Other" Building category)
Energy Intensity (kWh /1000ft^2)	unknown
Installed Base (1000s)	15
Units / 100,000 ft^2	unknown
Energy Savings Potential	19% savings per unit – based on difference between avg UEC and best in class (Koomey, 2007)
Energy Savings Measures	High Efficiency power supplies, system level and processor level power management algorithms, integrated passive cooling
Data Uncertainties	Companies with data centers are notoriously mute regarding their internal configurations (Web Servers, 2009)

5.17.1 General Discussion

While servers in data centers constitute a very large component of commercial energy consumption in the United States, little detailed information is available on their characteristics. To a certain extent, this is due to a wide range of data center configurations between companies. In his 2007 report, Jonathan Koomey points out that the top level figures reported in the industry tend to obscure these variations (Koomey, 2007). Each application differs in its processing, memory, and storage needs. For example, for search indexing, advertisement and search result serving, and 'cloud' based application companies generally utilize hundreds of thousands of "volume servers. However, on the other end of the spectrum are high intensity processing applications that require large, high-end servers which can consume as much as 100 times as much power as a volume server.

In newer configurations, some companies are packaging as many as 1,160 of these volume servers into a single 1AAA shipping container to use as a standard module in building their facilities (CNET, 2009). Each container consumes up to 250 kW at peak load (Data Centers, 2009) and each data center may contain more than 40 containers for a total of more than 45,000 servers (Data Center, 2009) and 10 MW in energy consumption (Google, 2009). Anecdotal evidence indicates that in total, a company like this may have upwards of 450,000 servers in total (Web Servers, 2009). Initial reports indicate that significantly larger facilities are currently being planned and built – some with energy intensities of nearly 1 kWh/sq ft.

Uncertainty surrounding the total impact of data centers is also nebulous due to the desire for many large companies to protect the intellectual property that surrounds their designs for servers and data centers. The ability to design an efficient data center represents a significant business advantage over their competitors. Independent companies have collected as much data as possible on server counts for large internet companies, but all the largest continue to keep all their information private.

5.17.2 Energy Savings Discussion

Significant advances are available in the area of energy savings for data centers, and as a result of the high energy intensities of these facilities, there is great economic motivation to implement these strategies. A given facility may consume electricity at a rate of a few megawatts or more of steady load. Achieving small gains in efficiency can therefore make large impacts in the expenses of the company.

One measure of efficiency for these centers is the Power Usage Effectiveness (PUE) which is simply a ratio of total energy consumption to energy consumption used for actual computing. For example, if a data center uses 1.5 megawatts, and 0.5 megawatts is used for cooling and lighting, then the PUE is 1.5/1 or 1.5. Recently published information indicates that some companies are running their most efficient data centers with a PUE as low as 1.12 (CNET, 2009). These low statistics are generally achieved through reductions in both supply and demand for HVAC. That is, in addition to highly efficient cooling, the servers are designed to operate at higher average temperatures thereby imparting lower cooling loads on the system.

While a low PUE means that less energy is being used on non-primary end uses for the company, the statistic says very little about the efficiency of the servers. To save energy at the server level, the main technologies with the largest impact include:

- High efficiency power supplies – by converting to better power supplies (up to 90% efficiency) from conventional units (60-70% efficiency), significant energy savings can be achieved. Unlike PCs, loads can be relatively well anticipated on a server, thereby allowing for more appropriately sized power supplies which are generally more efficient. The additional benefit is that with higher efficiency, the units will dissipate less energy as heat, thereby requiring lower cooling loads from the HVAC system. (Hoelzle, 2006)

- System level power management – many data centers do not have uniform load over the course of a day, week, etc. Power management (i.e. an idle or sleep mode) could be enabled on subsets of servers that are not currently be used, and the subset could be rotated to ensure even usage and maintain consistent life.

- Processor level power management – processor manufacturers all have the ability to implement power management schemes into the processor such that clock speeds are varied depending on requirements of the operating system. Upgrading to the latest technologies would improve partial load energy consumption.

- Decreased cooling requirements and passive cooling – while major focus is put on savings in building HVAC, savings can also be achieved on individual servers. Passive cooling systems, including innovative heat sink systems can reduce the per-server load by not requiring the use of built in cooling fans. More efficient system fans can effectively pull heat from the heat sinks, thus transferring some of the load to HVAC, and eliminating some of the load.

TIAX estimates that by incorporating these currently available technologies, energy consumption could be reduced by 19% (weighted average between various classes of servers).

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5.18 Slot Machines

Table 37: Overview of findings for Slot Machines in buildings for which it is a key load

	Lodging	**Other**	**Total**
Total AEC (TWh/yr)	2.7	0	2.7
Energy Intensity (kWh /1000ft^2)	530	0	530
Installed Base (1000s)	780	0	780
Units / 100,000ft^2	16	0	16
Energy Savings Potential	40%		1.1 TWh/yr
Energy Savings Measures	Implementing any form of power management such as the one described by (Underdahl et. al, 2009) patent application.		
Data Uncertainties	Adoption and energy savings potential of power management in slot machines.		

5.18.1 General Discussion

Slot machines are one of the most popular gambling methods in casinos; they constitute about 70% of the average casino's income (Cooper, 2005). Once primarily built on mechanical mechanisms, modern slot machines are almost completely computerized. They are equipped with digitally pulsed step motors to turn and stop each reel, monitors to display games, speakers, specialized electronics and random number generators to ensure the fairness of each play. Due to the legal restrictions on gambling, slot machines are only found in certain licensed establishments with the vast majority concentrated in commercial casinos, which most often are an extension of hotels or resorts.

With most casinos operating twenty-four hours a day and year round, slot machines are assumed to be continuously on (Underdahl et al., 2009) often with elaborate lighting, displays and sound to attract gamblers. As a result, slot machines are estimated to consume up to about 2.7TWh annually.

5.18.2 Energy Savings Discussion

Since current slot machines are almost always actively on, implementing any level of power management could result in appreciable energy savings. However, it is vital that power management does not interfere with certain essential features such as security to prevent fraudulent transaction and the need to attract and attain potential users. For example, in casinos potential users are often people who are passing by the gaming machines and whose attentions are often drawn to a machine because of strategic lighting, sounds and display known as “attraction sequences” (Underdahl et al., 2009). Furthermore, most users have little patience to wait for machines to power up if they are initially shut off.

Underdahl et al. (2009) has applied for a patent describing a method for wager gaming machine to have software and components to allow for automatic powering on and off of machine components via a network interface (also referred to as remote out-of-band power control). Most games and slot machines have numerous components, such as displays, lights, coin acceptors, disk drives, card-readers, bill acceptors, printers, card readers, motor controller, and light controller all of which consume power. In a preferred embodiment described in their application, the power consumption control system of the invention controls power consumption of machines by controlling the power provided to their selected components, rather than by cutting off power to the entire gaming machine (Underdahl et al., 2009). The patent application claims that it is foreseeable that power consumption in gaming machines can be reduced by up 40%.

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5.19 Televisions

Table 38: Overview of findings for Televisions in buildings for which it is a key load

	Retail and Service: Non-food	Food Service	Healthcare	Lodging	Total for Non-key Building Types	Total
Total AEC (Twh/yr)	0.7	1.3	0.5	0.4	0.9	3.8
Energy Intensity (kWh/1,000 ft^2)	48	774	51	87	21	56
Installed Base (1000s)	900	1,400	1,500	5500	7000	16,000
Units/100,000 ft^2	5.9	84.2	17.1	107.6	16.6	24.2
Energy Savings Potential (TWh/yr)	0.2	0.3	0.1	0.1	0.2	0.9
Energy Savings Measures	LED backlit LCDs, brightness control					
Data Uncertainties	Installed base, active mode usage, DTV screen size and technology distribution					
UEC kWh/yr	574	919	300	81	125	233

5.19.1 General Discussion

Televisions (TVs) in commercial buildings are generally the same devices that are found in homes. TVs are ubiquitous in residential homes and are the highest energy consuming MEL in homes as reported in TIAX (2008). TVs are common in commercial buildings, but are generally less widespread than they are in homes. Additionally, there are also far fewer commercial buildings than residential buildings.

Televisions can be divided into analog and digital devices. Even after the switch to digital broadcast, there remains a significant installed base of analog TVs in homes. However, it is assumed that in commercial buildings that digital TVs (DTVs) account for the bulk of the installed base.

Digital TVs can use any number of display technologies including traditional cathode ray tube (CRT) screens. Digital projection TVs use liquid crystal display (LCD), digital light processing (DLP), and liquid crystal on silicon (LCoS) display technology. Flat-panel direct-view DTVs use either LCD or plasma display technology. While there is some data on the breakdown of installed TV technologies and screen sizes in residential homes, there is considerable uncertainty on this breakdown in commercial buildings. It is generally assumed that the majority of TVs in commercial buildings are flat panel displays, which have dominated DTV sales for the past several years, but there may be analog and front projection DTVs in certain commercial building types.

Television energy consumption can be characterized by two operating modes: active mode (when the TV displays an image), and off mode (when the screen is off). TVs, like many other electronics, continue to draw power while they are “off”. Typically, televisions draw power while in off mode so they can respond to a signal from a remote. Memory and time-keeping functions also require power while the TV is off. Although active mode power draw increases with screen size, screen size does not have an impact on off mode power draw. Digital TVs may have cooling fans that remain on for some period after the TV has been switched off. This intermediate power draw and its energy impact are not well understood, but at this time likely does not have a significant impact on overall TV energy consumption.

Generally, active mode dominates the energy consumption of TVs, accounting for approximately 90% of the total. However, the active mode percentage can be even higher for larger screen TVs or TVs that exhibit higher than average usage. The main factor contributing to the active mode power draw is the screen size (see TIAX 2007). Similar size DTVs of different technologies also affects the power draw. Other factors include the manufacturer, resolution, and brightness and contrast settings.

Television usage in commercial buildings will vary considerably depending on the type of commercial building. For example, TV usage in food service buildings (e.g., restaurants and bars) will generally be higher than usage in lodging. In all cases, there is a high degree of uncertainty around TV usage, due to the lack of data.

5.19.2 Energy Savings Discussion

Active mode accounts for approximately 90% of total TV AEC. TV active mode power draw generally increases with screen area. Consequently, a straightforward way to reduce TV AEC would be to reduce the screen size. TV display technology and brightness also impact the active mode power draw for a TV. In practice, however, these traits are desirable product attributes that consumers clearly value. Consequently, these measures are not evaluated as practical energy-saving opportunities.

To estimate the energy savings potential from best in class products, we used a similar methodology to that reported in TIAX (2008). That is, for DTVs of similar size, technology, and resolutions, more efficient models draw approximately 25% less power in active mode than the average. Given that active mode accounts for the bulk of the energy consumption, and given that we don’t have a detailed breakdown of the installed DTV technologies, we estimate that the overall energy savings potential is approximately 25%.

5.19.3 References

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5.20 Vending Machines

Table 39: Overview of findings for vending machines in buildings for which it is a key load

	Office	Retail & Service	Education	Public AOR	Other	Total
Total AEC (TWh/yr)	1.9	2.9	1.9	1.1	3.5	11
Energy Intensity (kWh /1000ft^2)	150	190	190	120	140	160
Installed Base (1000s)	1,100	1,700	1,100	630	2,100	6,600
Units / 100,000 ft^2	9	11	11	7.2	8.2	9.2
Energy Savings Potential	33% for refrigerated units, 50% for non-refrigerated units					4.2 TWh/yr
Energy Savings Measures	Removal of advertising lighting, use of load manager electronics to optimize energy consumption with respect to time of day and usage					
Data Uncertainties	Installed base varies among sources – used ADL 1991 estimates with annual growth. Additionally, data on installed base of non-refrigerated units is very sparse					

5.20.1 General Discussion

Vending machines are used in a wide variety of commercial building types. The quantity per building is generally based on the occupancy rather than the square footage. That is, the greater the number of people in the space, the more vending machines will be present. In addition, vending machines are targeted towards both employees and customers/clients, so the actual number of users can vary significantly depending on the building type.

There are approximately 6.7 million vending machines in the United States, of which only 35% are refrigerated. These two million refrigerated units however, account for 74% of the AEC of the vending machines in the United States.

While there are numerous types of refrigerated vending machines, the standard cold beverage vending machines can typically hold anywhere from 300 to 800 cans of soda, but are capable of holding both cans and bottles of various sizes. LBNL estimates that in 2008, 77,000 of this type of cold beverage vending machine were shipped; 31% of these units were Energy Star qualified (BEDB, 2008).

The refrigerated, closed-front unit is a very common type of cold beverage vending machine. By nature of having a fully enclosed and insulated refrigeration compartment, these can be used both indoors and out. When used in a hot outdoor environment, the energy consumption will be higher than average due to a higher duty cycle on the refrigeration system.

The refrigerated glass-front units are typically used indoors due to a decreased level of insulation as compared to closed-front units. Currently there are no Energy Star qualifying glass-front units for outdoor use.

As shown in Figure 33, almost 30% of education buildings have vending machines. While this is a very significant percentage, the fact that education buildings are only 8.3% (EIA, 2006), of all commercial buildings means that the overall annual load is small in educational buildings.

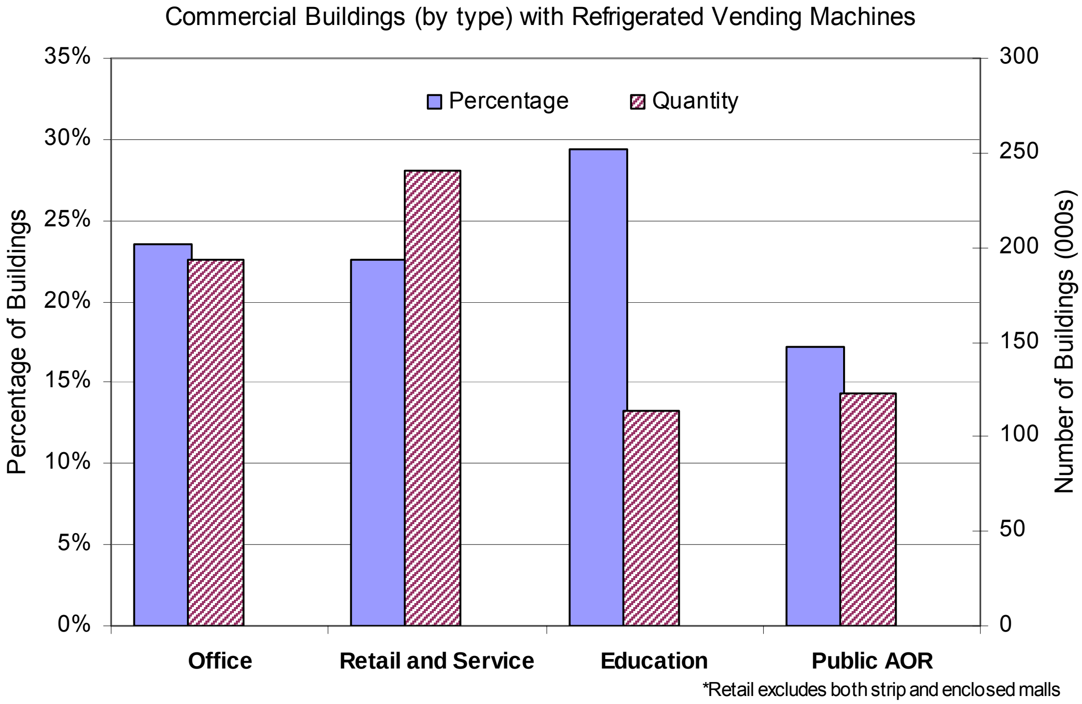

Figure 33: Lodging facilities, such as hotels, motels, and dorm rooms, are much more likely than other building types to have vending machines. Source: EIA 2006

5.20.2 Energy Savings Discussion

Energy Star ratings are currently in their second revision (Tier II), and are calculated for new and rebuilt units with the formula (Energy Star Vending, 2009):

$$DailyEnergyConsumption(KWh/day) = 0.45 * \left[8.66 + \left(0.009 * C\right)\right]$$

where C is the 'vendible capacity' or the equivalent capacity of 12 oz soda cans. By these standards, a typical 600 oz capacity vending machine may not consume more than 6.33 kWh/day. In addition, the criteria include a specification for a low power mode in which the lighting and refrigeration can be reduced to lower levels after an extended period of inactivity. This specification is based on additional reductions beyond the Canadian energy savings specification listed under CAN/CSA C804-96.

A study of the sixteen (16) vending machines on the NREL campus (Deru, 2003) provided comprehensive insight into the savings potential for cold beverage vending machines. The study assessed two main methods for decreases energy consumption: (1) removing the advertising lights, or de-lamping, and (2) using a load manager. In combination, these two approaches reduced energy consumption by 56% without creating any greater temperature fluctuations than existed in the baseline test unit.

The lighting in cold beverage machines in merely for aesthetic reasons to help catch people's eyes as they walk by and to generally promote sales. De-lamping can either be done by the manufacturer by excluding the necessary parts or as a retrofit by a machine owner by simply removing the bulbs. On average, Deru estimated that de-lamping would reduce energy consumption by 29% (Deru, 2003).

Using a Load Manager (LM) allows the device to be shut off during periods of inactivity. The LM used in the NREL vending machines used passive IR to turn off the unit when the area was unoccupied. Deru notes that varying results have been published on testing of LMs due to location of the vending unit; if the unit is in a large room that is commonly occupied, there is minimal savings because the sensor will indicate that the unit should continue to run at approximately normal conditions. An additional benefit of using a LM, was that it reduced cycling of the compressor and other components and thereby increased the life of the unit. On average, the savings for the NREL units was found to be 33% (Deru, 2003).

Various load managers claim potential savings of upwards of 40% on refrigerated vending machines, and upwards of 50% on non-refrigerated machines (Miser, 2009).

For the purposes of this study, a 'Best in Class' refrigerated unit will have a 33% lower UEC than the baseline, and a non-refrigerated unit will have a 50% lower UEC than the baseline.

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5.21 Vertical Transport (Elevators and Escalators)

Table 40: Overview of findings for vertical transport in buildings for which it is a key load

	Office	Lodging	Education	Healthcare	Other	Total
Total AEC (Twh/yr)	1.7	0.5	0.3	0.4	1.0	3.9
Energy Intensity (kWh/million ft^2)	137	94	32	140	24	55
Installed Base (millions)	254	78	82	69	177	660
Units/100,000 ft^2	2.1	1.5	0.8	2.2	0.4	0.9
Energy Savings Potential (TWh/yr)	0.5	0.1	0.1	0.1	0.3	1.2
Energy Savings Measures	Permanent magnet motors, advanced drives, drive regeneration, lighting and ventilation controls, motor controls, energy recovery, occupancy sensing and load management (for escalators)					
Data Uncertainties	Usage: wide variance of usage of elevators among buildings, expressed as the number of door openings per year, and of escalators among buildings					

5.21.1 General Discussion

There are approximately 625,000 elevators in U.S. commercial buildings (EIA 2006, Elevator World 2001) that are designed for vertical transportation inside buildings to save time and offer comfort to occupants. Generally the number and usage of elevators in a building increases with the number of floors in a building. Major retrofits occur on approximately a 20 to 30 year cycle. Elevators consume about 80% of the total vertical transport energy.

Elevators can be divided into three basic categories: hydraulic, geared traction, and gearless traction. 80% of elevators are found in buildings with two to seven floors, mainly because there are many more buildings with seven or less floors than more than there are with seven floors. These elevators are typically hydraulically driven.

Fifteen percent of elevators are found in buildings with 8 to 24 floors and are generally geared traction elevators. The remaining 5% of elevators are in buildings with 25 or more floors and are typically gearless traction. Figure 34 and Figure 35 provide further detail.

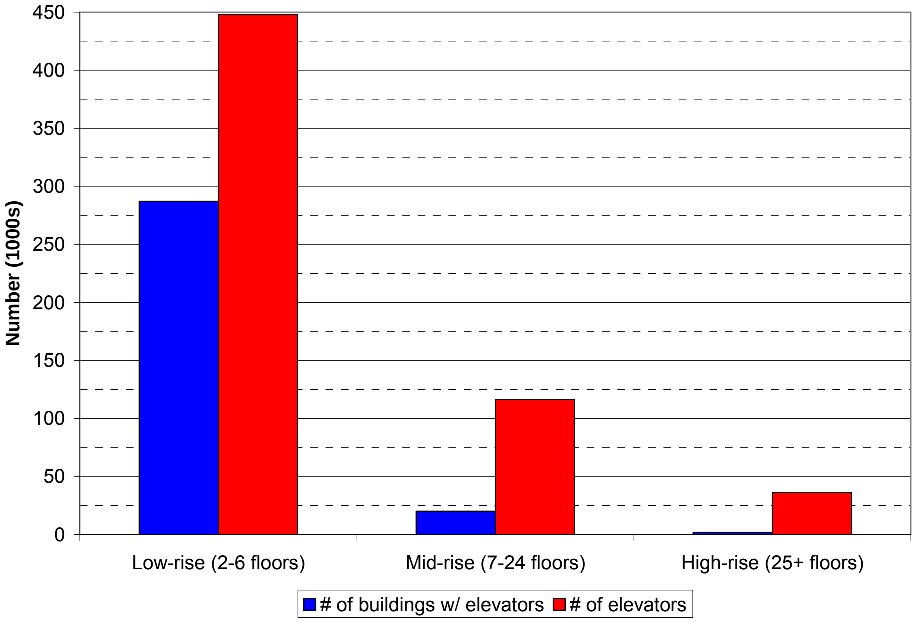

Figure 34: Allocation of elevators in buildings by number of floors

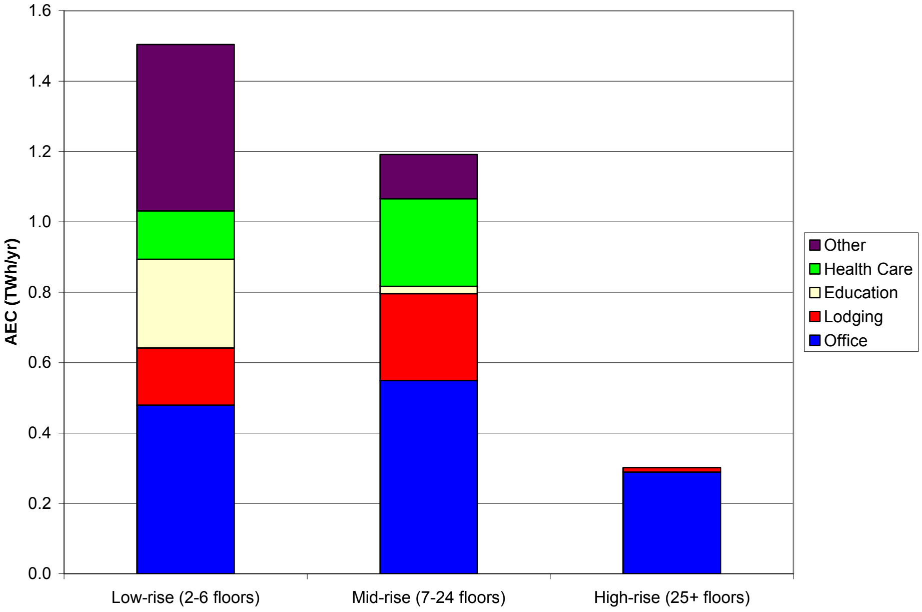

Figure 35: Breakdown of building size by building type

There are approximately 35,000 escalators in the U.S. (EIA 2006, Elevator world 2001) and about 40% of them are found in office buildings. Because there are significantly more elevators than escalators, the escalator energy only has an appreciable impact on office building vertical transport energy.

There is a wide range of escalator rises, but Enermodal (2004) estimates that about 90% of escalators in Canada are in the range of 10-15 ft. Escalator drive systems (namely, motors) are the major energy consuming component, and the energy consumption generally increases with the operating time and the amount of foot traffic.

5.21.2 Energy Savings Discussion

Both geared and gearless traction elevators have regeneration (energy recovery) capability, meaning they are able to recover energy during down trips for reuse during up trips. However, only a small number of elevators actually use regeneration. Hydraulic elevators, generally found in smaller buildings, have no regeneration capability and require round-the-clock hydraulic fluid heating.

Additional energy is required to power the elevator lights and ventilation fans, and there is generally not an automatic power down during periods of inactivity. Using simple occupancy sensing, various power management schemes could be implemented.

Energy efficient elevators in general consume about 30% less energy than typical elevators (Enermodal 2004). The main barrier to the adoption of energy efficient elevators is initial cost and longer than desirable payback periods.

Energy efficient escalators can have more efficient gear systems that improve the mechanical efficiency of the drive system. Load-management systems are also offered that cut back the electric motor power during periods of light loads. If there are times when escalators are operating without any passengers, the most energy efficient approach would be to implement a standby mode (initiated by occupancy sensors and timers) that stops the motor during these periods. Manufacturers of energy efficient escalators claim energy savings of 30-50% (Enermodal 2004).

5.21.3 References

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5.22 Wastewater Treatment (WWT)

Table 41: Overview of findings for wastewater treatment

	Public Wastewater Treatment	Commercial Wastewater Treatment	Industrial Wastewater Treatment
AEC (TWh/yr)	25	2.7	19
Billions of Gallons (per yr)	13,700	1,200	7,800

	Public Wastewater Treatment	Commercial Wastewater Treatment	Industrial Wastewater Treatment
UEC (kWh/million gal)			
Trickling Filter	955		
Activated Sludge	1,322		
Advanced WWT	1,541		
Advanced WWT plus Nitrification	1,911		
Composite	1,388	2,500	2,500
UEC Savings	Estimated 5% for upgraded facilities providing the same treatment		
Data uncertainty	Variability in UECs are due to pumping and additional energy for more extensive treatment		
Energy Savings Potential	Economies of scale for wastewater treatment plants (going from 1 MGD to 100 MGD); Water systems (including pumps, drives and water processing units) are mature technologies, minimal benefit from replacement		

5.22.1 General Discussion

An estimated 80% of the potable water from the public water supply system returns and travels to wastewater treatment plants requiring treatment. Due to varying wastewater regulations, pollutant levels and discharge locations, the level and subsequently the type of treatment also varies. The more advanced treatment requires additional energy. To determine the electricity used for wastewater treatment, it is necessary to determine the volumes of water undergoing each type of treatment. Figure 36 shows the breakdown of total design capacity by level of wastewater treatment.

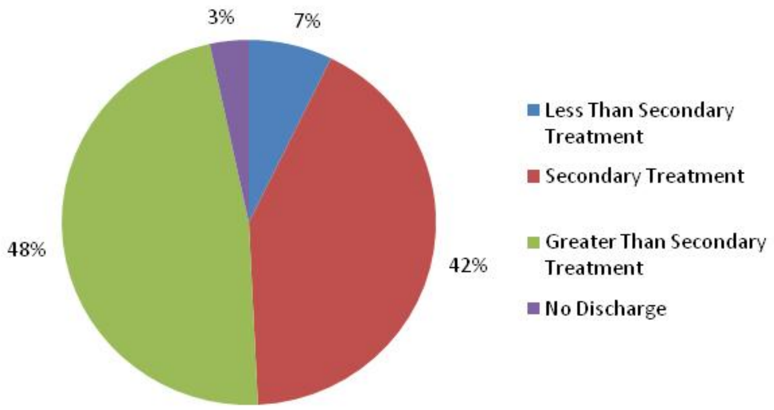

Figure 36: Breakdown of Design Capacity by Level of Treatment (EPRI, 2002)

As Figure 36 shows, most wastewater undergoes secondary or greater than secondary treatment. To determine the composite UEC (1388 kWh/million gal), the following assumptions were made, consistent with the EPRI report:

- For less than secondary treatment, a value of 50% of activated sludge treatment was used (661 kWh/million gal)

- For secondary treatment, weighted value of 70% activated sludge and 30% trickling filter was used (1212 kWh/million gal)
- For greater than secondary treatment, a weighted values of 50% with and 50% without nitrification was used (1726 kWh/million gal)
- For plants with no discharge, an assumption of 400 kWh/million gal was used (EPRI, 2002)

Private commercial and industrial wastewater treatment plants have much higher UEC than the public systems. This is due to the fact that private wastewater treatment plants are smaller size, therefore not taking advantage of the economy of scale, and they are usually designed to remove concentrations of specific compounds related to the industrial or commercial operation. These facilities could be pulp and paper mills, food processing plants, metal manufacturing (heavy metals) facilities or chemical manufacturing facilities. These facilities have small volumes and high concentrations (versus public systems with large volumes and low concentrations) which lead to higher UECs. In addition, many private systems discharge to surface water which requires more treatments as this water typically gets reintroduced to the drinking/potable water system. This will most likely lead to increased regulation and treatment in the future.

5.22.2 Energy Savings Discussion

The technologies and systems associated with wastewater treatment are mature. The drivers, pumps, and water processing units have been used for many years and there are not any fundamentally new ways to pump and treat water.

The only ways to achieve any energy saving would be through the two following means:

- Economies of Scale
- Replacement of older equipment

The achievable benefits with economies of scale for wastewater treatment plants can be between 47 – 63% depending on the type of wastewater treatment with an increase in plant size from 1 MGD to 100 MGD. (EPRI, 2002). The problem is the condensing treatment plants to this scale would require an immense amount of new infrastructure and increased energy for pumping, which may not allow for a positive cost-benefit analysis. The benefits from replacement of older mechanical equipment at a currently operating wastewater treatment plant are minimal. TIAX estimates only a 5% increase in efficiency by replacing pumps and other mechanical equipment. Additionally, there could be savings achieved with restrictions on water usage. These savings would most likely be realized in the AEC, but would coincide with increases in the UEC.

At the same time efficiencies can be achieved for wastewater treatment, other factors are increasing UEC (EPRI, 2002):

- Age of the water delivery system
- Requirements for improved treatment

As wastewater treatment systems age, there is increased friction in the piping system at the facility and wear on the pumps and other operating equipment. Although there are electricity savings that can be gathered by replacing the entire piping of the system, this can be extremely expensive and not cost effective when compared to the electricity energy savings. Requirements for improved treatment are likely to have the biggest impact on the future increase in water supply and purification UEC. As with drinking water, there are increased amounts of chemicals from pharmaceuticals entering the wastewater system that will need to be removed.

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5.23 Water Supply and Purification

Table 42: Overview of findings for water supply and purification

	Public Supply and Distribution	Commercial Private Supply	Industrial Private Supply
AEC (TWh/yr)			
Ground Water	11.6	0.29	1.3
Surface Water	21.7	0.25	2.2
Total	33.2	0.54	3.5
UEC (kWh/million gal)			
Ground Water	1,824	700	750
Surface Water	2,005	300	300
Billions of Gallons (yr)			
Ground Water	6,340	410	1,780
Surface Water	10,800	850	7,340
UEC Variability	The variability of the UEC is related to the immense amount of pumping and distance water must travel in public systems		
UEC Savings	Estimated 5% for upgraded mechanical systems		
Data Uncertainties	Breakdown of electricity load for each type of building from water purification		

Energy Savings Potential	Economies of scale for surface water treatment plants (going from 1 MGD to 100 MGD); Water systems (including pumps, drives and water processing units) are mature technologies, minimal benefit from replacement

5.23.1 General Discussion

To determine the electricity used for water supply and purification, it is necessary to determine the volumes of water both from the public and private (i.e. self) supply and where the water is coming from (i.e. ground or surface). This is due to the differences in pumping distance and the necessary amount of water treatment. Public supply can be used within the following sectors: domestic, commercial, industrial and thermo-electric power. The breakdown of the public supply for the above sectors is shown in Figure 37 below, including the water for public use and losses.

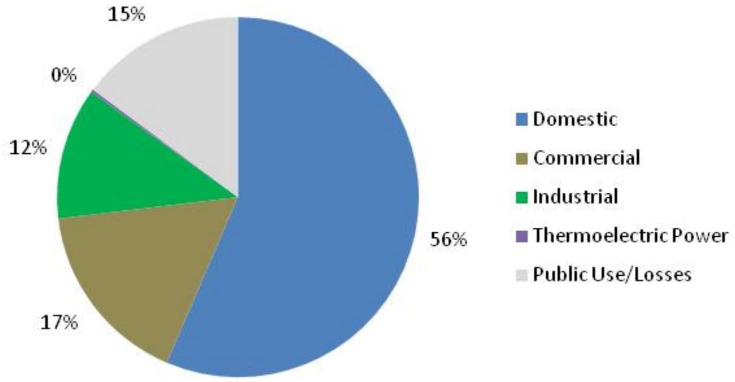

Figure 37: Breakdown of End-Use for Public Water Supply (Solley, 1998)

As Figure 37 shows, a minimal amount of public supply water is used for thermo-electric power. Most of the water for thermo-electric power is supplied onsite. The determination of the electricity necessary for private supply of thermo-electric power was not included in this report as the electricity used for the pumping is produced onsite and not from the grid.

Public supply comes from both ground and surface water and may need to be pumped and transported a significant distance, such as in California, Arizona, and NYC before being treated and entering the supply system. The surface water UEC for the public system is so high because the surface water is usually transported long distances to the storage and treatment locations. For example, a portion of the surface runoff from the Sierra Nevada Mountain range in Northern California, through the State Water Project, travels 600 miles to Southern California, distributing water to 23 million residents along the way. It takes an estimated 9,200 kWh to pump one million gallons of water (3,000 kWh/acre-foot) through the State Water Project to Southern California (NRDC, 2004).

Private supply usually comes from more local ground or surface water sources and can require less treatment as some is used in manufacturing processes and does not need to meet the same requirements and regulations as the public supply. For private supply of water, ground water sources require more electricity than surface sources due to the need to pump the water out of the ground.

5.23.2 Energy Savings Discussion

The technologies and systems associated with water supply and treatment are mature. The drivers, pumps and water processing units have been used for many years and there are not any fundamentally new ways to pump and treat water.

The only ways to achieve any energy saving would be through the two following means:

- Economies of Scale
- Replacement of older equipment

Although there are achievable benefits with economies of scale, only an estimated 5% reduction can be achieved through an increase in plant size from 1 MGD to 10 MGD. (EPRI, 2002). Also, the benefits from replacement of older mechanical equipment are minimal. TIAX estimates only a 5% increase in efficiency by replacing pumps and other mechanical equipment. Additionally, there could be savings achieved with restrictions on water usage. These savings would most likely be realized in the AEC, but would coincide with increases in the UEC.

At the same time efficiencies can be achieved for water supply and treatment, other factors are increasing UEC (EPRI, 2002):

- Age of the water delivery system
- Requirements for improved treatment

As water treatment systems age, there is increased friction in the piping system requiring additional electricity. Although there are electricity savings that can be gathered by replacing the entire piping of the system, this can be extremely expensive and not cost effective when compared to the electricity energy savings. Requirements for improved treatment are likely to have the biggest impact on the future increase in water supply and purification UEC. With studies showing the significant quantities of pharmaceutical drugs (including antibiotics, anti-convulsants, mood stabilizers and sex hormones) being found, although in very small concentrations, in drinking water across the country, one can conclude that increased regulatory standards for water treatment and purification will come in the future (AP, 2008).

5.23.3 References

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6 ENERGY CONSUMPTION BY BUILDING TYPE

6.1 Offices

Key MELs for office buildings are shown in Figure 38. The total annual energy consumption for key MELs in office buildings is almost 58 TWh/yr.

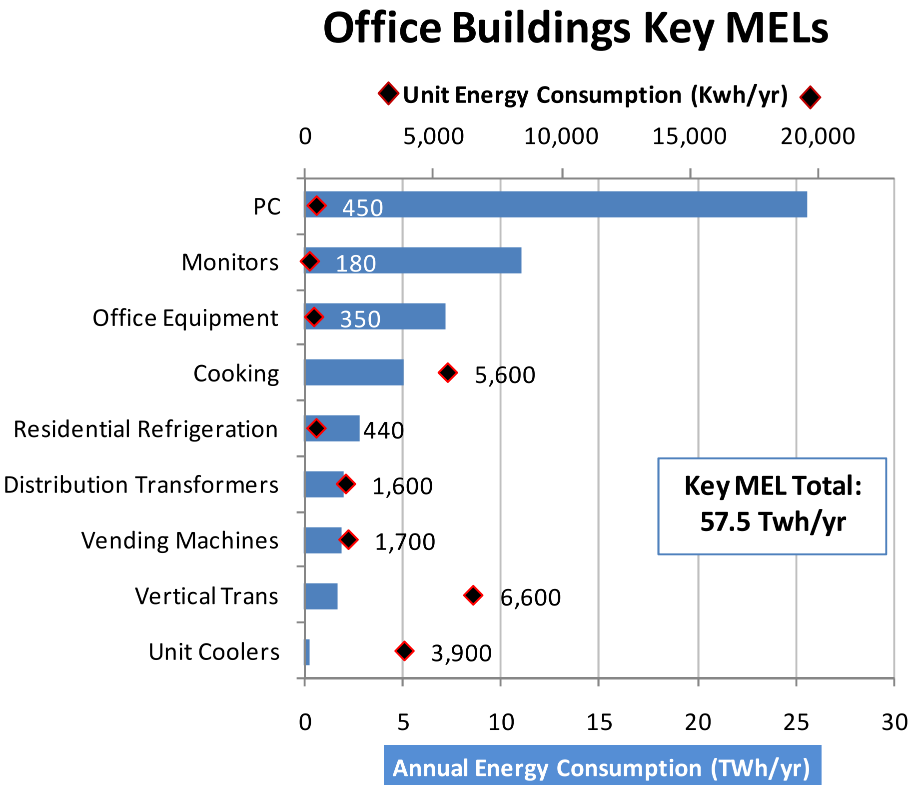

Figure 38: Key MELs for office buildings

6.1.1 Cooking Equipment

Table 43: Detailed findings for Cooking Equipment in Office buildings

	Comments/Values
AEC (TWh/yr)	5.1
Installed Base (1000s)	920
Units per 100,000ft^2	7.5
UEC (kWh/yr)	5,600

	Comments/Values
UEC variability	Varying usage patterns as well as number of units per establishment based on 1993 data. Appreciable uncertainty of the number of gas-fired equipment versus electric. No standard method to determine equipment efficiency
Best in Class	11% savings from typical unit (5,000 kWh/yr UEC)
Office Energy Savings Potential	0.6 TWh/yr
Office Trends and Notes	The relatively large AEC is attributed to the high number of building of this type. Cooking equipment is primarily located in cafeterias, lounge and kitchen areas.

Unit Energy Consumption

The UEC and best in class UEC are calculated based on a weighted average value of each cooking equipment type. Summarized in the table below, ADL (1993) estimates the quantity of cooking equipment per building and the average power consumption for each equipment type. The best in class UEC for each equipment type is based on the highest energy reduction percentage provided by ADL (1993) when certain energy saving technologies (see Section 5.3) are applied to a particular piece of equipment.

Table 44: Overview of Cooking Equipment average power consumption and usage in Office buildings

Equipment Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Office Energy Savings Potential (TWh/yr)
Broilers	0.4	37	10,000	15	0.05
Fryers	0.4	170	2,500	10	0.05
Griddles	0.8	210	3,800	10	0.07
Ovens	1.6	190	8,800	15	0.18
Ranges	0.2	37	4,400	10	0.01
Steamers	1.7	280	6,300	15	0.20

Annual Energy Consumption

The AEC for each type of cooking equipment in office buildings is calculated by multiplying its respective UEC with its installed base. The installed base is calculated from the number of units in each building type from by ADL (1993) and the number of buildings of that type from EIA (2006). In the case of office buildings, ADL (1993) has indicated that there is a substantial amount of all types of cooking equipment. TIAX has adjusted the number of units per building to better suit the current number and diversity of office buildings than when the ADL (1993) report was originally written. The total AEC is a sum of the AECs of each cooking equipment type in office buildings.

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6.1.2 Distribution Transformers

Table 45: Detailed findings for Distribution Transformers in Office buildings

	Comments/Values
AEC (TWh/yr)	2
Installed Base (1000s)	1200
Units per 100,000ft^2	9.8
UEC (kWh/yr)	1600
UEC variability	Efficiency primarily affected by rated capacity, average load, and temperature. Capacity varies significantly while avg load remains relatively consistent according to Cadmus Group (1999).
Best in Class	20% savings from typical unit (1,300 kWh/yr UEC)
Office Building Energy Savings Potential	0.4 TWh/yr
Office Building Trends and Notes	Typical dry-type distribution transformers are found in commercial buildings which are less efficient than liquid-immersed type.

Unit Energy Consumption

The UEC is calculated by dividing the AEC by the installed base. We assume that a "typical" distribution transformer in commercial building to be constantly on and have a capacity of 75kVA, which is the most common among the sampled transformers in Cadmus Group (1999) study. Also to be consistent with Cadmus Group (1999) findings, we assume that the average loads on the transformers were consistent across all building types, varying from only 14.1 to 17.6 percent (~16% on average). Since distribution transformers are primarily found in large commercial buildings, we used the electrical energy going into buildings greater than 50,000 square feet obtained from CBECS to calculate the installed base for each building type using the aforementioned assumptions.

Annual Energy Consumption

The AEC, which is the energy loss due to transformer inefficiencies, is calculated by taking the total energy used by buildings of greater than 50,000 square feet and applying by a 98.5% efficiency value to obtain the energy loss. Typically, distribution transformer efficiencies are in the range of 97% to 99.5% (LBNL’s Energy Efficiency Standards, 2009). Building types that do not have an abundance of buildings greater than 50,000 square feet were excluded.

References

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ORNL, 1996, "Determination Analysis of Energy Conservation Standards for Distribution Transformers," Report for the DOE, July.

6.1.3 Monitors

Table 46: Detailed findings for Monitors in Office buildings.

	Comments/Values
AEC (TWh/yr)	11
Installed Base (1000s)	63,000
Units per 100,000 ft^2	520
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% Savings from typical unit (60 kWh/yr UEC)
Office Energy Savings Potential	7.3 TWh/yr
Office Trends and Notes	Monitor usage patterns and installed base are highly correlated with that of desktop PCs. Office buildings will continue to see the highest concentration of monitors.

Unit Energy Consumption

The average power consumption of monitors in this report is based on TIAX (2007) data and was calculated using a weighted average of the four key monitor categories. Each grouping weight is based on installed base and shipment estimates for each monitor type from iSuppli (2005) and power draw values from Roberson et al. (2002) and data from EPA Energy Star (Energy Star 2006). Although the TIAX (2007) data looks at the four monitor categories in residential setting, it is assumed that their installed base ratio is similar in commercial buildings. (See Table 47):

Table 47: Monitor Power Draw Values (from TIAX 2007, iSuppli 2005)

Monitor Size	Installed Base [%]	Power Draw [W]		
		Active	Sleep	Off
CRT – 17”	40%	61	2	1
LCD – 15”	15%	20	1	1
LCD – 17”	35%	31	1	1
LCD – 19”	10%	35	1	1
Average	100%	42	1	1

As seen in the above table, CRTs constitute slightly under half of the overall installed base in addition to drawing almost twice as much power as LCDs. The electron gun and electromagnets in CRT monitors are the main hardware components consuming the most power. In LCD monitors, the backlights account for approximately 80% of the active power draw, yet only about one percent of the electricity flowing into the backlights comes out the front of the display, i.e., a system efficiency of around 1% (TIAX, 2004).

Approximately 95% of all monitors sold in 2004 met the 2004 Energy Star power requirements for sleep and off mode power draw (TIAX, 2008). Starting in 2005, an active mode power requirement was implemented based on monitor resolution along with sleep and off mode requirements of less than 4 and 2 watts respectively (EPA, 2006.). The current Energy Star criteria for monitors are summarized in the table below:

Table 48: Monitors Key Product Criteria (Energy Star, 2009)

	On Mode	Sleep Mode	Off Mode
Tier 1 Maximum Allowable Power Consumption: Effective January 1, 2005	Y = 38X + 30. Y is expressed in watts and rounded up to the nearest whole number and X is the number of megapixels in decimal form	<= 4 watts	<= 2 watts
Tier 2 Maximum Allowable Power Consumption: Effective January 1, 2006	If X < 1 megapixel, then Y = 23; if X > 1 megapixel, then Y = 28X. Y is expressed in watts and rounded up to the nearest whole number and X is the number of megapixels in decimal form	<= 2 watts	<= 1 watt

In this report, TIAX infers monitor usage patterns in three key building types (offices, education and healthcare) based on the LBNL (2007) study where sixteen buildings in three cities were surveyed. Table 39 and Table 49 summarize the density of all the office equipment (which includes monitors) and remaining miscellaneous equipment in the various sampled buildings (including the power states of all the monitors during after-hours).

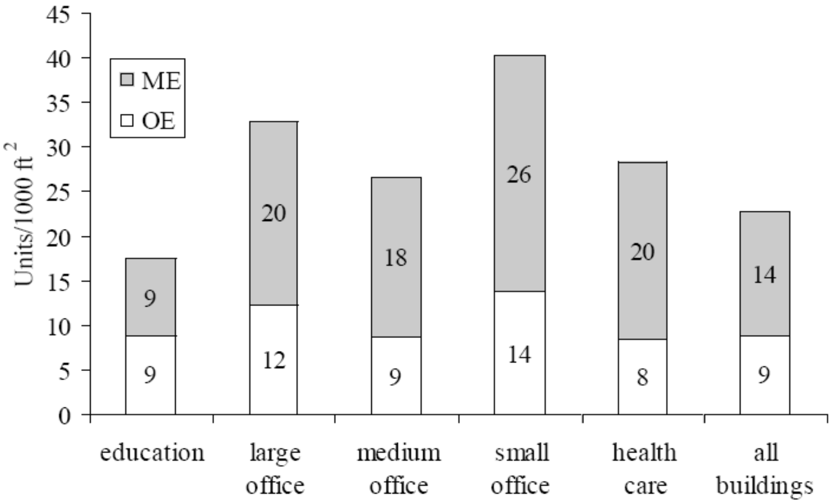

Figure 39: Office and Miscellaneous Equipment Density by Building Type (LBNL, 2007)

Table 49: Monitor After-Hours Power States (LBNL, 2007)

	Number of Monitor Samples					Percent				
Type	**low**	**off**	**on**	**unplugged**	**total**	**low**	**off**	**on**	**unplugged**	**PM rate**
CRT	648	422	259	12	1341	48%	31%	19%	1%	71%
LCD	164	49	56	17	286	57%	17%	20%	6%	75%
Plasma	0	2	1	0	3	0%	67%	33%	0%	-

According to LBNL (2007), 75% of the U.S. population of computers was found in offices, education buildings, and healthcare buildings, which is where highest concentration of monitors will be located as well. Using the EIA (2006) data of the total square feet of each of the aforementioned three building types, the installed base of monitors was calculated based on the LBNL (2007) monitor density data.

References

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TIAX, 2008, “ Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2006 and Scenario-based Projections for 2020”, Final Report by TIAX LLC to the U.S. Department of Energy, Building Technologies Program, April.

6.1.4 Office Equipment

Table 50: Detailed findings for Office Equipment in Office buildings.

	Comments/Values
AEC (TWh/yr)	7.2
Installed Base (1000s)	22,000
Units per 100,000ft^2	180
UEC (kWh/yr)	350
UEC variability	Varying usage patterns. Mode of operations varies among types of office equipment. UEC for an “office equipment is calculated” using a weighted average of the UEC each type of office equipment
Best in Class	85% savings from typical unit (300 kWh/yr UEC)
Office Energy Savings Potential	6.1 TWh/yr
Office Trends and Notes	Office equipment is PC-centric. Office buildings will by nature continue to see the largest concentration and installed base of office equipment

Table 51: Breakdown of equipment type

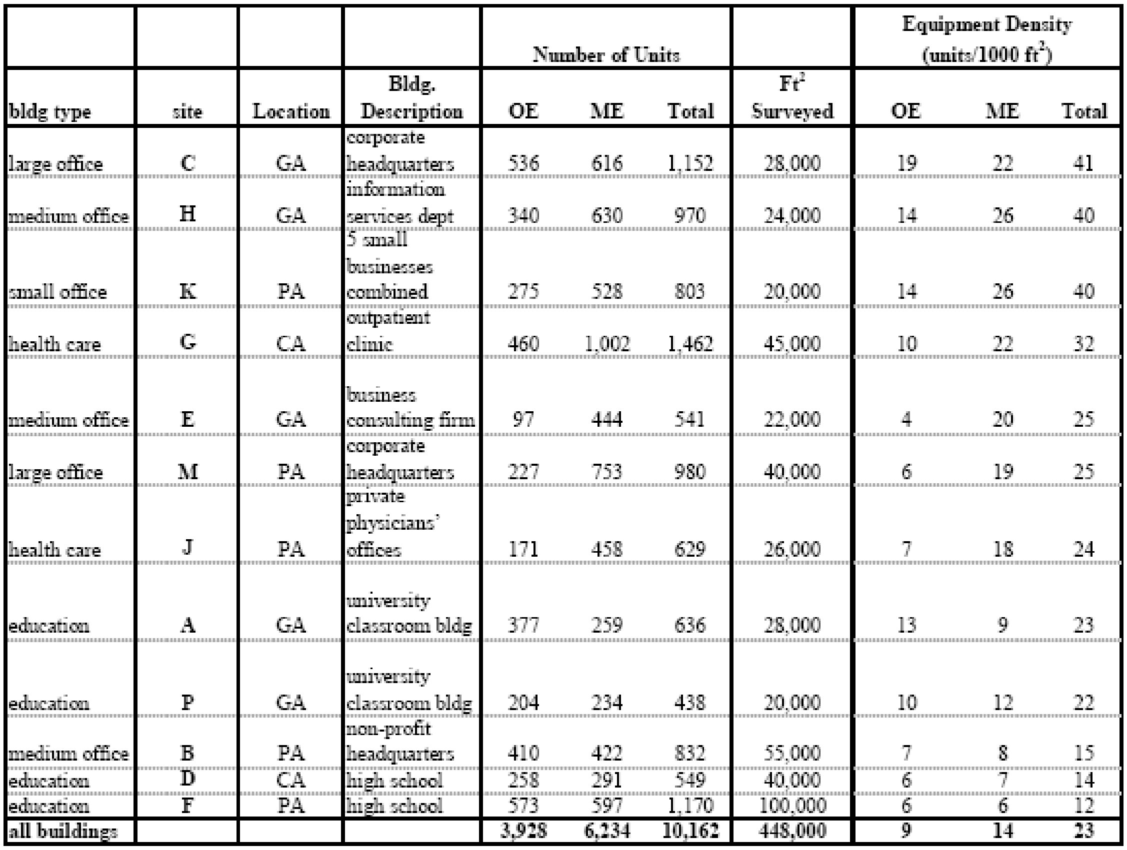
Unit Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class savings (%)	Office Energy Savings Potential (TWh/yr)
Printers	4.7	14,000	380	88	4.2

Copiers	1.1	1,500	710	73	0.8
Multi-Function Devices	0.2	2,500	59	87	0.1
Scanners	0.05	1,500	35	47	0.02
Fax Machines	0.1	2,300	53	59	0.1
Servers	1.1	490	2,200	86	1.0

Unit Energy Consumption

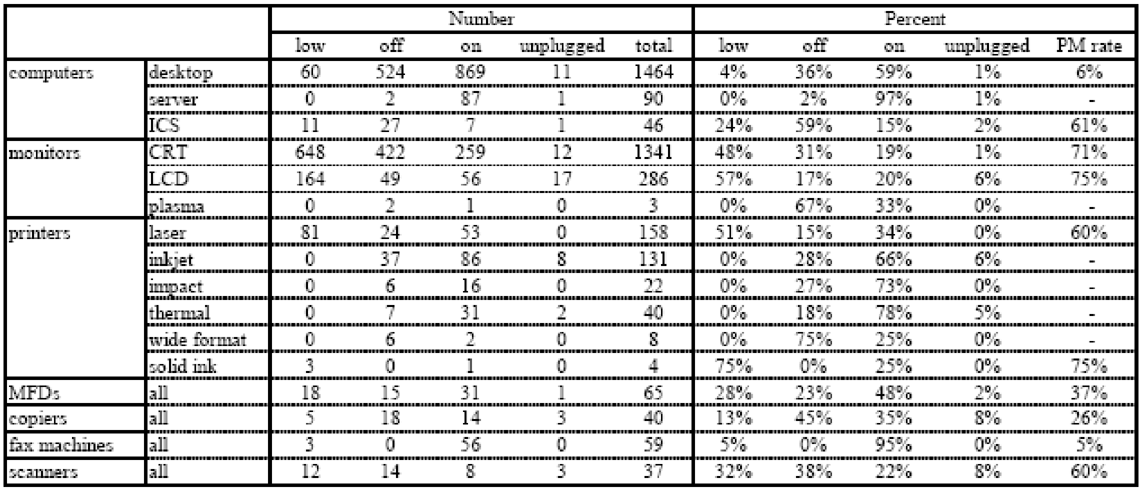
The diffuse nature of office equipment poses challenges in estimating their usage patterns. They are PC-centric and are most common in office settings and in close proximity to PCs. Since around 74% of the US population of computers were found among office, education and healthcare buildings (LBNL, 2007), it follows that the same percentage of office equipment is found in the aforementioned types of buildings as well. TIAX estimates of office equipment usage patterns as well as their installed base in the context of various commercial building types were deduced from the LBNL (2007) study. For this study, LBNL conducted an after-hours power status survey of over 500 office equipment units in sixteen commercial buildings in three cities. Table 52 and Table 53summarize the equipment densities in each sampled building and the after-hours power states of the various loads:

Table 52: Office Equipment: Number of Units and Density (LBNL, 2007)



				Number of Units				Equipment Density (units/1000 ft^2)		
bldg type	site	Location	Bldg. Description	OE	ME	Total	Ft^2 Surveyed	OE	ME	Total
large office	C	GA	corporate headquarters	536	616	1,152	28,000	19	22	41
medium office	H	GA	information services dept	340	630	970	24,000	14	26	40
small office	K	PA	5 small businesses combined	275	528	803	20,000	14	26	40
health care	G	CA	outpatient clinic	460	1,002	1,462	45,000	10	22	32
medium office	E	GA	business consulting firm	97	444	541	22,000	4	20	25
large office	M	PA	corporate headquarters	227	753	980	40,000	6	19	25
health care	J	PA	private physicians' offices	171	458	629	26,000	7	18	24
education	A	GA	university classroom bldg	377	259	636	28,000	13	9	23
education	P	GA	university classroom bldg	204	234	438	20,000	10	12	22
medium office	B	PA	non-profit headquarters	410	422	832	55,000	7	8	15
education	D	CA	high school	258	291	549	40,000	6	7	14
education	F	PA	high school	573	597	1,170	100,000	6	6	12
all buildings				**3,928**	**6,234**	**10,162**	**448,000**	**9**	**14**	**23**

Table 53: Office Equipment: After-Hours Power States (LBNL, 2007)



		Number					Percent				
		low	off	on	unplugged	total	low	off	on	unplugged	PM rate
computers	desktop	60	524	869	11	1464	4%	36%	59%	1%	6%
	server	0	2	87	1	90	0%	2%	97%	1%	-
	ICS	11	27	7	1	46	24%	59%	15%	2%	61%
monitors	CRT	648	422	259	12	1341	48%	31%	19%	1%	71%
	LCD	164	49	56	17	286	57%	17%	20%	6%	75%
	plasma	0	2	1	0	3	0%	67%	33%	0%	-
printers	laser	81	24	53	0	158	51%	15%	34%	0%	60%
	inkjet	0	37	86	8	131	0%	28%	66%	6%	-
	impact	0	6	16	0	22	0%	27%	73%	0%	-
	thermal	0	7	31	2	40	0%	18%	78%	5%	-
	wide format	0	6	2	0	8	0%	75%	25%	0%	-
	solid ink	3	0	1	0	4	75%	0%	25%	0%	75%
MFDs	all	18	15	31	1	65	28%	23%	48%	2%	37%
copiers	all	5	18	14	3	40	13%	45%	35%	8%	26%
fax machines	all	3	0	56	0	59	5%	0%	95%	0%	5%
scanners	all	12	14	8	3	37	32%	38%	22%	8%	60%

For this study, TIAX assumed an average power consumption of servers of approximately 250W as per Koomey (2007), and assumed that the servers are constantly on throughout the day, which accounts for their relatively large energy consumption. The server installed base was inferred from server density data in a sample of 12 commercial buildings surveyed by LBNL (2004).

References

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6.1.5 Personal Computers (PCs)

Table 54: Detailed findings for PCs (Desktops & Notebooks) in Office buildings.

	Comments/Values
AEC (TWh/yr)	25.5
Installed Base (1000s)	57,000
Units per 100,000 ft^2	470
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% savings from typical unit (95 kWh/yr UEC)
Office Energy Savings Potential	20 TWh/yr

	Comments/Values
Office **Trends and Notes**	Office buildings will continue to see the highest concentration of PCs and thus AEC and installed base due to the vital role PCs play in office settings.

Unit Energy Consumption

Currently, most PCs meet the Energy Star specifications depicted in Table 5 (from Energy Star 2006).

Table 55: Key Product Criteria for Energy Star Qualified Computers

Model Ship Date	Guideline	Power Draw	
		Power Supply	Watts (W) in Sleep Mode
Before July 1, 2000	-Shall enter a sleep mode within 30 minutes of inactivity -If shipped with network capability, shall sleep on networks and respond to wake events	< 200W > 200W	< 30W < 15% of power supply's maximum continuous output rating
On & After July 1, 2000	-Shall enter a sleep mode within 30 minutes of inactivity -If shipped with network capability, shall sleep on networks and respond to wake events	**Guideline A:** < 200W > 200W < 300W > 300W < 350W > 350W < 400W > 400W	< 15W < 20W < 25W < 30W < 10% of power supply's max continuous output rating
		Guideline B	< 15% of power supply's max continuous output rating

Table 56: PC average power consumption and usage patterns

	Desktop	Desktop Best in Class	Notebook	Notebook Best in Class
Power (W)	75W Active; 4W Low; 2W Off	14.9W Active; 1.5W Low; 0.6W Off	25W Active; 2W Low; 2W Off	14W Active; 1.1W Low; 0.7W Off
Usage Pattern (annual hrs)	6424 Active; 233.6 Low; 2102.4 Off		3212 Active; 1401.6 Low; 4126.4 Off	

It is assumed that most PCs are in active mode during the working hours of the weekday. The average power consumptions among the various modes of operation were based on TIAX (2008) as seen in the above table. Estimating the PC installed base in the various building types as well as the PC usage patterns during non-business hours are the two main areas of potential data uncertainty. Much of the estimates are based on LBNL (2004) data which surveyed 12 buildings in three states and has an accurate breakdown of PC usage pattern based on building types. Values from LBNL (2004) and from CBECS (2003) are used to project values up to 2008 as well as to obtain PC energy consumption values in building types that were not surveyed in LBNL (2004). LBNL (2004) recorded the number of computers in each buildings as well as the power state during after-hours. The data are summarized in the tables below:

Table 57: Building Sample and Computer Density (LBNL, 2004)

				In area surveyed (approximate no.)			Computer density per	
site	**state**	**building type**	**occupancy**	**computers**	**ft^2**	**employee**	**1000 ft^2**	**employee**
A	GA	education	university classroom bldg	171	38,000	n/a	6.1	n/a
B	PA	medium office	non-profit headquarters	182	55,000	128	3.3	1.42
C	GA	large office	corporate headquarters	262	28,000	120	9.4	2.18
D	CA	education	high school	112	40,000	n/a	2.8	n/a
E	GA	medium office	business consulting firm	37	22,000	70	1.7	0.53
F	PA	education	high school	248	100,000	n/a	2.5	n/a
G	CA	healthcare	outpatient clinic	177	45,000	n/a	3.9	n/a
H	GA	medium office	information services dept	153	24,000	76	6.4	2.01
J	PA	healthcare	private physicians' office	56	26,000	n/a	2.2	n/a
K	PA	small office	5 small businesses combined	117	20,000	77	5.9	1.52
M	PA	large office	corporate headquarters	73	40,000	125	1.8	0.58
N	GA	education	university classroom bldg	95	20,000	n/a	4.8	n/a
			total	1,683	448,000	n/a = not available		

Table 58: Computer after-hours power state (LBNL, 2004)

	Number of PC Samples				Percentage			
	On	**Low**	**Off**	**Sum**	**On**	**Low**	**Off**	**PM rate**
Desktop	869	60	524	1453	60%	4%	36%	6%
Laptop	9	26	136	171	5%	24%	71%	n/a

References

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6.1.6 Refrigeration

Table 59: Summary for Refrigeration in Office Buildings

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
210.6	10.3	Residential type and commercial units

Estimates are based on 2003 CBECS data.

6.1.6.1 Refrigeration – Residential type

Table 60: Detailed findings for residential type refrigeration in Office Buildings

	Comments/Values
AEC (TWh/yr)	2.8 (0.8 for full size & 2.0 for compact)
Installed Base	7.3 million (1.2 Million full size & 6.1 million compact)
Units per 100,000 ft^2	60
UEC (kWh/yr)	440 (weighted avg of full-size (660 kWh/yr) and compact (330 kWh/yr)
UEC Variability	Energy consumption may be skewed in cases where ratio of full size to compact is dramatically different than expected
Best in Class	30% savings for full size and 10% for compact (360 kWh/yr avg UEC)
Office Energy Savings Potential	0.4 TWh/yr
Office Trends and Notes	Office Buildings have a high number of residential refrigerators in comparison to other commercial buildings

Unit Energy Consumption

Office buildings commonly have both full size refrigerator-freezer units and compact units. TIAX estimates that the average installed full size unit uses 660 kWh/yr. This takes into account the current average UEC for 2009 model year units, as well as the fact that the average life is approximately 15 years. New units consume as little as 300 kWh/yr or less, while the older models still in use can consume up to four times that much.

The preliminary estimate came from the 2009 Buildings Energy Data Book (EERE, 2009). Further analysis confirmed the data. Using the CBECS installed base for all commercial buildings (7,148,595) and an annual sales growth rate equal to the commercial building growth rate (0.75% - calculated from growth between 1995 and 2003 in CBECS), TIAX calculated the sales over the past 15 years (average life span). Weighting the average energy consumption by model year from the Canadian Office of Energy Efficiency (COEE) with these calculated sales numbers resulted in a UEC of installed full size units of 660 kWh/yr (Lindia, 2007). This number confirmed the preliminary estimate.

The Residential Energy Consumption Study (RECS, 2001) listed an average UEC of 1239 kWh/yr for full size units. This value is believed to be markedly higher due to the fact that many years have passed since this information was collected. According to the COEE, in 2001 the average residential refrigerator-freezer on the market consumed approximately 600 kWh/yr. Beginning soon after that time, significant improvements were made that resulted in units that consumed 400 to 450 kWh/yr starting in 2004 (Lindia, 2007).

Alternatively, the Energy Star calculations list an average UEC of 560 kWh/yr using a 13 year average life span (ES calculations - Residential, 2009). An LBNL study in 2007 lists the UEC as 567 kWh/yr (LBNL, 2007). These numbers are lower than the TIAX estimate mainly due to the shorter life span which means that fewer of the older and less efficient units were included in the average. The life span of 15 years was calculated using the various life estimates from Association of Home Appliance Manufacturers. The estimates for various types were weighted using the market share estimates from the COEE.

Compact units were broken out as a separate value given how different they are in terms of energy consumption. TIAX estimates that for compact refrigerators and refrigerator-freezers (defined as having less than 7.75 cu ft capacity and being shorter than 36” by Energy Star), the UEC is 325 kWh/yr. This is the average of the values found by the COEE for the model years between 2000 and 2005. In this case it is not a weighted average because unlike full size units, the performance has stayed relatively consistent over the last 10 years.

Annual Energy Consumption

TIAX estimates that the AEC of residential refrigeration in office buildings is 2.8 TWh/yr. This is based on a combination of full size units and compact units; the installed base is 1.2 million units (EIA, 2006) for full size, consuming 0.8 TWh/yr, and 6.4 million for compact units, consuming 2.0 TWh/yr.

6.1.6.2 Refrigeration – Commercial Units

Table 61: Detailed findings for Commercial Refrigeration in Office Buildings

	Comments/Values
AEC (TWh/yr)	0.3

	Comments/Values
Installed Base	74,000 (EIA, 2006)
Units per 100,000 ft^2	0.6
UEC (kWh/yr)	3,900 (weighted average of coolers and freezers)
UEC Variability	Significantly larger size range than residential units. Large units can contain 6+ doors and have UEC that is dramatically higher than avg.
Best in Class	62% savings from typical unit (2400 kWh/yr)
Office Energy Savings Potential	0.2 TWh/yr
Office Trends and Notes	Very few assumed to be in office space – majority are for food industry located in office buildings.

Unit Energy Consumption

TIAX estimates that the UEC of commercial refrigeration units is 3,900 kWh/yr. This is based on a 60/40 split between refrigerators and freezers (CEE, 2007) and Energy Star "Conventional Unit" estimates for UEC of "conventional freezers" of 4519 kWh/yr (ES Commercial Freezer calculations, 2009) and "conventional refrigerators" of 3548 kWh/yr (ES Commercial Refrigerator calculations, 2009). Energy Star's "Conventional Freezer" is 24 cu ft while the "Conventional refrigerator" is 44 cu ft.

Estimates from other sources that were on the low side included the American Council for an Energy Efficient Economy, which estimated a UEC of 3200 kWh/yr (ACEEE, 2004). As with Energy Star, this is presumed to be a 48 cu ft, two-door unit. This estimate does not include freezer units, and likely is not an estimate of the average installed unit, thereby consuming much closer to what a new unit on the market today would consume.

Other published estimates run higher; using the same 60/40 refrigerator/freezer split used in TIAX calculations, an ADL study from 1996 estimates as high as 5040 kWh/yr. An LBNL study in 2007 continued to use these numbers despite being 11 years old at the time (LBNL, 2007). This is significantly higher than the TIAX estimate since it is out of date, and efficiencies have improved dramatically in that time.

The ADL estimated market breakdown of units is assumed to still be accurate. The percentages are shown below in Table 62 (ADL, 1996).

Table 62: Percentage of commercial units that are refrigerators and freezers, listed by size

Size	% of Refrigerators	% of Freezers
One door	50%	55%
Two doors	45%	40%
Three or more doors	5%	5%

Annual Energy Consumption

The 74,000 units (EIA, 2006) in office buildings in the US consume 0.3 TWh/yr. Since offices generally do not need this type of refrigeration, TIAX assumes that they are used instead in restaurants or other food related businesses and laboratories in buildings that are greater than 50% office space.

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6.1.7 Vertical Transport – Elevators and Escalators

Table 63: Detailed findings for Vertical Transport in Office Buildings

	Elevators	Escalators

	Elevators	Escalators
AEC (TWh/yr)	1.4	0.3
Installed Base (1,000s)	240	14
Units per 100,000 ft^2	2.0	0.1
UEC (kWh/yr)	5,800	20,460
UEC Variability	High variability based on usage and elevator type	High variability in usage and escalator rise
Best in Class	30% savings from typical unit (4,100 kWh/yr UEC)	30% savings from typical unit (14,000 kWh/yr UEC)
Office Energy Savings Potential	0.4 TWh/yr	0.1 TWh/yr
Office Trends and Notes	93% of high rise buildings (25+ floors) are office buildings and the elevators in an average high rise building consume 280 MWh/yr, office buildings consume 40% of elevator energy. Products generally have long lifetimes and are selected based on first cost.	

Unit Energy Consumption

The UEC for elevators is based on the breakdown of low-, medium-, and high-rise buildings for the particular building type, an assumed elevator type, average energy consumption per elevator start, and number of elevator starts per year. For office buildings, the UEC was calculated to be 5800 kWh/yr, as shown in Table 64.

Table 64: Calculation of the average UEC of elevators in office buildings

	# Floors	# of buildings w/ elevators	# of Elevators	Avg. Starts/year	Avg. (kWh/start)	UEC (kWh/yr)
Low-rise	<7	95,000	148,000	200,000	0.017	3,400
Mid-rise	7-24	10,000	56,000	400,000	0.026	10,000
High-rise	25+	2,000	36,000	500,000	0.017	8,500
Weighted Avg.			240,000			5,800
Comments/ Sources		EIA, 2006	EIA, 2005 scaled to 2008	Enermodal, 2004	Enermodal, 2004	

The UEC for escalators is calculated based on an escalator energy formula derived by an industry expert. (Al-Sharif 1997) The model was developed from actual measurements of in situ escalator rise, usage, and energy consumption. The model outputs energy as a function of escalator rise and operating time. The average escalator rise is based on a distribution of rises for a sample of in situ escalators. (Enermodal 2004) TIAX estimates the average usage to be approximately twelve hours per day. It is also assumed that there is an equal number of up and down escalators installed in buildings.

Annual Energy Consumption

In office buildings, there are 240,000 elevators and 14,000 escalators installed, which consume 1.4 and 0.3 TWh/yr, respectively.

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6.2 Non-Food Retail and Service

Key MELs for non-food retail and service buildings are shown in Figure 40. The total annual energy consumption for key MELs in non-food retail and service buildings is almost 27 TWh/yr.

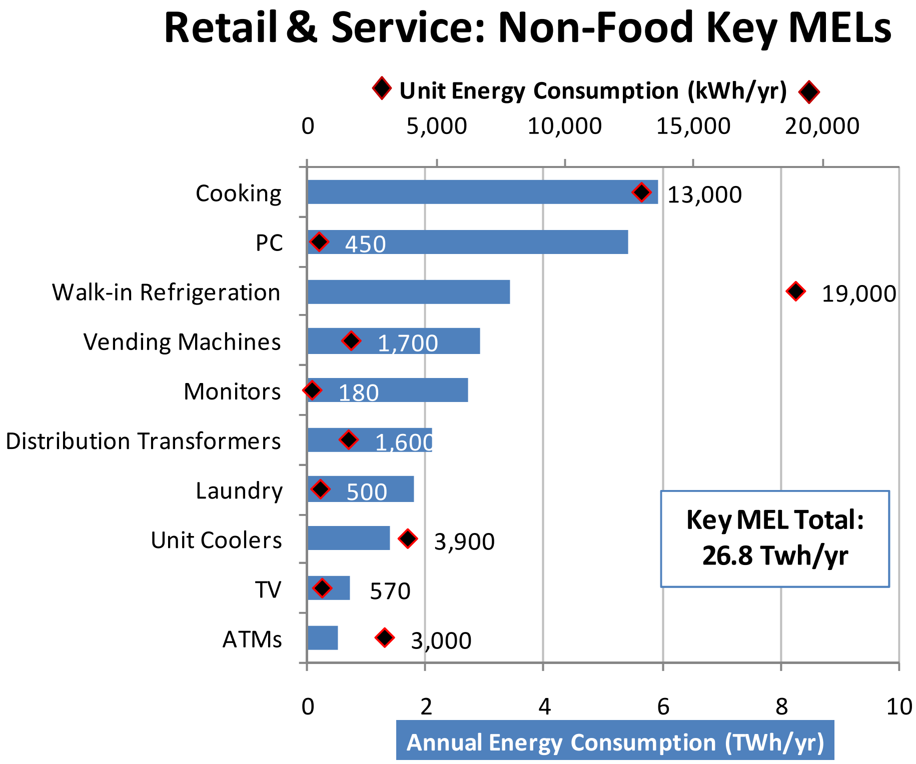

Figure 40: Key MELs for non-food retail and service buildings

6.2.1 Automated Teller Machines (ATM)

Table 65: Detailed findings for ATMs in Retail and Service Buildings

	Comments/Values
AEC (TWh/yr)	0.5
Installed Base	150,000 (~63% are full service)
Units per 100,000 ft^2	1.0
UEC (kWh/yr)	3000 (3600 for full service & 1900 for cash dispensers)
UEC Variability	Increasing use of credit/debit cards is leading to decreasing installed base. Differences in installed base for cash dispensers versus full-function units are unclear.
Best in Class	80% Savings from typical unit (610 kWh/yr UEC)
Retail & Service Energy Savings Potential	0.4 TWh/yr
Retail and Service Trends and Notes	The majority of units are stand alone

Unit Energy Consumption

As the installed base has grown, so has the energy consumption. The growth has generally been in line with that of other electronics, such as monitors, PCs, etc, which are all included in each ATM.

In 1993, ADL estimated that in active mode (currently servicing a customer), an ATM consumed 350 Watts, and in stand-by mode, an ATM consumed 300 Watts. Combined with ADL's estimates of time in each mode (790 hrs/yr in active and 7880 in stand-by), the annual UEC was 2600 kWh/yr (ADL, 1993). In 2002, however, Roth estimated a new UEC of 3600 kWh/yr for a full service unit and 1900 kWh/yr for a cash dispenser (Roth, 2002). These numbers are based on averages of active and idle mode measurements on a few machines. The power consumption for each mode is detailed below in Table 66. Based on this data, TIAX assumed a weighted average UEC of 3000 kWh/yr.

Table 66: The power consumption for the two types of ATM based on mode (Roth, 2002)

	Power Use		Annual Usage		% of Units	UEC
	Active	Stand-by	Active	Stand-by		
	Watts	Watts	Hrs/yr	Hrs/yr	%	kWh/yr
Full Service	471	379	1240	7880	63	3600
Cash Dispenser	250	200			37	1900

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 150,000 ATMs in retail and service buildings consume 0.6 TWh/yr of electricity (Kerber, 2008).

To obtain the installed base for this calculation, TIAX performed an informal review of typical retail and service buildings and estimates ATM installations to be at a rate of 1 per 100,000 sq ft of space.

References

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6.2.2 Cooking Equipment

Table 67: Detailed findings for Cooking Equipment in Retail & Services buildings.

	Comments/Values
AEC (TWh/yr)	5.9
Installed Base (1000s)	460
Units per 100,000ft^2	3.0
UEC (kWh/yr)	13,000
UEC variability	Varying usage patterns as well as number of units per establishment based on 1993 data. Appreciable uncertainty of the number of gas-fired equipment versus electric. No standard method to determine equipment efficiency.
Best in Class	12% Savings from typical unit (11,000 kWh/yr avg UEC)
Retail & Service Energy Savings Potential	0.7 TWh/yr
Retail & Service Trends and Notes	It is assumed that the majority of cooking equipment in this building type is in food service portions of malls

Unit Energy Consumption

The UEC and best in class UEC are calculated based on weighted averages of each cooking equipment type. Summarized in the table below, ADL (1993) estimates the number of cooking units per building and the average power consumption for each equipment type. The best in class UEC for each equipment type is based on the highest energy reduction percentage provided by ADL (1993) when certain energy saving technologies (see Section 5.3) are applied to a particular cooking equipment type.

Table 68: Overview of Cooking Equipment average power consumption and usage in Retail & Services buildings

Equipment Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Building Energy Savings Potential (TWh/yr)
Broilers	0.5	18	29,000	14	0.09
Fryers	0.6	86	7,300	10	0.06
Griddles	1.1	100	11,000	10	0.11
Ovens	1.9	92	20,000	13	0.30
Ranges	0.3	19	14,000	10	0.02
Steamers	1.5	140	11,000	15	0.20

Annual Energy Consumption

The AEC for each cooking equipment type in retail and service buildings is calculated by multiplying its respective UEC with its installed base. The installed base is calculated from the number of units in each building type from ADL (1993) and the number of buildings of that type from EIA (2006). In the case of retail and service buildings, ADL (1993) has indicated that there is a substantial amount of all types of cooking equipment. TIAX has adjusted the number of units per building in this building type to better suit the current number and diversity of retail and services buildings than when the ADL (1993) report was originally written. The total AEC is a sum of the AECs of each cooking equipment type in retail and services buildings.

References

ADL, 1993, “Characterization of Commercial Building Appliances,”Final Report to the Building Equipment Division Office of Building Technologies, U.S. Department of Energy, June.

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6.2.3 Distribution Transformers

Table 69: Detailed findings for Distribution Transformers in Retail and Services buildings

	Comments/Values
AEC (TWh/yr)	2.1
Installed Base (1000s)	1400
Units per 100,000ft^2	9.2
UEC (kWh/yr)	1600

	Comments/Values
UEC variability	Efficiency primarily affected by rated capacity, average load and temperature. Capacity varies significantly while avg load remains relatively consistent according to Cadmus Group (1999).
Best in Class	20% Savings from typical unit (1,300 kWh/yr UEC)
Retail and Service Energy Savings Potential	0.42 TWh/yr
Retail and Service Trends and Notes	Typical dry-type distribution transformers are found in commercial buildings which are less efficient than liquid-immersed type.

For discussion, see Section 6.1.2.

6.2.4 Laundry

Table 70: Detailed findings for Laundry in Retail and Service Buildings

	Washers	Dryers	Dry cleaning
AEC (TWh/yr)	0.3	0.2	0.3
Installed Base (1,000s)	1.8	2.0	
Units per 100,000 ft^2	11.5	13.1	0.12 kWh/lb
UEC (kWh/yr)	190	90	
UEC Variability	High based on washer capacity and usage		
Best in Class UEC	25% savings (140 kWh/yr UEC)	25% savings (68 kWh/yr UEC)	
Energy Savings Potential	0.1	~0	
Office Trends and Notes	Federal standard for residential-style commercial units began in 2007, DOE has begun to reach out to commercial laundry route operators		

Unit Energy Consumption

Laundry equipment in retail and service buildings consists of washers, dryers, and dry cleaning equipment. Service buildings with significant laundry equipment energy consumption include buildings for laundry route operations and coin operations (a.k.a., Laundromats). As mentioned in Section 5.9, the energy consumption evaluated in this study is the electric energy consumed by laundry equipment motors and controls. Most of the energy associated with laundry goes towards heating the water used for laundry and to heat gas fired dryers. Neither water heating energy, nor gas consumption are accounted for in this assessment.

Energy Star suggests that the average energy consumption for residential-style commercial washers, like those used in coin operation facilities, is 0.15 kWh/load for Energy Star units and 0.21 kWh/load for conventional units. The Energy Star calculator also appears to account for dryer energy, but it is unclear if the electric energy for tumbling and controls in gas dryers is included, since the stated energy for washing with no drying is equal to the energy for washing with gas drying. (EPA 2009) ADL (1993) estimates the washer electric energy to be 0.013 kWh/lb for a 10.7 lb load, and PNNL (2008) estimates 0.023 kWh/lb for larger 75 lb washers, both exclusive of dryer energy. For this study, 0.2 kWh/load was taken as a representative baseline for washer energy. This gives an average UEC of 190 kWh/yr, assuming 950 loads per year for an average commercial washer. (EPA 2009) The UEC will vary depending on usage and load capacity. Also, horizontal-axis (i.e., front load) washers generally consume less electric energy than vertical (i.e., top load) washers.

It is assumed that commercial dryers are generally gas fired. As indicated above, the Energy Star calculator does not seem to account for the electric energy consumed by gas dryers (i.e., the energy consumed by the tumble motor and controls). ADL (1993) estimated that the electric energy consumption of a commercial gas dryer was 0.33 kWh/load, or 0.028 kWh/lb. This is a somewhat outdated estimate, and generally newer appliances have become more efficient than older versions. Newer dryers likely consume less electric energy because washers are more effective at removing water during the final spin cycle. PNNL (2008) states that large 60 lb capacity gas dryers consume 0.01 kWh/lb. This estimate is likely more in line with the current installed base, yielding an average electric UEC of approximately 90kWh/yr, based on approximately 10,000 lbs per year per dryer.

The energy consumption of dry cleaning equipment was calculated based on the estimated weight of clothes dry cleaned annually, 2.4 billion pounds, and the estimated electric energy consumption per pound of clothes, 0.12 kWh/lb (ADL 1993). There are approximately 50,000 dry cleaning facilities in the U.S.

Annual Energy Consumption

TIAX estimated the installed base of commercial washers and dryers by scaling the estimates from ADL (1993) based on population. This method yields 1.8 million washers and two million dryers. The annual energy consumption for washers, dryers, and dry cleaners was 0.3 TWh, 0.2 TWh, and 0.3 TWh, respectively.

Federal standards were initiated for residential-style commercial washer energy and water usage in 2007. The modified energy factor (MEF) sets the amount of energy that can be consumed for the sum of water heating energy, operation energy, and post wash drying energy per load capacity. Additionally, a water factor (WF) sets the maximum amount of water that can be consumed during a wash per load capacity. Tax incentives such as EPACT 2005 have also helped to promote the penetration of more efficient wash equipment. Generally, the electric energy consumption of laundry equipment is reduced by reducing wash agitator energy or by reducing dryer time. The Energy Star commercial washer energy calculator indicates that efficient commercial equipment (with a gas dryer) consumes about 25% less electric energy than conventional equipment.

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6.2.5 Monitors

Table 71: Detailed findings for Monitors in Retail and Service buildings.

	Comments/Values
AEC (TWh/yr)	2.7
Installed Base (1000s)	15,000
Units per 100,000 ft^2	98
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% Savings from typical unit (60 kWh/yr UEC)
Retail and Service Energy Savings Potential	1.8 TWh/yr
Retail and Service Trends and Notes	Monitor usage patterns and installed base are highly correlated with that of desktop PCs.

For discussion, see Section 6.1.3

6.2.6 Personal Computers (PCs)

Table 72: Detailed findings for PCs (Desktops & Notebooks) in Retail and Service buildings.

	Comments/Values
AEC (TWh/yr)	5.4

	Comments/Values
Installed Base (1000s)	11,500
Units per 100,000 ft^2	75
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% savings from typical unit (95 kWh/yr UEC)
Retail and Service Energy Savings Potential	4.3 TWh/yr
Retail and Service Trends and Notes	

For discussion, see Section 6.1.5

6.2.7 Refrigeration

Table 73: Overview of Refrigeration in Retail and Service buildings

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
258.7	16.9	Walk-in and commercial units

Estimates are based on 2003 CBECS data.

6.2.7.1 Refrigeration – Walk-in

Table 74: Detailed findings for Walk-in Refrigeration in Retail and Service buildings

	Comments/Values
AEC (TWh/yr)	3.4
Installed Base	180,000 (CBECS)
Units per 100,000 ft^2	1.2
UEC (kWh/yr)	19,000 (weighted avg of coolers/freezers/combinations)
UEC Variability	Systems can vary dramatically depending on size and temperature needed
Best in Class	62% Savings from typical unit (7,200 kWh/yr UEC - ADL, 1996)
Retail & Service Energy Savings Potential	3.4 TWh/yr

	Comments/Values
Retail & Service Trends and Notes	Use is mainly in food industry related businesses that are located in the building

Unit Energy Consumption

The UEC for walk-in refrigeration is a weighted average of the coolers, freezers, and combination freezer/coolers in the United States. The UEC for each type is sourced from a 1996 report by ADL (ADL, 1996). While this is not as recent as some other industry data, other institutions, including the Canadian Office of Energy Efficiency (COEE Walk-in, 2009), still cite this information as an accurate representation of the market.

Data for typical units are shown below in Table 75. While combination units provide economies of scale, the total UEC is still significantly higher than a typical freezer or cooler simply due to the inherent size.

Table 75: Typical walk-in refrigeration unit specifications (ADL, 1996)

Unit configuration	Size m^2 (ft^2)	UEC kWh/yr
Cooler	15 (161)	16,200
Freezer	15 (161)	21,400
Combination Freezer-Cooler	31 (334)	30,200

The weighting for calculating the UEC comes from ADL's estimated installed base in 1996. ADL lists 540,000 walk-in coolers, 275,000 walk-in freezers, and 65,000 walk-in combination units (for a total of 880,000 units).

Annual Energy Consumption

AEC data are from the 2003 CBECS survey which gives a total of 1.3 million units in the United States in 2003 (EIA, 2006). This value includes a TIAX estimate of 80,000 units in mall buildings (enclosed and strip-type malls) which are excluded from CBECS data. While TIAX believes this to be a high total estimate for 2003 based on the ADL 1996 numbers, it seems very reasonable as an estimate for an updated installed base for this study. For the 13 year period between 1995 and 2008, the increase in installed base of 420,000 units corresponds to a 3% compound annual growth rate. This rate approximates the average annual GDP growth over the time period (~3.1%), and is therefore believed to be a reasonable assumption.

6.2.7.2 Refrigeration – Commercial Units

Table 76: Detailed findings for Commercial Refrigeration in Retail and Service Buildings

	Comments/Values
AEC (TWh/yr)	1.4

	Comments/Values
Installed Base	360,000 (CBECS)
Units per 100,000 Sq Ft	2.4
UEC (kWh/yr)	3,900 (weighted average of coolers and freezers)
UEC Variability	Significantly larger size range than residential units. Large units can contain 6+ doors and have UEC that is dramatically higher than avg.
Best in Class	62% Savings from typical unit (2400 kWh/yr UEC)
Retail & Service Energy Savings Potential	0.9 TWh/yr
Retail & Service Trends and Notes	Use is mainly in food industry related businesses that are located in the building

Unit Energy Consumption

See Section 6.1.6.2 for commercial unit coolers/freezers UEC data, as listed under office buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 356,000 commercial refrigeration units in retail and service buildings (EIA, 2006) consume 1.4 TWh/yr of electricity.

References

ADL, 1996, "*Energy Savings Potential for Commercial Refrigeration Equipment*" Arthur D. Little, 1996.

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

COEE Walk-in, 2009, "*Walk-in Commercial Refrigeration,*" Natural Resources Canada (NRCan): Office of Energy Efficiency (OEE). Downloaded on Sept 22, 2009 from http://oee.nrcan.gc.ca/industrial/equipment/commercial-refrigeration/index.cfm?attr=20

6.2.8 Televisions

Table 77: Detailed findings for Televisions in Retail and Service Buildings

	Comments/Values
AEC (TWh/yr)	0.7
Installed Base (1,000s)	0.9
Units per 100,000 ft^2	6

	Comments/Values
UEC (kWh/yr)	940
UEC Variability	High based on active usage and screen size
Best in Class UEC	38% savings from typical unit (580 kWh/yr UEC)
Retail and Service Energy Savings Potential	0.2 TWh/yr
Retail and Service Trends and Notes	Large consumer electronics generally have large display models on all day

Unit Energy Consumption

The unit energy consumption for televisions is generally dominated by active mode, and the active mode power draw is mainly a function of screen area. In non-food retail and service buildings, there is very little data regarding the installed base, power draw, or usage of televisions. TIAX has estimated that installed TVs are generally digital TVs (DTVs), and the average UEC was calculated by estimating the UEC of TVs in two key applications. First, DTVs on display in big box electronics retail buildings are estimated to consume 1,550 kWh/yr, the equivalent of an average 50 inch, 350 W DTV on for 12 hours per day. Second, TIAX estimates that half of all other non-food retail and service buildings have a 30 inch, 125 W television that is operated for approximately 8 hours per day, which corresponds to a UEC of 390 kWh/yr. Installed televisions are estimated to consume 4 W in off mode, but this assumption has little impact on the UEC estimates.

TIAX estimates that there are approximately 10,000 big box electronics stores in the U. S., with approximately 300,000 displays. With an estimated 600,000 TVs in other retail and service buildings, the weighted averaged TV UEC was calculated to be 780 kWh/yr. Because of the lack of data, there is a relatively high degree of uncertainty in this estimate.

Annual Energy Consumption

Even with fairly aggressive UEC estimates, the overall TV AEC for non-food retail and service buildings is only 0.7 TWh/yr, and therefore the uncertainty associated with the estimate will not have a large impact on the overall study results. However, in large consumer electronics retail buildings, display DTVs may consume a considerable portion of the overall building energy consumption. Therefore, it may be useful to understand the TV energy consumption more accurately in buildings with a high concentration of large DTVs that are on for a significant fraction of the time.

References

EIA 2006, “2003 Commercial Building Energy Consumption Survey”, DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/ .

TIAX, 2008, “Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2006 and Scenario-based Projections for 2020,” Final Report by TIAX LLC for the U.S. Department of Energy, Building Technologies Program, April

TIAX, 2007, “Energy Consumption by Consumer Electronics (CE) in U.S. Residences,” Final Report by TIAX LLC to the Consumer Electronics Association (CEA), January

6.2.9 *Vending Machines*

Table 78: Detailed findings for Vending Machines in Retail and Service Buildings

	Comments/Values
AEC (TWh/yr)	2.9 (2.2 refrig. & 0.7 non-refrig)
Installed Base	1,700,000 (600,000 refrig. & 1.1MM non-refrig.)
Units per 100,000 ft^2	11
UEC (kWh/yr)	1700 (weighted avg of refrigerated / non-refrigerated)
UEC Variability	Units in employee areas may have concentrated use at certain times – public units have more continuous usage
Best in Class	33% savings for refrigerated and 50% savings for non-refrigerated (1000 kWh/yr UEC)
Retail & Service Energy Savings Potential	1.1 TWh/yr
Retail & Service Trends and Notes	Energy savings based on room occupancy could be difficult to obtain due to locating in high-people-traffic areas

Unit Energy Consumption

See Section 6.1.1 for vending machine UEC data as listed under office buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the sum of the installed base multiplied by the UEC for each vending machine type. The 1.7 million vending machines in retail and service buildings (EIA, 2006) consume 2.9 TWh/yr of electricity.

The installed base used in these calculations for refrigerated units is the CBECS estimate from 2003 (EIA, 2006). While broadly defined as “vending machines” in the refrigeration section of the CBECS data, it is assumed that users would respond to the survey with the number of refrigerated units due to the structure and nature of the questions (EIA, 2006). Because CBECS does not explicitly categorize non-refrigerated units, estimates for installed base were calculated as a growth adjusted estimate from ADL (ADL, 1991). For consistency sake, the percentage of total units in each category was maintained across refrigerated and non-refrigerated units. (The units/building however was not maintained such that the total installed base in the US could grow appropriately.)

References

ADL, 1991, “*Characterization of Commercial Building End-Uses Other Than HVAC and Lighting,”* Arthur D. Little for DOE, September, 1991.

EIA, 2006, “2003 Commercial Building Energy Consumption Survey”, DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

6.3 Food Sales

Key MELs for food sales buildings are shown in Figure 41. The total annual energy consumption for key MELs in food sales buildings is about 34 TWh/yr. The 2003 CBECS found that food sales buildings consume 61 TWh/yr of electricity, of which 35 TWh/yr is for refrigeration. In its 2008 study on supermarkets and grocery stores, Energy Star found that the median energy intensity from all sources was 56 kWh/ ft^2.[11]

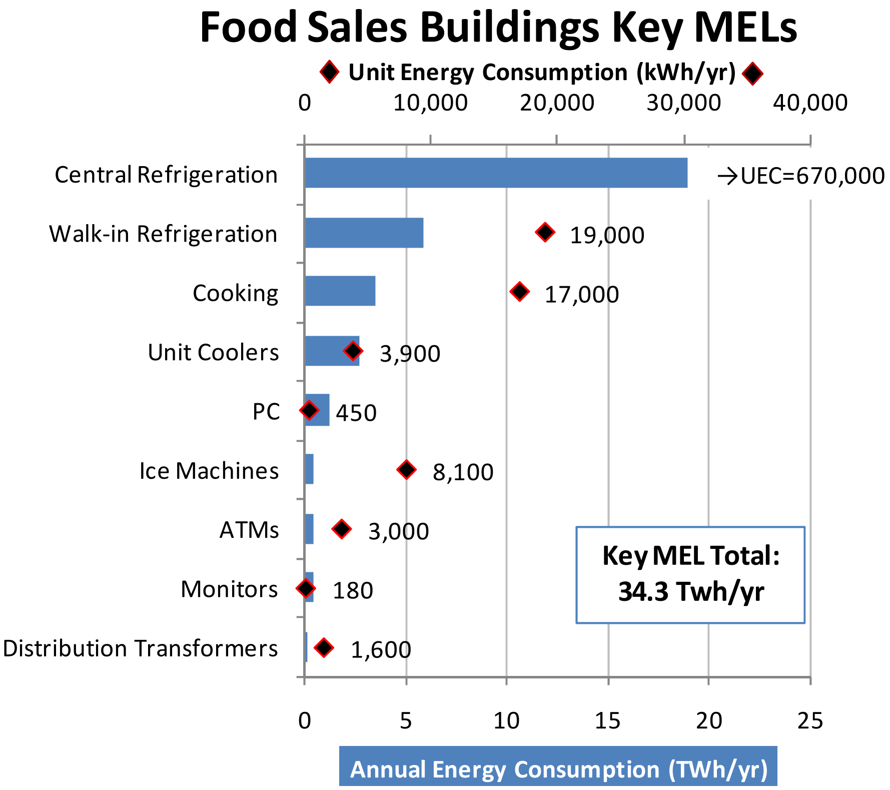

Figure 41: Key MELs for food sales buildings

6.3.1 Automated Teller Machines (ATM)

Table 79: Detailed findings for ATMs in Food Sales Buildings

	Comments/Values
AEC (TWh/yr)	0.5
Installed Base	150,000 (~63% are full service)
Units per 100,000 Sq Ft	12
UEC (kWh/yr)	3000 (3600 for full service & 1900 for cash dispensers)
UEC Variability	Increasing use of credit/debit cards is leading to decreasing installed base. Differences in installed base for cash dispensers versus full-function units is unclear.

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[11] Energy Star Building Manual, *"Chapter 11: Facility Type: Supermarkets and Grocery Stores,"* Downloaded on September 22, 2009 from http://www.energystar.gov/index.cfm?c=business.EPA_BUM_CH11_Supermarkets

	Comments/Values
Best in Class	80% Savings from typical unit (610 kWh/yr UEC)
Food Sales Energy Savings Potential	0.4 TWh/yr
Food Sales Trends and Notes	A significant number of units are stand alone

Unit Energy Consumption

See Section 6.2.1 for ATM UEC discussion, as listed under non-food service and retail buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all food sales buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 150,000 ATMs in food sales buildings consume 0.5 TWh/yr of electricity (Kerber, 2008).

To obtain the installed base for this calculation, TIAX used data from 2003 CBECS and assumed that 100% of supermarkets (86,000) have one unit, 50% of convenience stores have one unit (72,000) and 50% of convenience stores with gas (57,000) have one unit (EIA, 2006).

References

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

Kerber, 2008, *"Withdrawing from the ATM Habit,"* Boston Globe (online), February 19, 2008. Downloaded on September 30, 2009 from http://www.boston.com/business/personalfinance/articles/2008/02/19/withdrawing_from_the_atm_habit/

6.3.2 Cooking Equipment

Table 80: Detailed findings for Cooking Equipment in Food Sales buildings.

	Comments/Values
AEC (TWh/yr)	3.6
Installed Base (1000s)	220
Units per 100,000ft^2	18
UEC (kWh/yr)	17,000
UEC variability	Varying usage patterns as well as number of units per establishment based on 1993 data. Appreciable uncertainty of the number of gas-fired equipment versus electric. No standard method to determine equipment efficiency.

	Comments/Values
Best in Class	13% Savings from typical unit (15,000 kWh/yr UEC)
Food Sales Energy Savings Potential	0.5 TWh/yr
Food Sales Trends and Notes	

Unit Energy Consumption

The UEC and best in class UEC are calculated based on weighted averages of each cooking equipment type. Summarized in the table below, ADL (1993) estimates the number of cooking units per building and the average power consumption for each equipment type. The best in class UEC for each equipment type is based on the highest energy reduction percentage provided by ADL (1993) when certain energy saving technologies (see Section 5.3) are applied to a particular cooking equipment type.

Table 81: Overview of Cooking Equipment average power consumption and usage in Food Sales buildings

Equipment Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Food Sales Energy Savings Potential (TWh/yr)
Broilers	n/a	n/a	n/a	n/a	n/a
Fryers	0.6	95	7,000	10	0.07
Griddles	n/a	n/a	n/a	n/a	n/a
Ovens	2.5	100	25,000	17	0.41
Ranges	0.5	20	23,000	10	0.06
Steamers	n/a	n/a	n/a	n/a	n/a

Notes: Only a substantial amount of certain equipment types namely fryers, ranges and ovens in this building type (ADL,1993)

Annual Energy Consumption

The AEC for each type of cooking equipment type in food sales buildings is calculated by multiplying its respective UEC with its installed base. The installed base is calculated from the number of units in each building type from ADL (1993) and the number of buildings of that type from CBECS (EIA, 2006). In the case of food sales buildings, ADL (1993) has indicated that the only types of equipment with substantial quantities are fryers, ranges and ovens. The total AEC is a sum of the AECs of each cooking equipment type in food sales buildings.

References

ADL, 1993, “Characterization of Commercial Building Appliances,” Final Report to the Building Equipment Division Office of Building Technologies, U.S. Department of Energy, June.

EIA, 2006, “2003 Commercial Buildings Energy Consumption Survey (CBECS),” CBECS Public Use Microdata Files," Download from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html on August 2009.

6.3.3 Distribution Transformers

Table 82: Detailed findings for Distribution Transformers in Food Sales buildings

	Comments/Values
AEC (TWh/yr)	0.2
Installed Base (1000s)	100
Units per 100,000ft^2	8.0
UEC (kWh/yr)	1,600
UEC variability	Efficiency primarily affected by rated capacity, average load and temperature. Capacity varies significantly while avg load remains relatively consistent according to Cadmus Group (1999).
Best in Class	20% Savings from typical unit (1,300 kWh/yr UEC)
Food Sales Energy Savings Potential	0.04 TWh/yr
Food Sales Trends and Notes	Typical dry-type distribution transformers are found in commercial buildings which are less efficient than liquid-immersed type.

For discussion, see Section 6.1.2.

6.3.4 Ice Machines

Table 83: Detailed findings for Ice Machines in Food Sales Buildings

	Comments/Values
AEC (TWh/yr)	0.5
Installed Base	58,000
Units per Sq Ft	4.6
UEC (kWh/yr)	8,100
UEC Variability	Highly varying usage patterns. Choice of storage capacity and smaller unit w/high duty cycle versus large unit w/low duty cycle makes big impact on UEC.
Best in Class	24% Savings from typical unit (6200 kWh/yr)
Food Sales Energy Savings Potential	0.1 TWh/yr
Food Sales Trends and Notes	Uses include Meat/Seafood counter coolers, soft-drink dispensers, and for direct sale (by the bag).

Unit Energy Consumption

The UEC for ice machines is calculated based on daily usage parameters and therefore varies by building type. For food sales buildings, TIAX believes that daily usage is greater than the 'typical' or 'default' case. The usage variables that TIAX addresses include: duty cycle (%), energy consumption (kWh/100 lbs ice), and ice production (lbs per 24 hrs).

The Federal Energy Management Program (FEMP) under the DOE/EERE provides default values for usage as 500 lbs ice per 24 hrs for 3000 hours per year (34% duty cycle) with energy consumption of 5.5 kWh per 100 lbs of ice (FEMP, 2009). Many discrepancies exist in duty cycle estimates, for example, the Northwest Power and Conservation Council assumes typical usage is approximately 4400 hours per year or a 50% duty cycle. In addition to the FEMP data, they cite the ADL 1996 study, which uses a 50% duty cycle (ADL 1996), and the Food Service Technology Center (FTSC) which uses a duty cycle of 75% (Fish-Nick, 2007) as a basis for choosing the 50% value. TIAX estimates that a 45% duty cycle is accurate based on these sources; this value is used for calculations in all building types.

In assessing energy consumption, TIAX reviewed all currently certified (AHRI) units. While consumption can vary significantly from one unit to another, above ~280 lbs/day (80% of certified units), energy consumption per 100 lbs of ice remains relatively flat versus unit capacity; the vast majority of units average approximately 5.2 kWh/100 lbs.

TIAX estimates that for food sales buildings, an accurate average daily capacity is 950 lbs. Using the variables that are summarized in Table 84, this means an annual UEC of 8,100 kWh/yr

Table 84: TIAX usage assumptions for Ice Machines in Food Sales Buildings

Usage Variable	Units	Value
Annual Duty Cycle	%	45
Daily Harvest	Lbs	950
Energy Consumption	kWh/100 lbs	5.2

Annual Energy Consumption

The UEC was assumed to be consistent across all food sales buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 58,000 ice machines in food sales buildings consume 0.5 TWh/yr of electricity.

To obtain the installed base for this calculation, TIAX assumed that the percentage of ice machines in each building type has not changed since the ADL estimates in 1991 (ADL, 1991). To update the value over the 18 years that have passed since that data was gathered, TIAX used a compound annual growth rate of 0.75%, which is an approximation of the growth rate of the number of commercial buildings in the same time period.

References

ADL, 1991, "*Characterization of Commercial Building End-Uses Other Than HVAC and Lighting,*" Arthur D. Little for DOE, September, 1991.

ADL, 1996, "*Energy Savings Potential for Commercial Refrigeration Equipment*" Arthur D. Little, 1996.

FEMP, 2009, "*Energy Cost Calculator for Commercial Ice Machines,*" DOE/EERE, Downloaded on Sept 21, 2009 from http://www1.eere.energy.gov/femp/technologies/eep_ice_makers_calc.html

Fish-Nick, 2007, "*A Field Study to Characterize Water and Energy Use of Commercial Ice-Cube Machines and Quantify Saving Potential*" Fischer-Nickel for PG&E's Food Technology Service Center (FTSC), December 2007. Downloaded on Sept 21, 2009 from http://www.fishnick.com/publications/appliancereports/special/Ice-cube_machine_field_study.pdf

NWCouncil, 2009, "*Commercial Ice-Makers: Calculator Update,*" Northwest Power and Conservation Council. Downloaded on Sept 21, 2009 from http://www.nwcouncil.org/energy/rtf/meetings/2008/05/Ice%20Maker%20Calculator%20Update%20ii.ppt

6.3.5 Monitors

Table 85: Detailed findings for Monitors in Food Sales buildings.

	Comments/Values
AEC (TWh/yr)	0.5
Installed Base (1000s)	3,000
Units per 100,000 ft^2	240
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% savings from typical unit (60 kWh/yr UEC)
Food Sales Energy Savings Potential	0.3 TWh/yr
Food Sales Trends and Notes	

For discussion, see Section 6.1.3.

6.3.6 Personal Computers (PCs)

Table 86: Detailed findings for PCs (Desktops & Notebooks) in Food Sales buildings.

	Comments/Values

	Comments/Values
AEC (TWh/yr)	1.3
Installed Base (1000s)	3,000
Units per 100,000 ft^2	240
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% savings from typical unit (95 kWh/yr UEC)
Food Sales Energy Savings Potential	1 TWh/hr
Food Sales Trends and Notes	

For discussion, see Section 6.1.5.

6.3.7 Refrigeration

Table 87: Summary for Refrigeration in Food Sales Buildings

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
61.1	34.9	Central, Walk-in, and commercial units

Estimates are based on 2003 CBECS data.

The larger stores (> 5000 sq ft) tend to have nearly all of their refrigeration run from a central system, with coolant pipes running throughout the building to heat exchangers in each open or closed case. These buildings are estimated to use 48% (Kauffeld, 2007) to 52% (EIA, 2006) of their electricity for refrigeration. TIAX estimates that 90% of the refrigeration electric load in these buildings is from the central system. The remaining 10% is for walk-in units that are in the back for short term inventory storage and for stand-alone cases such as beverage merchandisers, deli counter refrigerators, and other self-contained display cases (e.g. ice cream freezers near the checkout).

In smaller food sales buildings, such as small markets and convenience stores, the trend toward central refrigeration is reversed; fewer small food sales stores have central systems for economic reasons. These stores rely on walk-in units for inventory storage and self-contained units and glass-door merchandiser units for holding goods on the main sales floor. These buildings may consume as much as 75% of the electricity on refrigeration (EIA 2006).

6.3.7.1 Refrigeration – Central

Table 88: Detailed findings for Central Refrigeration in Food Sales Buildings

	Comments/Values
AEC (TWh/yr)	19
Installed Base	28,000
Units per 100,000 Sq Ft	NA – generally one unit per building
UEC (kWh/yr)	670,000 (some as large as 1,000,000 or more)
UEC Variability	UEC can range up to 1.25MM kWh/yr/unit or more – proportional to store size
Best in Class	46% Savings from typical unit (360,000 kWh/yr)
Food Sales Energy Savings Potential	8.6 TWh/yr
Food Sales Trends and Notes	This is unique to Food Sales buildings; most similar is warehouse refrigeration, which is unique to warehouses.

Unit Energy Consumption

TIAX estimates that the UEC for a single system is 500,000 kWh/yr. More than other loads, this value varies dramatically since each individual system has different needs in terms of square footage, refrigeration tonnage, etc. Some systems can be 1,000,000 kWh/yr (ADL, 1996) or more, such as those in the 200 grocery stores in the US that have more than 100,000 sq ft of space (EIA 2006).

Annual Energy Consumption

TIAX estimates that the 27,800 central refrigeration systems in food sales buildings in the United States consume 19 TWh/yr. This is based on the assumption that all grocery stores and markets (as defined by CBECS) over 5000 sq ft have central refrigeration systems, and that 95% of their refrigeration load is from their central system. The remaining 5% is for commercial units (see Section 6.3.7.2) and walk-in units (see Section 6.3.7.3).

6.3.7.2 Refrigeration – Commercial Units

Table 89: Detailed findings for Commercial Refrigeration in Food Sales Buildings

	Comments/Values
AEC (TWh/yr)	2.8
Installed Base	720,000 (CBECS)
Units per 100,000 Sq Ft	57
UEC (kWh/yr)	3,900 (weighted average of coolers and freezers)
UEC Variability	Significantly larger size range than residential units. Large units can contain 6+ doors and have UEC that is dramatically higher than avg.
Best in Class	62% Savings from typical unit (2400 kWh/yr UEC)
Food Sales Energy Savings Potential	1.8 TWh/yr
Food Sales Trends and Notes	Generally concentrated in smaller markets, convenience stores, and markets that do not have central refrigeration.

Unit Energy Consumption

See Section 6.1.6.2 for commercial unit coolers/freezers UEC data as listed under office buildings. Noteworthy however, is the fact that generally more commercial units in food sales buildings have glass doors than in other building types due to the nature of the application. It is common that the only solid-door units in food sales will be those in employee-only areas of the store. Without greater knowledge of usage patterns and observational support data, TIAX must assume that the UEC remains the same across the various building types.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 720,000 commercial unit coolers and freezers in food sales buildings (EIA, 2006) consume 2.8 TWh/yr.

6.3.7.3 Refrigeration – Walk-in Units

Table 90: Detailed findings for Walk-in Refrigeration in Food Sales Buildings

	Comments/Values
AEC (TWh/yr)	5.9
Installed Base	310,000 (EIA, 2006)
Units per 100,000 Sq Ft	25
UEC (kWh/yr)	19,000 (weighted avg of coolers/freezers/combinations)

	Comments/Values
UEC Variability	Systems can vary dramatically depending on size and temperature needed
Best in Class	62% Savings from typical unit (7,200 kWh/yr UEC ADL, 1996)
Food Sales Energy Savings Potential	3.7 TWh/yr
Food Sales Trends and Notes	Generally used in employee-only areas for short term inventory of non-shelved items.

Unit Energy Consumption

See Section 6.2.7.1 for walk-in refrigeration UEC data, as listed under retail and service buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 310,000 walk-in refrigeration units in food sales buildings in the US (EIA, 2006) consume 5.9 TWh/yr.

References

ADL, 1996, "Energy Savings Potential for Commercial Refrigeration Equipment", Arthur D. Little for DOE, June 1996

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

Kauffeld, 2007, *"Trends and Perspectives in Refrigeration Technology,"* Institute of Refrigeration, Air Conditioning and Environmental Engineering, May, 23, 2007. Downloaded on Sept 22, 2009 from http://www.umweltbundesamt.de/produkte/fckw/co2ol/04_Kauffeld_TrendsandPerspectivesinRefrigerationTechnology.pdf

6.4 Food Service

Key MELs for food service buildings are shown in Figure 42. The total annual energy consumption for key MELs in food service buildings is almost 26 TWh/yr.

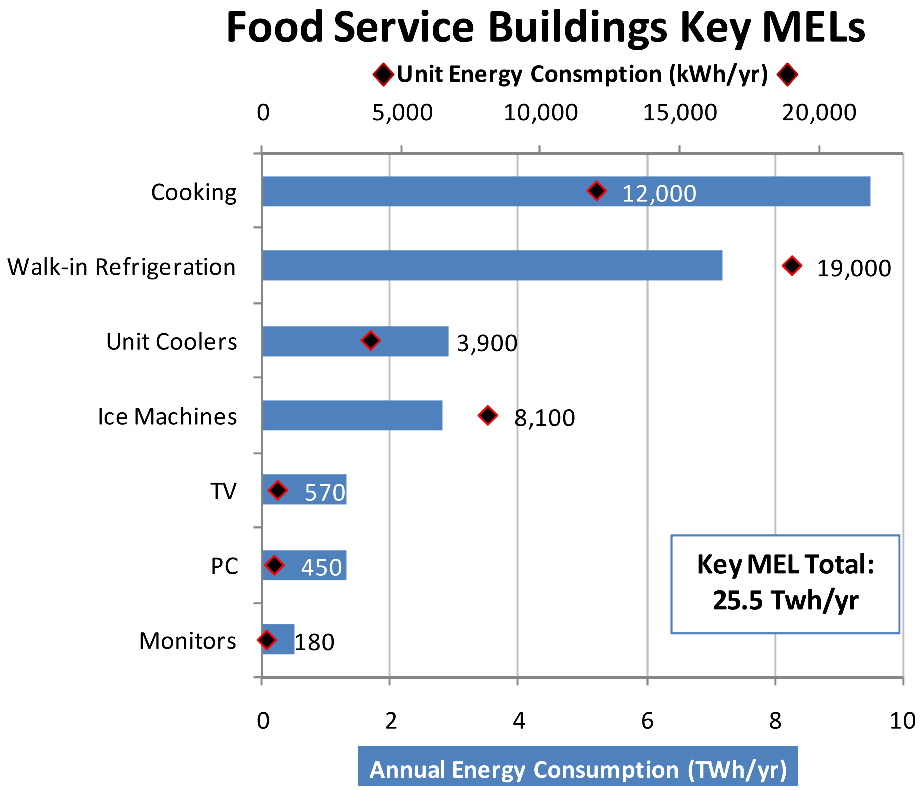

Figure 42: Key MELs for food service buildings

6.4.1 Cooking Equipment

Table 91: Detailed findings for Cooking Equipment in Food Service buildings.

	Comments/Values
AEC (TWh/yr)	9.5
Installed Base (1000s)	780
Units per 100,000ft^2	47
UEC (kWh/yr)	12,000
UEC variability	Varying usage patterns as well as number of units per establishment based on 1993 data. Appreciable uncertainty of the number of gas-fired equipment versus electric. No standard method to determine equipment efficiency
Best in Class	12% Savings from typical unit (10,600 kWh/yr UEC)

	Comments/Values
Food Service Energy Savings Potential	1.1 TWh/yr
Food Service Trends and Notes	AEC is obviously highest in food service building type due to the function of this type of building which is predominantly used to prepare large quantity of food throughout the day. It is likely that the AEC as well as installed base of cooking equipment in this type of building with continue to remain the highest

Unit Energy Consumption

The UEC and best in class UEC are calculated based on weighted averages of each cooking equipment type. Summarized in the table below, ADL (1993) estimates the number of cooking units per building and the average power consumption for each equipment type. The best in class UEC for each equipment type is based on the highest energy reduction percentage provided by ADL (1993) when certain energy saving technologies (see Section 5.3) are applied to a particular cooking equipment type.

Table 92: Overview of Cooking Equipment average power consumption and usage in Food Service buildings

Equipment Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Building Energy Savings Potential (TWh/yr)
Broilers	0.8	27	29,000	14	0.11
Fryers	1.8	250	7,300	10	0.16
Griddles	1.6	150	11,000	10	0.12
Ovens	2.7	130	20,000	13	0.44
Ranges	0.4	27	15,000	8	0.04
Steamers	2.2	200	11,000	15	0.34

Annual Energy Consumption

The AEC for each cooking equipment type in food service buildings is calculated by multiplying its respective UEC with its installed base. The installed base is calculated from the number of units in each building type from ADL (1993) and the number of buildings of that type from CBECS (EIA 2006). In the case of food service buildings, ADL (1993) has indicated that there is a substantial amount of all types of cooking equipment. The total AEC is a sum of the AECs of each cooking equipment type in food service buildings.

References

ADL, 1993, “Characterization of Commercial Building Appliances,” Final Report to the Building Equipment Division Office of Building Technologies, U.S. Department of Energy, June.

EIA, 2006, “2003 Commercial Buildings Energy Consumption Survey (CBECS),” CBECS Public Use Microdata Files," Download from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html on August 2009.

6.4.2 *Ice Machines*

Table 93: Detailed findings for Ice Machines in Food Service Buildings

	Comments/Values
AEC (TWh/yr)	2.8
Installed Base	340,000
Units per 100,000 Sq Ft	21
UEC (kWh/yr)	8,100
UEC Variability	Highly varying usage patterns. Choice of storage capacity and smaller unit w/high duty cycle vs large unit w/low duty cycle makes big impact on UEC.
Best in Class	24% Savings from typical unit (6200 kWh/yr UEC)
Food Service Energy Savings Potential	0.7 TWh/yr
Food Service Trends and Notes	~2lbs ice per person in restaurant and ~3 lbs per seat in a bar (Monkey-Dish, 2009 and IceMachineMaker, 2009)

Unit Energy Consumption

See Section 6.3.4 for general information regarding ice machine UEC data, as listed under food sales buildings. Multiple sources indicate that in food service buildings, users should anticipate 2 lbs of ice per person in restaurants and 3 lbs per seat in a bar (MonkeyDish, 2009 and Ice Machine Maker, 2009).

Table 84 summarizes the usage characteristics for ice machines in both food service and food sales buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all food service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 340,000 ice machines in food service buildings (EIA, 2006) consume 2.6 TWh/yr of electricity.

To obtain the installed base for this calculation, TIAX assumed that the percentage of ice machines in each building type has not changed since the ADL estimates in 1991 (ADL, 1991). To update the value over the 18 years that have passed since that data was gathered, TIAX used a compound annual growth rate of 0.75%, which is an approximation of the growth rate of the number of commercial buildings in the same time period.

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ADL, 1991, "*Characterization of Commercial Building End-Uses Other Than HVAC and Lighting*," Arthur D. Little for DOE, September, 1991.

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MonkeyDish, 2009, "*Ice Machines and Dispensers,*" Downloaded on Sept 21, 2009 form http://www.monkeydish.com/2007061322343/buying-stories/ice-machines-and-dispensers.html

6.4.3 Monitors

Table 94: Detailed findings for Monitors in Food Service buildings.

	Comments/Values
AEC (TWh/yr)	0.5
Installed Base (1000s)	3,000
Units per 100,000 ft^2	180
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% savings from typical unit (60 kWh/yr UEC)
Food Service Energy Savings Potential	0.3 TWh/yr
Food Service Trends and Notes	

For discussion, see Section 6.1.3.

6.4.4 Personal Computers (PCs)

Table 95: Detailed findings for PCs (Desktops & Notebooks) in Food Service buildings.

	Comments/Values
AEC (TWh/yr)	1.3
Installed Base (1000s)	3,000
Units per 100,000 ft^2	180
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% savings from typical unit (95 kWh/yr UEC)

	Comments/Values
Food Service Energy Savings Potential	1 TWh/yr
Food Service Trends and Notes	

For discussion, see Section 6.1.5.

6.4.5 Refrigeration

Table 96: Summary of Refrigeration in Food Service Buildings

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
63.5	20.4	Walk-in and commercial units

Estimates are based on 2003 CBECS data.

6.4.5.1 Refrigeration – Commercial Units

Table 97: Detail of Commercial Refrigeration in Food Service buildings

	Comments/Values
AEC (TWh/yr)	2.9
Installed Base	740,000 (EIA, 2006)
Units per 100,000 Sq Ft	45
UEC (kWh/yr)	3,900 (weighted average of coolers and freezers)
UEC Variability	Significantly larger size range than residential units. Large units can contain 6+ doors and have UEC that is dramatically higher than avg.
Best in Class	62% Savings from typical unit (2400 kWh/yr UEC)
Food Service Energy Savings Potential	1.8 TWh/yr
Food Service Trends and Notes	Used in every restaurant – often one cooler and one freezer.

Unit Energy Consumption

See Section 6.1.6.2 for commercial unit coolers/freezers UEC data as listed under office buildings.

Annual Energy Consumption

The AEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 740,000 Commercial unit coolers and freezers in food service buildings (EIA, 2006) consume 2.9 TWh/yr.

6.4.5.2 Refrigeration – Walk-in

Table 98: Detail of Walk-in Refrigeration in Food Service Buildings

	Comments/Values
AEC (TWh/yr)	7.2
Installed Base	380,000 (EIA, 2006)
Units per 100,000 Sq Ft	23
UEC (kWh/yr)	19,000 (weighted avg of coolers/freezers/combinations)
UEC Variability	Systems can vary dramatically depending on size/temperature needed. Variation in Food Service may have larger impact than expected
Best in Class	62% Savings from typical unit (7,200 kWh/yr UEC ADL, 1996)
Food Service Energy Savings Potential	4.5 TWh/yr
Food Service Trends and Notes	A staple to all food service businesses – often one cooler and one freezer in each

Unit Energy Consumption

See Section 6.2.7.1 for walk-in refrigeration UEC data, as listed under retail and service buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 380,000 walk-in refrigeration units in food service buildings in the US (EIA, 2006) consume 7.2 TWh/yr.

References

ADL, 1996, "Energy Savings Potential for Commercial Refrigeration Equipment", Arthur D. Little for DOE, June 1996

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

6.4.6 Televisions

Table 99: Detailed findings for Televisions in Food Service Buildings

	Comments/Values

	Comments/Values
AEC (TWh/yr)	1.3
Installed Base (1,000s)	1.4
Units per 100,000 ft^2	84
UEC (kWh/yr)	940
UEC Variability	High based on active usage and screen size
Best in Class UEC	25% savings from typical unit (700 kWh/yr UEC)
Food Service Energy Savings Potential	0.3 TWh/yr
Food Service Trends and Notes	Generally large screen; high usage; flat panel displays makes more screen installations possible

Unit Energy Consumption

The unit energy consumption for televisions is generally dominated by active mode, and the active mode power draw is mainly a function of screen area. In food service buildings, there is very little data regarding the installed base, power draw, or usage of televisions. TIAX has estimated that installed TVs are generally digital TVs (DTVs) in restaurants and bars, and the average UEC was calculated to be 940 kWh/yr. This is the UEC corresponding to an average 40 inch flat panel DTV, about 250 W, operating for 8 hours per day. Installed televisions are estimated to consume 4 W in off mode, but this assumption has little impact on the UEC estimates. As with DTVs in other commercial buildings, there is little data to support the UEC calculations, and the estimates are based mainly on anecdotal evidence.

Annual Energy Consumption

The installed base of TVs in food service buildings was estimated by assuming that there is one TV per 1,000 square feet of floor area in restaurants, excluding fast food restaurants and cafeterias. This results in an installed base of 1.4 million TVs which consume 1.3 TWh/yr.

References

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/ .

TIAX, 2008, "Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2006 and Scenario-based Projections for 2020," Final Report by TIAX LLC for the U.S. Department of Energy, Building Technologies Program, April

TIAX, 2007, "Energy Consumption by Consumer Electronics (CE) in U.S. Residences," Final Report by TIAX LLC to the Consumer Electronics Association (CEA), January

6.5 Education

Key MELs for education buildings are shown in Figure 38. The total annual energy consumption for key MELs in education buildings is almost 40 TWh/yr.

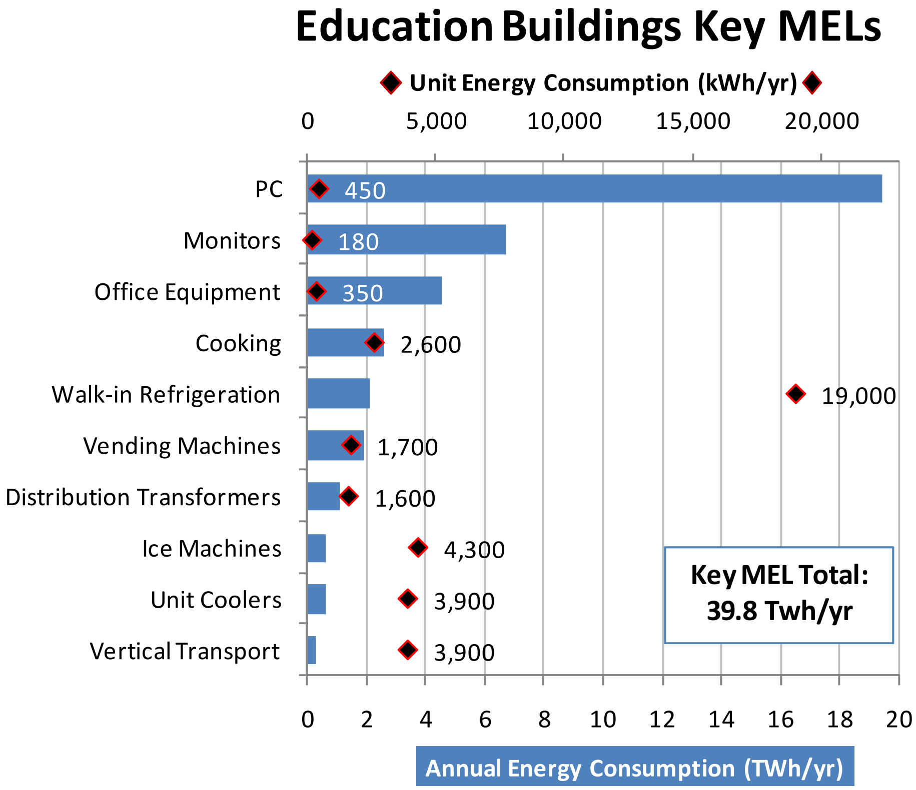

Figure 43: Key MELs for education buildings

6.5.1 *Cooking Equipment*

Table 100: Detailed findings for Cooking Equipment in Education buildings.

	Comments/Values
AEC (TWh/yr)	2.6
Installed Base (1000s)	1,000
Units per 100,000ft^2	10
UEC (kWh/yr)	2,600
UEC variability	Varying usage patterns as well as number of units per establishment based on 1993 data. Appreciable uncertainty of the number of gas-fired equipment versus electric. No standard method to determine equipment efficiency.
Best in Class	13% Savings from typical unit (2,300 kWh/yr UEC)

	Comments/Values
Education Energy Savings Potential	0.3 TWh/yr
Education Trends and Notes	The low AEC is attributed to the low usage of equipment in education buildings which primarily only occurs during meal time. For example, cafeterias in high schools are open only during lunch time.

Unit Energy Consumption

The UEC and best in class UEC are calculated based on weighted averages of each cooking equipment type respectively. Summarized in the table below, ADL (1993) estimates the number of cooking units per building and the average power consumption for each equipment type. The best in class UEC for each equipment type is based on the highest energy reduction percentage provided by ADL (1993) when certain energy saving technologies (see Section 5.3) are applied to a particular cooking equipment type.

Table 101: Overview of Cooking Equipment average power consumption and usage in Education buildings

Equipment Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Education Energy Savings Potential (TWh/yr)
Broilers	0.1	17	4,300	15	0.01
Fryers	0.2	160	1,000	10	0.02
Griddles	0.3	190	1,600	9	0.03
Ovens	1.3	350	3,800	15	0.18
Ranges	0.1	35	1,900	11	0.01
Steamers	0.7	260	2,700	15	0.10

Annual Energy Consumption

The AEC for each cooking equipment type in education buildings is calculated by multiplying its respective UEC with its installed base. The installed base is calculated from the number of units in each building type from ADL (1993) and the number of buildings of that type from CBECS (EIA, 2006). In the case of education buildings, ADL (1993) has indicated that there is a substantial amount of all types of cooking equipment. The total AEC is a sum of the AECs of each cooking equipment type in education buildings.

References

ADL, 1993, “Characterization of Commercial Building Appliances,” Final Report to the Building Equipment Division Office of Building Technologies, U.S. Department of Energy, June.

EIA, 2006, “2003 Commercial Buildings Energy Consumption Survey (CBECS),” CBECS Public Use Microdata Files," Download from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html on August 2009.

6.5.2 Distribution Transformers

Table 102: Detailed findings for Distribution Transformers in Education buildings

	Comments/Values
AEC (TWh/yr)	1.1
Installed Base (1000s)	690
Units per 100,000ft^2	7.0
UEC (kWh/yr)	1600
UEC variability	Efficiency primarily affected by rated capacity, average load and temperature. Capacity varies significantly while avg load remains relatively consistent according to Cadmus Group (1999).
Best in Class	20% Savings from typical unit (1,300 kWh/yr UEC)
Education Energy Savings Potential	0.2 TWh/yr
Education Trends and Notes	Typical dry-type distribution transformers are found in commercial buildings which are less efficient than liquid-immersed type.

For discussion, see Section 6.1.2.

6.5.3 Ice Machines

Table 103: Detailed findings for Distribution Transformers in Education buildings

	Comments/Values
AEC (TWh/yr)	0.6
Installed Base	140,000
Units per 100,000 Sq Ft	1.4
UEC (kWh/yr)	4,300
UEC Variability	Highly varying usage patterns. Choice of storage capacity and smaller unit w/high duty cycle vs large unit w/low duty cycle makes big impact on UEC.
Best in Class	24% Savings from typical unit (3200 kWh/yr UEC)
Education Energy Savings Potential	0.1 TWh/yr
Education Trends and Notes	Used mainly for food service in education buildings

Unit Energy Consumption

See Section 6.3.4 for general information regarding ice machine UEC data, as listed under food sales. Unlike food sales Buildings, however, ice machines in education buildings tend to be lower capacity. TIAX assumes that the average daily capacity is approximately 500 lbs. Analysis of various AHRI certified units indicates that, as with the majority of units rated for greater than 280 lbs per day, the energy consumption is relatively flat at a function of unit capacity at 5.2 kWh/100 lbs of ice. Using these assumptions, the UEC is 4300 kWh/yr.

Table 104 summarizes the usage characteristics that are used for ice machines in education buildings in this study.

Table 104: TIAX usage assumptions for Ice Machines in Education Buildings

Usage Variable	Units	Value
Annual Duty Cycle	%	45
Daily Harvest	Lbs	500
Energy Consumption	kWh/100 lbs	5.2

Annual Energy Consumption

The UEC is assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC.

To obtain the installed base for this calculation, TIAX assumed that the percentage of ice machines in each building type has not changed since the ADL estimates in 1991 (ADL, 1991). To update the value over the 18 years that have passed since that data was gathered, TIAX used a compound annual growth rate of 0.75%, which is an approximation of the growth rate of the number of commercial buildings in the same time period.

References

ADL, 1991, "Characterization of Commercial Building End-Uses Other Than HVAC and Lighting," Arthur D. Little for DOE, September, 1991.

6.5.4 Monitors

Table 105: Detailed findings for Monitors in Education buildings.

	Comments/Values
AEC (TWh/yr)	6.7
Installed Base (1000s)	38,000
Units per 100,000ft^2	390
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types

	Comments/Values
Best in Class	66% Savings from typical unit (60 kWh/yr UEC)
Education Energy Savings Potential	4.4 TWh/yr
Education Trends and Notes	Monitor usage patterns and installed base are highly correlated with that of desktop PCs. Office buildings will continue to see the highest concentration of monitors.

For discussion, see Section 6.1.3.

6.5.5 Office Equipment

Table 106: Detailed findings for Office Equipment in Education buildings.

	Comments/Values
AEC (TWh/yr)	4.5
Installed Base (1000s)	14,000
Units per 100,000ft^2	140
UEC (kWh/yr)	350
UEC variability	Varying usage patterns. Mode of operations varies among types of office equipment. UEC for an “office equipment is calculated” using a weighted average of the UEC each type of office equipment
Best in Class	85% Savings from typical unit
Education Energy Savings Potential	3.8 TWh/yr
Education Trends and Notes	Office equipment is PC-centric. Most common in office areas and computer labs and libraries.

Table 107: Breakdown of Printers in Education buildings

Unit Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Building Energy Savings Potential (TWh/yr)
Printers	2.8	8,500	380	88	2.5
Copiers	0.7	940	710	73	0.5
Multifunctional Devices	0.09	1,500	59	87	0.08
Scanners	0.03	890	35	47	0.02
Fax Machines	0.07	1,400	53	59	0.04

Unit Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Building Energy Savings Potential (TWh/yr)
Servers	0.8	380	2,200	86	0.7

For discussion, see Section 6.1.4.

6.5.6 Personal Computers (PCs)

Table 108: Detail of PCs (Desktops & Notebooks) in Education buildings.

	Comments/Values
AEC (TWh/yr)	19.4
Installed Base (1000s)	44,000
Units per 100,000ft^2	450
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktops and notebooks
Best in Class	79% Savings from typical unit (95 kWh/yr UEC)
Education Energy Savings Potential	15 TWh/yr
Education Trends and Notes	It is like that education buildings will continue to see the second highest concentration of PCs.

For discussion, see Section 6.1.5.

6.5.7 Refrigeration

Table 109: Summary of Refrigeration in Education Buildings

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
108.8	4.6	Walk-in and commercial units

Estimates are based on 2003 CBECS data.

6.5.7.1 Refrigeration – Commercial Units

Table 110: Detailed findings for Commercial Refrigeration in Education Buildings

	Comments/Values
AEC (TWh/yr)	0.6
Installed Base	160,000 (EIA, 2006)
Units per 100,000 Sq Ft	1.6
UEC (kWh/yr)	3,900 (weighted average of coolers and freezers)
UEC Variability	Significantly larger size range than residential units. Large units can contain 6+ doors and have UEC that is dramatically higher than avg.
Best in Class	62% Savings from typical unit (2400 kWh/yr UEC)
Education Energy Savings Potential	0.4 TWh/yr
Education Trends and Notes	Often associated with cafeterias or food courts within the education building. Some are used in lab space

Unit Energy Consumption

See Section 6.1.6.2 for commercial unit coolers/freezers UEC data, as listed under office buildings.

Annual Energy Consumption

The AEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 160,000 Commercial unit coolers and freezers in education buildings (EIA, 2006) consume 0.6 TWh/yr.

6.5.7.2 Refrigeration – Walk-in

Table 111: Summary for Walk-in Refrigeration in Education Buildings

	Comments/Values
AEC (TWh/yr)	2.1
Installed Base	110,000 (EIA, 2006)
Units per 100,000 Sq Ft	1.1
UEC (kWh/yr)	19,000 (weighted avg of coolers/freezers/combinations)
UEC Variability	Systems can vary dramatically depending on size and temperature needed. TIAX assumes similar usage to food service units, but independent confirmation of assumption is unavailable.
Best in Class	62% Savings from typical unit (7,200 kWh/yr UEC ADL, 1996)

	Comments/Values
Education Energy Savings Potential	1.3 TWh/yr
Education Trends and Notes	Used mainly for food service, but sometime for science and lab related activities.

Unit Energy Consumption

See Section 6.2.7.1 for walk-in refrigeration UEC data as listed under retail and service buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 110,000 walk-in refrigeration units in education buildings in the US (EIA, 2006) consume 2.1 TWh/yr.

References

ADL, 1996, "Energy Savings Potential for Commercial Refrigeration Equipment", Arthur D. Little for DOE, June 1996

EIA, 2006, "Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

6.5.8 Vending Machines

Table 112: Detailed findings for Vending Machines in Education Buildings

	Comments/Values
AEC (TWh/yr)	1.9 (1.4 refrig. & 0.5 non-refrig)
Installed Base	1,100,000 (390,000 refrig. & 730,000 non-refrig.)
Units per 100,000 Sq Ft	11
UEC (kWh/yr)	1700 (weighted avg of refrigerated / non-refrigerated)
UEC Variability	Units in employee areas may have concentrated use at certain times – public units have more continuous usage
Best in Class	33% savings for refrigerated and 50% savings for non-refrigerated (1000 kWh/yr UEC)
Education Energy Savings Potential	0.7 TWh/yr
Education Trends and Notes	Potentially higher energy saving due to regular traffic schedule that occurs with regular class timetable. Highest vending concentration of any building category.

Unit Energy Consumption

See Section 6.1.1 for vending machine UEC data, as listed under office buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. Therefore, the AEC is calculated as the sum of the installed base multiplied by the UEC for each vending machine type. The 1.7 million vending machines in retail and service buildings (EIA, 2006) consume 2.9 TWh/yr of electricity.

The installed base used in these calculations for refrigerated units is the CBECS estimate from 2003 (EIA, 2006). While broadly defined as "vending machines" in the refrigeration section of the CBECS data, it is assumed that users would respond to the survey with the number of refrigerated units due to the structure and nature of the questions (EIA, 2006). Because CBECS does not explicitly categorize non-refrigerated units, estimates for installed base were calculated as a growth adjusted estimate from ADL (ADL, 1991). For consistency sake, the percentage of total units in each category was maintained across refrigerated and non-refrigerated units. (The units/building however was not maintained such that the total installed base in the US could grow appropriately.)

References

ADL, 1991, "*Characterization of Commercial Building End-Uses Other Than HVAC and Lighting,"* Arthur D. Little for DOE, September, 1991.

EIA, 2006, "Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

6.5.9 Vertical Transport – Elevators and Escalators

Table 113: Detailed findings for Vertical Transport in Education Buildings

	Elevators	Escalators
AEC (TWh/yr)	0.3	~ 0
Installed Base (1,000s)	80	1
Units per 100,000 ft^2	0.8	~ 0
UEC (kWh/yr)	3,600	20,000
UEC Variability	High variability based on usage and elevator type	High based on variability in usage and escalator rise
Best in Class	30% savings from typical unit (2,500 kWh/yr UEC)	30% savings from typical unit (14,000 kWh/yr UEC)
Education Energy Savings Potential	0.1 TWh/yr	~ 0
Education Trends and Notes		

Unit Energy Consumption

The UEC for elevators is based on the breakdown of low-, medium-, and high-rise buildings for the particular building type, an assumed elevator type, average energy consumption per elevator start, and number of elevator starts per year. For education buildings, the UEC was calculated to be 3,600 kWh/yr, as shown in Table 114.

Table 114: Calculation of the average UEC of elevators in education buildings

	# Floors	# of buildings w/ elevators	# of Elevators	Avg. Starts/year	Avg. (kWh/start)	UEC (kWh/yr)
Low-rise	<7	50,000	78,000	200,000	0.017	3,400
Mid-rise	7-24	1,000	2,000	400,000	0.026	10,400
High-rise	25+	0	0	500,000	0.017	8,500
Weighted Avg.			80,000			3,600
Comments/ Sources		EIA, 2006	EIA, 2005 scaled to 2008	Enermodal, 2004	Enermodal, 2004	

The UEC for escalators is calculated based on an escalator energy formula derived by an industry expert. (Al-Sharif 1997) The model was developed from actual measurements of in situ escalator rise, usage, and energy consumption. The model outputs energy as a function of escalator rise and operating time. The average escalator rise based on a distribution of rises for a sample of in situ escalators. (Enermodal 2004) TIAX estimates the average usage to be approximately twelve hours per day. It is also assumed that there is an equal number of up and down escalators installed in buildings.

Annual Energy Consumption

In education buildings, there are 80,000 elevators and 1,000 escalators installed, which consume 0.3 and 0.03 TWh/yr, respectively.

References

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/ .

Enermodal Engineering Limited, 2004, "Market Assessment for Energy Efficient Elevators and Escalators," Report for the Office of Energy Efficiency, Natural Resources Canada, September.

Al-Sharif, L., 1997, "The General Theory of Escalator Energy Consumption," *Lift Report*, May/June.

6.6 Warehouse

Unlike other building types, warehouses tend to be focused in terms of the variety of electric loads used in the building. In refrigerated warehouses, the largest load is often the refrigeration system. Other common loads include lighting and transport vehicle such as forklifts. Often small offices are included in warehouses that may include PCs, monitors, fax machines, printers, vending machines and other office equipment. Besides office space, warehouses do not generally have other building activities mixed in such as retail; they are generally stand alone buildings that are located in industrial zoned areas or other more economically favorable sections of cities that have less commercial activity.

The largest warehouses can be more than one million square feet in size and if they are refrigerated, they can have annual energy intensities on the order of tens of kWh/sq ft. CBECS found that of the more than 13 Terawatt-hours of electricity used in refrigerated warehouses every year, almost 8 Terawatt-hours are for refrigeration (EIA, 2006). Key MELs for warehouse buildings are shown in Figure 44. The total annual energy consumption for key MELs in warehouse buildings is almost 16 TWh/yr.

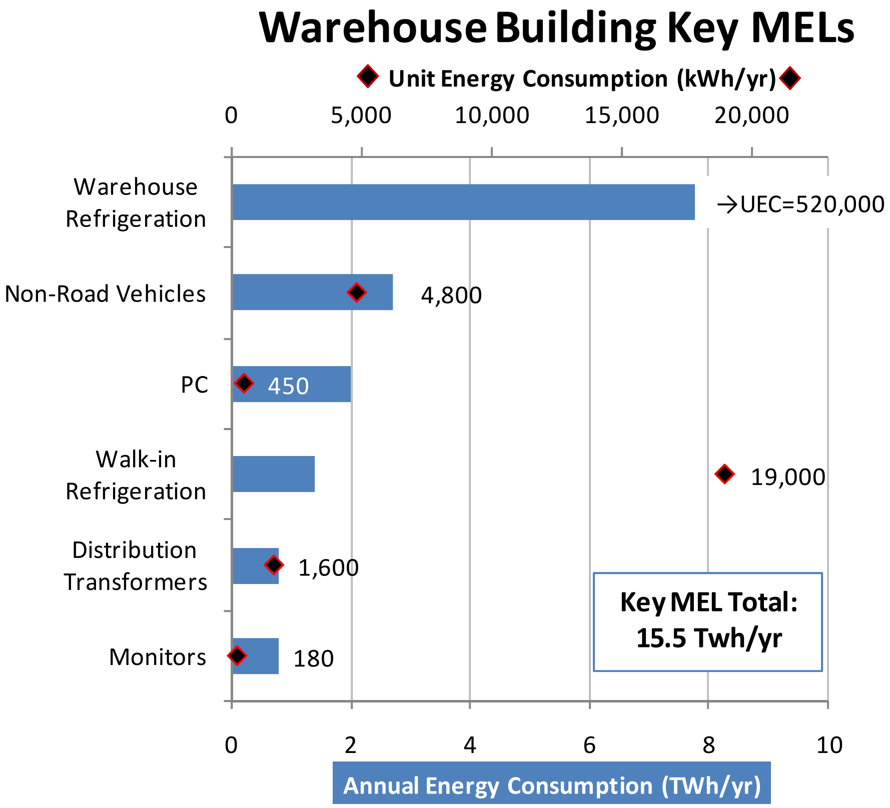

Figure 44: Key MELs for warehouse buildings

6.6.1 Distribution Transformers

Table 115: Detailed findings for Distribution Transformers in Warehouse buildings

	Comments/Values

	Comments/Values
AEC (TWh/yr)	0.8
Installed Base (1000s)	490
Units per 100,000ft^2	4.9
UEC (kWh/yr)	1600
UEC variability	Efficiency primarily affected by rated capacity, average load and temperature. Capacity varies significantly while avg load remains relatively consistent according to Cadmus Group (1999).
Best in Class	20% Savings from typical unit (1,300 kWh/yr UEC)
Warehouse Energy Savings Potential	0.16 TWh/yr
Warehouse Trends and Notes	Typical dry-type distribution transformers are found in commercial buildings which are less efficient than liquid-immersed type.

For discussion, see Section 6.1.2.

6.6.2 Monitors

Table 116: Detailed findings for Monitors in Warehouse buildings.

	Comments/Values
AEC (TWh/yr)	0.8
Installed Base (1000s)	4,400
Units per 100,000 ft^2	44
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% savings from typical unit (60 kWh/yr UEC)
Warehouse Energy Savings Potential	0.5 TWh/yr
Warehouse Trends and Notes	

For discussion, see Section 6.1.3.

6.6.3 *Non-road Vehicles*

Table 117: Detailed findings for Non-road vehicles in Warehouse Buildings

	Values	Comments
AEC (TWh/yr)	2.7	
Installed Base (millions)	0.58	Installed base of lift trucks; ITA (2006), EPRI (1997)
Units per 100,000 ft^2	5.7	
UEC (kWh/yr)	4750	UEC for lift trucks (TIAX 2005)
UEC Variability		
Best in Class	unclear	
Warehouse Energy Savings Potential	unclear	
Warehouse Trends and Notes		

Annual Energy Consumption

Based on the UEC and installed base estimate for lift trucks, the estimated AEC for non-road vehicles in warehouses is 2.7 TWh/yr. If there is a shift in the future to more fuel cell fork lifts, a target market for fuel cells, the *electric* energy consumption of non-road vehicles would be reduced.

References

EPRI, 1997, "Electric Lift Trucks: Market Description and Business Opportunities," EPRI Final Report, EPRI TR-109189, November.

ITA, 2006, "History of U.S. Shipments," Data Downloaded on 5 May, 2006 from the Industrial Truck Association Website, http://www.indtrk.org/marketing.asp .

TIAX, 2005, "Electric Transportation and Goods-Movement Technologies in California: Technical Brief," Report by TIAX LLC for the California Electric Transportation Coalition, October.

6.6.4 *Personal Computers (PCs)*

Table 118: Detailed findings for PCs (Desktops & Notebooks) in Warehouse buildings.

	Comments/Values
AEC (TWh/yr)	2
Installed Base (1000s)	4,500
Units per 100,000ft^2	45

	Comments/Values
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% savings from typical unit (95 kWh/yr UEC)
Warehouse Energy Savings Potential	1.6 TWh/yr
Warehouse Trends and Notes	

For discussion, see Section 6.1.5.

6.6.5 Refrigeration

Table 119: Summary of Refrigeration in Warehouses

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
71.6	10.4	Warehouse refrigeration

Estimates are based on 2003 CBECS data.

6.6.5.1 Warehouse Refrigeration

Table 120: Detailed findings for Warehouse Refrigeration in Warehouses

	Comments/Values
AEC (TWh/yr)	7.8
Installed Base	15,000 (EIA, 2006)
Units per 100,000 Sq Ft	NA – Generally one unit per building
UEC (kWh/yr)	520,000
UEC Variability	Systems can vary dramatically depending on size and temperature needed, and on climate region in which it is installed.
Best in Class	35% Savings from typical unit (390,000 kWh/yr UEC PG&E 2009)
Warehouse Energy Savings Potential	2.7 TWh/yr
Warehouse Trends and Notes	This is the only application for warehouse refrigeration (by definition)

Unit Energy Consumption

The UEC is calculated based on the installed base and refrigeration load in refrigerated warehouses by the 2003 CBECS study. Refrigerated warehouses are specifically broken out as a building type in the survey, so using 99% of the refrigeration load (~7.9 TWh/yr) and dividing by the total number of buildings (15,000) gives a UEC of approximately 520,000 kWh/yr (EIA, 2006).

The other 1% of electricity used for refrigeration in warehouses (~.1TWh/yr) is for various other uses such as compact residential units in small offices that may be part of the building. CBECS found that 1048 of the refrigerated warehouses has residential refrigerators in the building, and that of these buildings, they each had ~2 units each.

Annual Energy Consumption

CBECS found that there are 15,000 refrigerated warehouses in the United States which collectively consume 7.9 TWh/yr of electricity for all refrigeration. Approximately 99%, or 7.8 TWh/yr, is believed to be from central warehouse refrigeration systems. Table 121, shown below, gives a comparison of refrigeration data between refrigerated and non-refrigerated warehouses.

Table 121: Refrigerated vs. Non-refrigerated warehouse energy consumption comparison

	Non-Refrigerated	Refrigerated	All Warehouses
Number of Buildings	580,000	15,000	595,000
Total Electricity Use (TWh/yr)	59	13	72
Electricity use for Refrigeration (TWh/yr)	2.5	7.9	10.4
Qty Buildings with Refrigeration	210,000	15,000	225,000
Electricity for refrig - density (kWh/ft^2)	0.3	15	1.0

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6.7 Healthcare

Key MELs for healthcare buildings are shown in Figure 45. The total annual energy consumption for key MELs in healthcare buildings is about 31 TWh/yr.

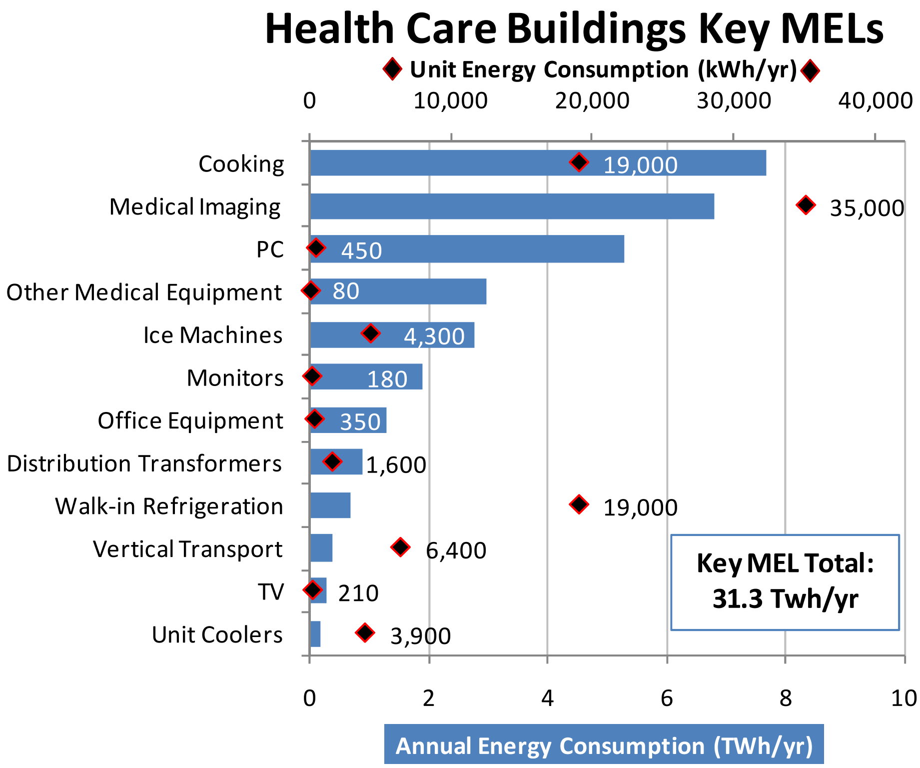

Figure 45: Key MELs for healthcare buildings

6.7.1 Distribution Transformers

Table 122: Detailed findings for Distribution Transformers in Healthcare buildings

	Comments/Values
AEC (TWh/yr)	0.9
Installed Base (1000s)	570
Units per 100,000ft^2	18.0
UEC (kWh/yr)	1600
UEC variability	Efficiency primarily affected by rated capacity, average load, and temperature. Capacity varies significantly while avg load remains relatively consistent according to Cadmus Group (1999).
Best in Class	20% Savings from typical unit (1,300 kWh/yr UEC)
Healthcare Energy Savings Potential	0.18 TWh/yr

	Comments/Values
Healthcare Trends and Notes	Typical dry-type distribution transformers are found in commercial buildings which are less efficient than liquid-immersed type.

For discussion, see Section 6.1.2.

6.7.2 Ice Machines

Table 123: Detailed findings for Ice Machines in Healthcare Buildings

	Comments/Values
AEC (TWh/yr)	2.8
Installed Base	650,000
Units per 100,000 Sq Ft	22
UEC (kWh/yr)	4300
UEC Variability	Highly varying usage patterns. Choice of storage capacity and smaller unit w/high duty cycle vs large unit w/low duty cycle makes big impact on UEC.
Best in Class	24% Savings from typical unit (3200 kWh/yr UEC)
Healthcare Energy Savings Potential	0.7 TWh/yr
Healthcare Trends and Notes	Estimated usage is ~8-10 lbs per person (bed) per day (MonkeyDish, 2009)

Unit Energy Consumption

See Section 6.3.4 for general information regarding ice machine UEC data, as listed under food sales buildings. TIAX assumes that in total one unit will provide approximately 500 lbs of ice per day in healthcare facilities. Analysis of various AHRI certified units indicates that, as with the majority of units rated for greater than 280 lbs per day, the energy consumption is relatively flat as a function of unit capacity at 5.2 kWh/100 lbs of ice. Using these assumptions, the UEC is 4300 kWh/yr.

Table 124 summarizes the usage characteristics that are used for ice machines in healthcare buildings in this study.

Table 124: TIAX usage assumptions for Ice Machines in Healthcare Buildings

Usage Variable	Units	Value
Annual Duty Cycle	%	45
Daily Harvest	Lbs	500
Energy Consumption	kWh/100 lbs	5.2

Annual Energy Consumption

The UEC was assumed to be consistent across all healthcare buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 650,000 ice machines in healthcare buildings therefore consume 2.8 TWh/yr of electricity.

To obtain the installed base for this calculation, TIAX assumed that the percentage of ice machines in each building type has not changed since the ADL estimates in 1991 (ADL, 1991). To update the value over the 18 years that have passed since that data was gathered, TIAX used a compound annual growth rate of 0.75%, which is an approximation of the growth rate of the number of commercial buildings in the same time period.

References

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6.7.3 Medical Equipment

Table 125: Detailed findings for Medical Equipment in Healthcare Buildings

	MRI	CT	X-ray
AEC (TWh/yr)	0.9	1.2	4.7
Installed Base (1,000s)	9	16	170
Units per 100,000 ft^2	0.3	0.5	5.4
UEC (kWh/yr)	93,000	73,000	28,000
UEC Variability	High based on washer capacity and usage	High based on washer capacity and usage	High based on washer capacity and usage
Best in Class	40% savings (55,800 kWh/yr UEC)	unknown	unknown
Healthcare Energy Savings Potential	0.3	unknown	unknown

	MRI	CT	X-ray
Healthcare Trends and Notes	Growing installation of higher power systems, but the industry is becoming aware of energy consumption concerns in hospitals	Growing energy consumption do to growing installed base	Growing energy consumption due to installation of higher power systems and steady installed base growth

Unit Energy Consumption

The UEC for magnetic resonance imaging (MRI) equipment was calculated from estimates of power draw and usage in different operating modes. The power draw estimates are taken from product specification sheets and pre-installation manuals for 0.5 Tesla, 1.5 Tesla, and 3 Tesla MRI systems and weighted based on the installed base of each category. 1.5 Tesla systems are estimated to account for approximately half of the installed base. MRI equipment has significant cooling requirement in all modes of operation.

The active and standby mode usage values come from conversation with industry installation experts (Johnson 2006) and hospital imaging technicians (Isom 2006), as well as from estimates for the number of annual exams. (CIHI 2008)

Table 126: UEC calculation for MRI equipment

	Operating Mode	Value	Comments/Sources
Power Draw (kW)	**Active**	30	GE Healthcare (2005); GE Healthcare (2005 (2)); GE Healthcare (2002); Siemens Medical Solutions USA (2005); Bell (2004)
	Standby	14	
	Off	7	
Annual Usage (hours)	**Active**	359	Discussions wit industry experts
	Standby	3,290	Based on 70 hrs/wk less active usage (CIHI 2008)
	Off	5,110	
UEC (kWh/yr)		93,000	Calculated

The UEC for computerized tomography (CT) equipment was similarly calculated, except an average operating mode was used to approximate the active and standby operating modes. There are short pulses of high power when the systems fire, but these high power pulses only occur for very short periods of time. Therefore, standby power dominates the average operating mode. The average power draw estimate is taken from product specification sheets and pre-installation manuals for 16 slice CT scanners, which are the standard unit based on discussions with manufacturer representatives. Furthermore, 64 slice CT scanners do not seem to have an increased power requirement.

The CT equipment usage is based on an average system operating time of 58 hours per week (CIHI 2008).

Table 127: UEC calculation for CT equipment

	Operating Mode	Value	Comments/Sources
Power Draw (kW)	**Avg. Operating**	21	GE Healthcare (2006)
	Off	1.7	Siemens Medical Solutions USA (2005 (2))
Annual Usage (hours)	**Avg. Operating**	3,000	CIHI (2008)
	Off	5,760	
UEC (kWh/yr)		73,460	

The UEC for X-ray equipment was calculated using a method similar to that for CT equipment. This study accounts for larger stationary medical X-ray equipment, but does not consider smaller portable equipment or smaller dental X-ray equipment.

Table 128: UEC calculation for X-ray equipment

	Operating Mode	Value	Comments/Sources
Power Draw (kW)	**Avg. Operating**	5	GE Healthcare (2005(2)), GE Healthcare (2004)
	Off	1.7	
Annual Usage (hours)	**Avg. Operating**	4,380	Input from industry (Isom 2006)
	Off	4,380	
UEC (kWh/yr)		27,900	

Annual Energy Consumption

X-ray equipment accounts for the majority of medical imaging equipment energy consumption, mainly because of the high installed base of X-ray equipment relative to other medical imaging equipment. There are 170,000 X-ray systems consuming 4.7 TWh per year. There are 9,000 MRI systems and 16,000 CT systems, consuming 0.9 and 1.2 TWh per year, respectively. Nonetheless, the energy consumption of MRI and CT equipment has grown considerably do to the rapid installation of newer, more powerful technology. The MRI market is growing faster than radiology markets, with the number of annual exams growing between 10% and 15% per year, and the installed base of MRI systems growing 5-10% per year. Industry experts also project that 2-6 Tesla systems will gain market penetration relative to the baseline 1.5 T system.

Energy efficiency has not generally been a key parameter for medical imaging equipment, although it seems that manufacturers are becoming more aware of the concerns with healthcare building energy consumption. One manufacturer now promotes a 1.5 T MRI system that consumes 40% less energy than conventional systems, claiming efficient gradient and electronics design and more efficient cooling technology.

In addition to large medical imaging equipment, there are other medical imaging technologies not accounted for above. Ultrasound, dental x-ray, mammography, and fluoroscopy equipment, for example, are not included. Furthermore, there is an abundance of other medical equipment that consumes energy. Heart rate monitors, oto-ophthalmoscopes, hospital beds, exam tables, exam lights, sterilizers, defibrillators, IV carts, etc. are all found in healthcare buildings. It does not appear that any one device consumes a significant amount of energy, but LBNL (2004) found that miscellaneous medical equipment consumed 1,000 kWh per 1,000 square feet of floor area for a small sample of healthcare buildings. This scales to approximately 3 TWh per year for all healthcare buildings, assuming approximately 3 billion square feet for healthcare buildings. If the buildings sampled by LBNL (2004) are representative of healthcare buildings in the U.S., there may be an installed base of over 30 million miscellaneous medical devices.

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6.7.4 Monitors

Table 129: Detailed findings for Monitors in Healthcare buildings.

	Comments/Values
AEC (TWh/yr)	1.9
Installed Base (1000s)	11,000
Units per 100,000ft^2	350
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% Savings from typical unit (60 kWh/yr UEC)
Healthcare Energy Savings Potential	1.3 TWh/yr
Healthcare Trends and Notes	Monitor usage patterns and installed base are highly correlated with that of desktop PCs.

For discussion, see Section 6.1.3.

6.7.5 Office Equipment

Table 130: Detailed findings for Office Equipment in healthcare buildings.

	Comments/Values
AEC (TWh/yr)	1.3
Installed Base (1000s)	3,800
Units per 100,000ft^2	120
UEC (kWh/yr)	350
UEC variability	Varying usage patterns. Mode of operations varies among types of office equipment. UEC for an "office equipment is calculated" using a weighted average of the UEC each type of office equipment
Best in Class	85% Savings from typical unit (50 kWh/yr UEC)
Healthcare Energy Savings Potential	1.1 TWh/yr
Healthcare Trends and Notes	Office equipment is PC-centric. Most common in office areas of Healthcare facilities.

Table 131: Breakdown of Office Equipment in healthcare buildings

Unit Type	AEC	Installed	UEC	Best in Class	Healthcare Energy

	(TWh/yr)	Base (1000s)	(kWh/yr)	UEC (%)	Savings Potential (TWh/yr)
Printers	0.8	2,400	380	88	0.7
Copiers	0.2	270	710	73	0.1
Multifunction Devices	0.03	430	59	87	0.02
Scanners	0.01	250	35	47	0.004
Fax Machines	0.02	390	53	59	0.01
Servers	0.2	100	2,200	86	0.19

For discussion, see Section 6.1.4.

6.7.6 Personal Computers (PCs)

Table 132: Detailed findings for PCs (Desktops & Notebooks) in healthcare buildings.

	Comments/Values
AEC (TWh/yr)	5.3
Installed Base (1000s)	12,000
Units per 100,000ft^2	380
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% Savings from typical unit (95 kWh/yr UEC)
Healthcare Energy Savings Potential	4.2 TWh/yr
Healthcare Trends and Notes	

For discussion, see Section 6.1.5.

6.7.7 Refrigeration

Table 133: Summary of Refrigeration in Healthcare Buildings

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
72.6	2.4	Walk-in and commercial units

Estimates are based on 2003 CBECS data.

6.7.7.1 Refrigeration – Commercial Units

Table 134: Detailed findings for Commercial Refrigeration in Healthcare Buildings

	Comments/Values
AEC (TWh/yr)	0.2
Installed Base	56,000 (EIA, 2006)
Units per 100,000 Sq Ft	1.8
UEC (kWh/yr)	3,900 (weighted average of coolers and freezers)
UEC Variability	Significantly larger size range than residential units. Large units can contain 6+ doors and have UEC that is dramatically higher than avg.
Best in Class	62% Savings from typical unit (2400 kWh/yr UEC)
Healthcare Energy Savings Potential	0.1 TWh/yr
Healthcare Trends and Notes	Usage is likely similar to Food Service – Most units are probably for food related businesses in the building

Unit Energy Consumption

See Section 6.1.6.2 for commercial unit coolers/freezers UEC data as listed under office buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all healthcare buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 56,000 commercial unit coolers and freezers in healthcare buildings (EIA, 2006) consume 0.2 TWh/yr.

6.7.7.2 Refrigeration – Walk-in

Table 135: Detailed findings for Walk-in Refrigeration in healthcare Buildings

	Comments/Values
AEC (TWh/yr)	0.7

	Comments/Values
Installed Base	39,000 (EIA, 2006)
Units per 100,000 Sq Ft	1.2
UEC (kWh/yr)	19,000 (weighted avg of coolers/freezers/combinations)
UEC Variability	Systems can vary dramatically depending on size and temperature needed. Initial analysis indicates that units for medical usage are insignificant – majority are used in food areas of buildings.
Best in Class	62% Savings from typical unit (7,200 kWh/yr UEC ADL, 1996)
Healthcare Energy Savings Potential	0.5 TWh/yr
Healthcare Trends and Notes	Generally used for food service so usage is comparable to other Food Service Buildings

Unit Energy Consumption

See Section 6.2.7.1 for walk-in refrigeration UEC data as listed under retail and service buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all healthcare buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 39,000 walk-in refrigeration units in healthcare buildings in the US (EIA, 2006) consume 0.7 TWh/yr.

References

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6.7.8 Vertical Transport – Elevators and Escalators

Table 136: Detailed findings for Vertical Transport in Healthcare Buildings

	Elevators	Escalators
AEC (TWh/yr)	0.4	0.0
Installed Base (1,000s)	68	2
Units per 100,000 ft^2	2.1	0.1
UEC (kWh/yr)	6030	20,500
UEC Variability		

	Elevators	Escalators
Best in Class	30% savings from typical unit (4,200 kWh/yr UEC)	30% savings from typical unit (14,000 kWh/yr UEC)
Healthcare Energy Savings Potential	0.1 TWh/yr	~0
Healthcare Trends and Notes		

Unit Energy Consumption

The UEC for elevators is based on the breakdown of low-, medium-, and high-rise buildings for the particular building type, an assumed elevator type, an average energy consumption per elevator start, and a number of elevator starts per year. For healthcare buildings, the UEC was calculated to be 6,030 kWh/yr, as shown in Table 137.

Table 137: Calculation of the average UEC of elevators in education buildings

	# Floors	# of buildings w/ elevators	# of Elevators	Avg. Starts/year	Avg. (kWh/start)	UEC (kWh/yr)
Low-rise	<7	16,000	43,000	200,000	0.017	3,400
Mid-rise	7-24	2,000	25,000	400,000	0.026	10,400
High-rise	25+	0	0	500,000	0.017	8,500
Weighted Avg.			68,000			6,030
Comments/ Sources		EIA, 2006	EIA, 2005 scaled to 2008	Enermodal, 2004	Enermodal, 2004	

The UEC for escalators is calculated based on an escalator energy formula derived by an industry expert. (Al-Sharif 1997) The model was developed from actual measurements of in situ escalator rise, usage, and energy consumption. The model outputs energy as a function of escalator rise and operating time. The average escalator rise based on a distribution of rises for a sample of in situ escalators. (Enermodal 2004) TIAX estimates the average usage to be approximately twelve hours per day. It is also assumed that there is an equal number of up and down escalators installed in buildings.

Annual Energy Consumption

In healthcare buildings, there are 68,000 elevators and 2,000 escalators installed, which consume 0.4 and 0.04 TWh/yr, respectively.

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Al-Sharif, L., 1997, “The General Theory of Escalator Energy Consumption,” *Lift Report*, May/June.

6.8 Public AOR

Key MELs for public assembly, order, and religious (AOR) buildings are shown in Figure 46. The total annual energy consumption for key MELs in public AOR buildings is 17 TWh/yr.

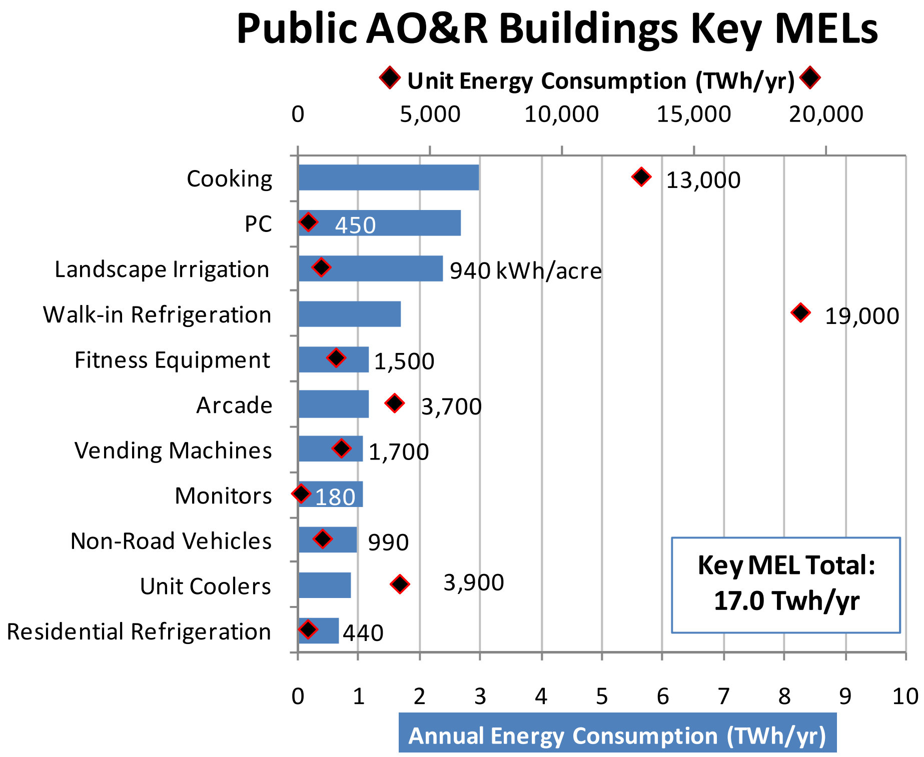

Figure 46: Key MELs for public AOR buildings

6.8.1 Arcades

Table 138: Detailed findings for Arcades in Public AOR buildings.

	Comments/Values
AEC (TWh/yr)	1.2
Installed Base (1000s)	320
Units per 100,000ft^2	4
UEC (kWh/yr)	3,700
UEC variability	High UEC variability is assumed due to varied models and types of arcade machines.
Best in Class	50% Savings from typical unit (1,850 kWh/yr UEC)
Public AOR Energy Savings Potential	0.6 TWh/yr

	Comments/Values
Public AOR Trends and Notes	Highest concentration of arcade gaming machines is in gaming centers and theme parks. Popularity of home video game consoles could negatively affect arcade installed base in commercial buildings.

Unit Energy Consumption

The computationally-intensive nature of video games to generate and display elaborate graphics is the primary reason why arcades consume an appreciable amount of energy. The energy consumption of an arcade gaming machine is estimated to about 10.2 kWh per day (NUS, 2009) and thus roughly 3,700 kWh per year. In addition, NUS (2009) also claims by fitting arcade machines with timer plugs, a savings of 1860kWh per arcade machine can be achieved. This savings is used as the baseline for the best in class unit.

Annual Energy Consumption

Estimating the number of arcade gaming machines per establishment includes an appreciable amount of uncertainty. It is assumed that arcades are predominantly found in gaming centers and theme parks and to a lesser extent in bowling centers and cinemas, all of which are considered public assembly buildings. For this study, we assume several machines in establishments such as cinemas and bowling centers and 250 machines per gaming centers and theme parks. The latter estimate is based from the fact that some of the largest gaming centers in the U.S. house around 500 arcade gaming machines (BMI Gamings, 2009). The AEC is calculated by multiplying the UEC with the estimated installed base of arcade machines, which we estimate to be around 320,000. Since a lot of games played in arcades are also available in equally powerful, home-based video game consoles, it is foreseeable that there could be a decline in arcade machines over the coming years. This could be indicative of why a major video game manufacturer reported in 2008 that their home video games segment drove sales while their arcade operations were sluggish (CAPCOM, 2009).

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6.8.2 *Fitness Equipment*

Table 139: Detailed findings for Fitness Equipment in Public AOR buildings.

	Comments/Values
AEC (TWh/yr)	1.2
Installed Base (1000s)	820
Units per 100,000ft^2	9
UEC (kWh/yr)	1,500
UEC Variability	Ratio and breakdown of various types of fitness equipment. Power consumption during standby mode.
Best in Class	50% Savings from typical unit (750 kWh/yr UEC)
Public AOR Energy Savings Potential	0.6 TWh/yr
Public AOR Trends and Notes	The highest concentration of fitness equipment will continue to be in gyms and fitness centers but could see a rise in office buildings with office gyms.

Unit Energy Consumption

When calculating UEC and best in class UEC, TIAX assumes a 1:1 ratio for treadmills and non-treadmill equipment where the latter is primary represented by elliptical trainers. The average power consumption during active mode for treadmills and elliptical trainers is about 855 Watts (Woody, 2009) and 200 Watts (Smooth Fitness, 2009) respectively. TIAX further infers a usage pattern for this equipment by looking at hours of operation and peak hours of a few commercial fitness centers. Best in class UEC is based on best in class models found for treadmills and lowest possible resistance settings for elliptical trainers.

Table 140: Breakdown of Fitness Equipment UEC and Power Consumption

Equipment Type	UEC (kWh/yr)	Best in Class UEC (kWh/yr)	Power (W)	Best in Class Power (W)
Treadmills	2400	1200	855 Active; 32 Low; 2 Off	200 Active; 32 Low; 2 Off
Elliptical trainers	560	290	413 Active; 32 Low; 2 Off	100 Active; 32 Low; 2 Off

Annual Energy Consumption

The AEC is calculated by multiply the UEC with the installed base of fitness equipment, which is deduced by obtaining the number of gyms and fitness centers in the U.S. and assuming the average number of fitness equipment per gym to be 24 (Atilano, 2006). As mentioned in Section 5.5, gyms belonging to universities and college are included in this building type and the report assumes one building housing a gym per academic institution of higher education.

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6.8.3 Landscape Irrigation

Table 141: Detailed findings for Irrigation in Public AOR buildings.

	Comments/Values
AEC (TWh/yr)	2.4
Total area to irrigate (1000s of acres)	2,600
Units per 100,000ft^2	n/a
UEC (kWh/acre/yr)	940
UEC variability	UEC variability is linked to variability of golf course acreage
Best in Class	30% Savings from typical unit (660 kWh/acre/yr)
Public Assembly Energy Savings Potential	0.7 TWh/yr
Public Assembly Trends and Notes	Golf courses make up the majority of energy consumption pertaining to irrigation in public assembly buildings.

Annual Energy Consumption

According to Staples (2009b), a typical golf course uses about 250,0000 to 500,000 kWh per year and between 25% to 50% of the electricity consumed by golf courses is used to power pumping systems to distribute water through the irrigation system. Utilizing various sources such as TheGolfcourses (2009) and EPA (2009), TIAX estimates that there are about 17,000 courses in the United States. Additionally, TIAX assumes that golf courses consume a significant majority of the energy use for irrigation in the public assembly category due to the disproportionate land area associated with courses. According to the Irrigation Association, of all fresh water used in the U.S. for the purpose of irrigation, golf courses consume 1.5% (Zoldoske, 2003). From the aforementioned parameters, TIAX estimates that the AEC of golf courses is 2.4 TWh/yr.

Unit Energy Consumption

There are approximately 17,000 golf courses as per TheGolfcourses (2009) and EPA (2009), each with an average area of 150 acres (EPA, 2009). After calculating the total AEC, the UEC was calculated (in terms of kWh per acre per yr) to be 970 kWh/acre/yr. In addition to using more efficient pumping motors and optimizing water usage, energy saving potential of about 30% can be achieved using various novel technologies such wireless sensors (Sciencedaily, 2009) and variable frequency drive (Sciencedaily, 2009).

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6.8.4 Monitors

Table 142: Detailed findings for Monitors in Public AOR buildings.

	Comments/Values
AEC (TWh/yr)	1.1
Installed Base (1000s)	6,000
Units per 100,000 ft^2	68
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% savings from typical unit (60 kWh/yr UEC)
Public AOR Energy Savings Potential	0.7 TWh/yr
Public AOR Trends and Notes	

For discussion, see Section 6.1.3.

6.8.5 Non-road Vehicles

Table 143: Detailed findings for Non-Road Vehicles in Public AOR buildings

	Values	**Comments**
AEC (TWh/yr)	1.0	Based on golf cart energy consumption at golf courses
Installed Base (millions)	1.0	Installed base of golf carts; National Golf Federation (2005), TIAX (2005), EPRI (1996)
Units per 100,000 ft^2	11	
UEC (kWh/yr)	990	UEC for golf carts, TIAX (2005)
UEC Variability		

	Values	Comments
Best in Class	33% savings from typical unit (660 kWh/yr UEC)	Golf carts with solar panel roofs
Public AOR Energy Savings Potential	0.3 TWh/yr	33% energy savings from solar power offset
Public AOR Trends and Notes		

Annual Energy Consumption

Based on the UEC and installed base estimate for golf cars, the estimated AEC for non-road vehicles in public assembly buildings is 1 TWh/yr.

References

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6.8.6 Personal Computers (PCs)

Table 144: Detailed findings for PCs (Desktops & Notebooks) in Public AOR buildings.

	Comments/Values
AEC (TWh/yr)	2.7
Installed Base (1000s)	5,500
Units per 100,000ft^2	63
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% savings from typical unit (95 kWh/yr UEC)
Public AOR Energy Savings Potential	2.1 TWh/yr
Public AOR Trends and Notes	

For discussion, see Section 6.1.5.

6.8.7 Refrigeration

Table 145: Summary of Refrigeration in Public AOR Buildings

Total Electricity Load (kWh/yr)	Total Refrigeration Load (TWh/yr)	Main Types
84.0	5.4	Walk-in and residential and commercial units

Estimates are based on 2003 CBECS data.

6.8.7.1 Refrigeration – Residential

Table 146: Detailed findings for Residential Refrigeration in Public AOR Buildings

	Comments/Values
AEC (TWh/yr)	0.7 (0.6 for full size & 0.1 for compact)
Installed Base	1,400,000 (890,000 full size & 460,000 compact)
Units per 100,000 Sq Ft	16
UEC (kWh/yr)	440 (weighted avg of full-size (660 kWh/yr) and compact (330kWh/yr))
UEC Variability	Energy consumption may be skewed in cases where ratio of full size to compact is dramatically different than expected
Best in Class	30% savings for full size and 10% for compact (360 kWh/yr UEC)
Public AOR Energy Savings Potential	0.2 TWh/yr
Public AOR Trends and Notes	Highly inconsistent usage within the building type.

Unit Energy Consumption

See Section 6.1.6.1 for residential refrigeration UEC data, as listed under office buildings.

Annual Energy Consumption

TIAX estimates that the AEC of residential refrigeration in public AOR buildings is 0.7 TWh/yr. This is based on a combination of full size units and compact units; the installed base is 890,000 units (EIA, 2006) for full size, consuming 0.6 TWh/yr, and 460,000 for compact units, consuming 0.1 TWh/yr.

6.8.7.2 Refrigeration – Commercial Units

Table 147: Detailed findings for Commercial Refrigeration in Public AOR Buildings

	Comments/Values
AEC (TWh/yr)	0.9
Installed Base	220,000 (EIA, 2006)
Units per 100,000 Sq Ft	2.5
UEC (kWh/yr)	3,900 (weighted average of coolers and freezers)
UEC Variability	Significantly larger size range than residential units. Large units can contain 6+ doors and have UEC that is dramatically higher than avg.
Best in Class	62% Savings from typical unit (2400 kWh/yr UEC)
Public AOR Energy Savings Potential	0.5 TWh/yr
Public AOR Trends and Notes	Similar usage to food service

Unit Energy Consumption

See Section 6.1.6.2 for commercial unit coolers/freezers UEC data, as listed under office buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all public AOR buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 220,000 commercial unit coolers and freezers in public AOR buildings (EIA, 2006) consume 0.9 TWh/yr.

6.8.7.3 Refrigeration – Walk-in

Table 148: Detailed findings for Walk-in Refrigeration in Public AOR Buildings

	Comments/Values
AEC (TWh/yr)	1.7
Installed Base	87,000 (EIA, 2006)
Units per 100,000 Sq Ft	1
UEC (kWh/yr)	19,000 (weighted avg of coolers/freezers/combinations)
UEC Variability	Systems can vary dramatically depending on size and temperature needed
Best in Class	62% Savings from typical unit (7,200 kWh/yr UEC - ADL, 1996)

	Comments/Values
Public AOR Energy Savings Potential	1.0 TWh/yr
Public AOR Trends and Notes	Similar usage to food service

Unit Energy Consumption

See Section 6.2.7.1 for walk-in refrigeration UEC data, as listed under retail and service buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all public AOR buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 87,000 walk-in refrigeration units in public AOR buildings in the U.S. (EIA, 2006) consume 1.7 TWh/yr.

References

ADL, 1996, "Energy Savings Potential for Commercial Refrigeration Equipment", Arthur D. Little for DOE, June 1996

EIA, 2006, "Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

6.8.8 Vending Machines

Table 149: Detailed findings for Vending Machines in Public AOR Buildings

	Comments/Values
AEC (TWh/yr)	1.1 (0.8 refrig. & 0.3 non-refrig)
Installed Base	623,000 (218,000 refrig. & 405,000 non-refrig.)
Units per 100,000 Sq Ft	7.2
UEC (kWh/yr)	1700 (weighted avg of refrigerated / non-refrigerated)
UEC Variability	Units in employee areas may have concentrated use at certain times – public units have more continuous usage
Best in Class	33% savings for refrigerated and 50% savings for non-refrigerated (1000 kWh/yr UEC)
Public AOR Energy Savings Potential	0.4 TWh/yr
Public AOR Trends and Notes	Generally has steady usage patterns over the course of a day (non concentrated like employee break-room units)

Unit Energy Consumption

See Section 6.1.1 for vending machine UEC data, as listed under office buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all retail and service buildings. The installed base used in these calculations for refrigerated units is the CBECS estimate from 2003 (EIA, 2006). While broadly defined as “vending machines” in the refrigeration section of the CBECS data, it is assumed that users would respond to the survey with the number of refrigerated units due to the structure and nature of the questions (EIA, 2006). Because CBECS does not explicitly categorize non-refrigerated units, estimates for installed base were calculated as a growth adjusted estimate from ADL (ADL, 1991). For consistency sake, the percentage of total units in each category was maintained across refrigerated and non-refrigerated units. (The units/building however was not maintained such that the total installed base in the US could grow appropriately.)

References

ADL, 1991, “*Characterization of Commercial Building End-Uses Other Than HVAC and Lighting,*” Arthur D. Little for DOE, September, 1991.

EIA, 2006, “Commercial Building Energy Consumption Survey”, DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

6.9 Lodging

Key MELs for lodging buildings are shown in Figure 47. The total annual energy consumption for key MELs in lodging buildings is about 27 TWh/yr.

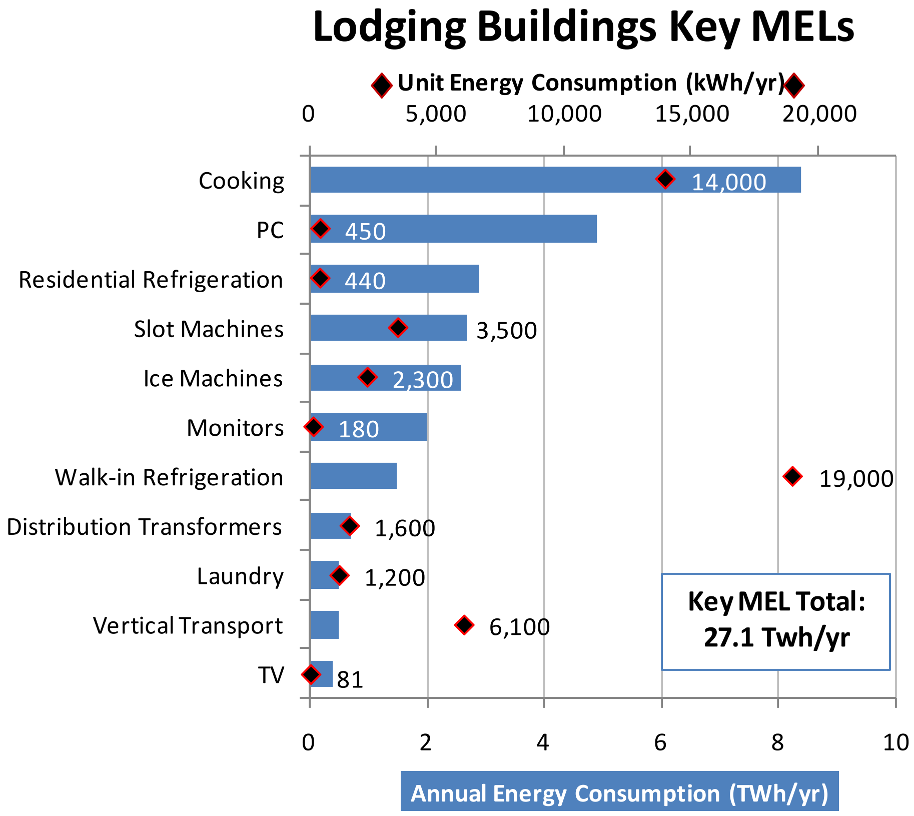

Figure 47: Key MELs for lodging buildings

6.9.1 Cooking Equipment

Table 150: Detailed findings for Cooking Equipment in Lodging buildings.

	Comments/Values
AEC (TWh/yr)	8.4
Installed Base (1000s)	610
Units per 100,000ft^2	12
UEC (kWh/yr)	14,000
UEC variability	Varying usage patterns as well as number of units per establishment based on 1993 data. Appreciable uncertainty of the number of gas-fired equipment versus electric. No standard method to determine equipment efficiency
Best in Class	14% Savings from typical unit (12,000 kWh/yr UEC)

	Comments/Values
Lodging **Energy Savings Potential**	1.2 TWh/yr
Lodging **Trends and Notes**	Lodging has the second highest AEC which can be attributed to the fact that a lot of lodging establishments as a kitchen or even full service restaurants to prepare food for guests.

Unit Energy Consumption

The UEC and best in class UEC are calculated based on weighted averages of each cooking equipment type. Summarized in the table below, ADL (1993) estimates the number of cooking equipment units per building and the average power consumption for each equipment type. The best in class UEC for each equipment type is based on the highest energy reduction percentage provided by ADL (1993) when certain energy saving technologies (see Section 5.3) are applied to a particular cooking equipment type.

Table 151: Breakdown of Cooking Equipment average power consumption and usage in Lodging buildings

Equipment Type	AEC (TWh/yr)	Installed Base (1000s)	UEC (kWh/yr)	Best in Class UEC (%)	Lodging Energy Savings Potential (TWh/yr)
Broilers	0.4	13	29,000	14	0.05
Fryers	0.9	120	7,300	10	0.08
Griddles	0.8	71	11,000	10	0.08
Ovens	3.9	190	20,000	13	0.60
Ranges	0.4	26	15,000	8	0.03
Steamers	2.1	190	11,000	15	0.33

Annual Energy Consumption

The AEC for each type of cooking equipment in lodging buildings is calculated by multiplying its respective UEC with its installed base. The installed base is calculated from the number of units in each building type from ADL (1993) and the number of buildings of that type from CBECS (EIA 2006). In the case of lodging buildings, ADL (1993) has indicated that there is a substantial amount of all types of cooking equipment. The total AEC is a sum of the AECs of each cooking equipment type in lodging buildings.

References

ADL, 1993, “Characterization of Commercial Building Appliances,” Final Report to the Building Equipment Division Office of Building Technologies, U.S. Department of Energy, June.

EIA, 2006, “2003 Commercial Buildings Energy Consumption Survey (CBECS),” CBECS Public Use Microdata Files," Downloaded from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html on August 2009.

6.9.2 *Distribution Transformers*

Table 152: Detailed findings for Distribution Transformers in Lodging buildings

	Comments/Values
AEC (TWh/yr)	0.7
Installed Base (1000s)	440
Units per 100,000ft^2	8.6
UEC (kWh/yr)	1600
UEC variability	Efficiency primarily affected by rated capacity, average load and temperature. Capacity varies significantly while avg load remains relatively consistent according to Cadmus Group (1999).
Best in Class	20% Savings from typical unit (1,300 kWh/yr UEC)
Lodging Energy Savings Potential	0.14 TWh/yr
Lodging Trends and Notes	Typical dry-type distribution transformers are found in commercial buildings which are less efficient than liquid-immersed type.

For discussion, see Section 6.1.2.

6.9.3 *Ice Machines*

Table 153: Detailed findings for Ice Machines in Lodging Buildings

	Comments/Values
AEC (TWh/yr)	2.6
Installed Base	1,100,000
Units per 100,000 Sq Ft	22
UEC (kWh/yr)	2300
UEC Variability	Highly varying usage patterns. Choice of storage capacity and smaller unit w/high duty cycle vs large unit w/low duty cycle makes big impact on UEC.
Best in Class	24% Savings from typical unit (1800 kWh/yr UEC)
Lodging Energy Savings Potential	0.6 TWh/yr
Lodging Trends and Notes	Daily lbs ice = 6 per room serviced by unit (Manitowoc, 2009)

Unit Energy Consumption

See Section 6.3.4 for general information regarding ice machine UEC data, as listed under food sales buildings. Unlike food sales buildings, however, ice machines in lodging buildings tend to be lower capacity. Manitowoc, an ice machine manufacturer based in Wisconsin, USA, recommends six pounds per room that is serviced by the unit (Manitowoc, 2009). TIAX estimates that the average unit services 25 rooms, thereby requiring a capacity of 150 lbs per day. Analysis of various AHRI certified units indicates that a unit of that size consumes approximately 9.5 kWh/100 lbs of ice. Using these assumptions, the UEC is 2300 kWh/yr.

Table 155 summarizes the usage characteristics that are used for ice machines in lodging buildings in this study.

Table 154: TIAX usage assumptions for Ice Machines in Lodging Buildings

Usage Variable	Units	Value
Annual Duty Cycle	%	45
Daily Harvest	Lbs	150
Energy Consumption	kWh/100 lbs	9.5

Annual Energy Consumption

The UEC was assumed to be consistent across lodging buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 1,100,000 ice machines in lodging buildings therefore consume 2.6 TWh/yr of electricity.

To obtain the installed base for this calculation, TIAX assumed that the percentage of ice machines in each building type has not changed since the ADL estimates in 1991 (ADL, 1991). To update the value over the 18 years that have passed since that data was gathered, TIAX used a compound annual growth rate of 0.75%, which is an approximation of the growth rate of the number of commercial buildings in the same time period.

References

ADL, 1991, "*Characterization of Commercial Building End-Uses Other Than HVAC and Lighting,*" Arthur D. Little for DOE, September, 1991.

Mantiwoc, 2009, "*Hotel/Motel Sizing Guide,*" Downloaded on Sept 21, 2009 from http://www.manitowocice.com/products/hotelmotel.asp?rooms=20&lbs_required=1500

6.9.4 Laundry

Table 155: Detailed findings for Laundry in Lodging Buildings

	Washers	Dryers
AEC (TWh/yr)	0.4	0.2

	Washers	Dryers
Installed Base (1,000s)	0.2	0.2
Units per 100,000 ft^2	4.7	4.7
UEC (kWh/yr)	1,600	730
UEC Variability	High based on washer capacity and usage	
Best in Class	25% savings from typical unit (1,200 kWh/yr UEC)	25% savings from typical unit (550 kWh/yr UEC)
Lodging Energy Savings Potential	0.1 TWh/yr	~0
Lodging Trends and Notes	Federal standard for residential-style commercial units began in 2007	

Unit Energy Consumption

Laundry equipment in lodging buildings consists of washers and dryers that are installed on-site at hotels, motels, nursing homes, and dormitories. For hotels, larger motels, and nursing homes, it is assumed that larger commercial laundry equipment is installed for buildings with on-site laundry. CBECS (EIA 2006) data indicate that about 72% of lodging building square footage and 82% of nursing home square footage have on-site laundry. Laundry usage in the lodging industry is approximately 9 lbs per room per day (PNNL 2008) and approximately the same for nursing home rooms (ADL 1993). PNNL (2008) estimates the average washer energy to be 1.39 kWh/load for a 60 lb washer, and 0.75 kWh/cycle for the average 75 lb gas fired commercial dryer. Assuming that two washers and two dryers are needed for every 60 guest rooms, the UEC for an average washer is 1,600 kWh/yr and 730 kWh/yr for an average dryer.

The UEC for laundry equipment in dormitories is expected to be more similar to that of laundromats. The overall energy consumption is estimated to be relatively low, and was not analyzed in further detail.

As indicated previously, this study only addresses the electric energy consumed laundry equipment (i.e., motors and controls). Most of the energy associated with laundry is consumed by water heaters, which heat the wash water, and by gas dryers. The gas energy is not evaluated in this study, but commercial dryers are assumed to be predominately gas fired. (ADL 1993, PNNL 2008)

Annual Energy Consumption

There are approximately five million hotel and motel guest rooms and 1.5 million nursing home beds in the U.S. If 72% of hotel and motel laundry is done on-site (based on the above percentage of square footage with on-site laundry), then there are 120,000 washers and 120,000 dryers installed, based on two washers and dryers per 60 rooms. Similarly, there are an estimated 40,000 washers and 40,000 dryers in nursing homes. Preliminary estimates suggest that there may be 80,000 washers and 80,000 dryers in dormitories, but the UECs for these smaller commercial units are expected to be lower, resulting in an insignificant amount (<0.05 TWh/yr) of total energy use.

The total annual energy consumption for washers and dryers in lodging buildings is estimated to be 3.6 TWh and 1.6 TWh, respectively.

Federal standards were initiated for residential-style commercial washer energy and water usage in 2007. The modified energy factor (MEF) sets the amount of energy that can be consumed for the sum of water heating energy, operation energy, and post wash drying energy per load capacity. Additionally, a water factor (WF) sets the maximum amount of water that can be consumed during a wash per load capacity.

References

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/ .

PNNL 2008, "Technical Support Document: The Development of Advanced Energy Design Guide for Highway Lodging Buildings," Prepared for the U.S. DOE, PNNL-17875, September.

ADL, 1993, "Characterization of Commercial Building Appliances," Final Report to the Building Equipment Division Office of Building Technologies, U.S. Department of Energy, June.

EPA, 2009, "Energy Star Commercial Clothes Washer Energy Savings Calculator," available at: http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/CalculatorCommercialClothesWasher.xls

6.9.5 Monitors

Table 156: Detailed findings for Monitors in Lodging buildings

	Comments/Values
AEC (TWh/yr)	2
Installed Base (1000s)	11,000
Units per 100,000 ft^2	220
UEC (kWh/yr)	180
UEC variability	Monitor usage patterns, Monitors attached to docking stations, Assumes same UEC across all building types
Best in Class	66% savings from typical unit (60 kWh/yr UEC)
Lodging Energy Savings Potential	1.3 TWh/yr
Lodging Trends and Notes	

For discussion, see Section 6.1.3.

6.9.6 Personal Computers (PCs)

Table 157: Detailed findings for PCs (Desktops & Notebooks) in Lodging buildings.

	Comments/Values
AEC (TWh/yr)	4.9
Installed Base (1000s)	1,100
Units per 100,000ft^2	22
UEC (kWh/yr)	450
UEC variability	PC usage patterns among desktop and notebooks
Best in Class	79% savings from typical unit (95 kWh/yr UEC)
Lodging Energy Savings Potential	3.9 TWh/yr
Lodging Trends and Notes	

For discussion, see Section 6.1.5.

6.9.7 Refrigeration

Table 158: Summary of Refrigeration in Lodging Buildings

Total Electricity Load (kWh/yr)	**Total Refrigeration Load (TWh/yr)**	**Main Types**
68.8	3.4	Walk-in and residential units

Estimates are based on 2003 CBECS data.

6.9.7.1 Refrigeration – Residential

Table 159: Detailed findings for Residential Refrigeration in Lodging Buildings

	Comments/Values
AEC (TWh/yr)	2.9 (1.3 for full size & 1.6 for compact)
Installed Base	6,800,000 (2.0MM full size & 4.8MM compact)

	Comments/Values
Units per 100,000 Sq Ft	130
UEC (kWh/yr)	440 (weighted avg of full-size (660 kWh/yr) and compact (330 kWh/yr))
UEC Variability	Energy consumption may be skewed in cases where ratio of full size to compact is dramatically different than expected
Best in Class	30% savings for full size and 10% for compact (360 kWh/yr UEC)
Lodging Energy Savings Potential	0.5 TWh/yr
Lodging Trends and Notes	A large majority of motel/hotel rooms have a compact refrigerator.

Unit Energy Consumption
See Section 6.1.6.1 for residential refrigeration UEC data, as listed under office buildings.

Annual Energy Consumption
TIAX estimates that the AEC of residential refrigeration in lodging buildings is 2.9 TWh/yr. This is based on a combination of full size units and compact units; the installed base is two million units (EIA, 2006) for full size, consuming 1.3 TWh/yr, and 4.8 million for compact units, consuming 1.6 TWh/yr.

6.9.7.2 Refrigeration - Walk-in

Table 160: Detailed findings for Walk-in Refrigeration in Lodging Buildings

	Comments/Values
AEC (TWh/yr)	1.5
Installed Base	77,000 (EIA, 2006)
Units per 100,000 Sq Ft	1.5
UEC (kWh/yr)	19,000 (weighted avg of coolers/freezers/combinations)
UEC Variability	Systems can vary dramatically depending on size and temperature needed
Best in Class	62% Savings from typical unit (7,200 kWh/yr UEC ADL, 1996)
Lodging Energy Savings Potential	0.9 TWh/yr
Lodging Trends and Notes	For food service within lodging

Unit Energy Consumption
See Section 6.2.7.1 for walk-in refrigeration UEC data, as listed under retail and service buildings.

Annual Energy Consumption

The UEC was assumed to be consistent across all lodging buildings. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 77,000 walk-in refrigeration units in lodging buildings in the U.S. (EIA, 2006) consume 1.5 TWh/yr.

References

ADL, 1996, “Energy Savings Potential for Commercial Refrigeration Equipment”, Arthur D. Little for DOE, June 1996

EIA, 2006, “Commercial Building Energy Consumption Survey”, DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/

6.9.8 Slot Machines

Table 161: Detailed findings for Slot Machines in Lodging buildings

	Comments/Values
AEC (TWh/yr)	2.7
Installed Base (1000s)	780
Units per 100,000ft^2	16
UEC (kWh/yr)	3,500
UEC variability	No major UEC variability
Best in Class	40% Savings from typical unit (2,100 kWh/yr UEC)
Lodging Energy Savings Potential	1.1 TWh/yr
Lodging Trends and Notes	Due to the legal restrictions on gambling, slot machines are found predominantly in commercial casinos (classified as lodging). Adoption of power savings initiatives poses a challenge due to the nature of gambling operators to keep machines actively on to attract users.

Unit Energy Consumption

UEC is calculated from the assumption that slot machines actively operate around the clock and consume on average 400W of power (Underdahl et al., 2009). Slot machines are one of the most popular gambling methods in casinos constituting about 70% of the average casino’s income (Cooper, 2005). Per Underdahl et al., (2009) patent application a 40% reduction in power consumption is foreseeable in gaming and slot machines.

Due to the legal restrictions on gambling, slot machines are only found in certain licensed establishments with the vast majority concentrated in commercial casinos, which most often are an extension of hotels or resorts, which are considered to be lodging building types.

Annual Energy Consumption

The AEC is calculated by multiplying the UEC with slot machine installed base which is about 780,000 according to a study from Cummings Associates (2005).

References

Cooper, M., 2005, "How slot machines give gamblers the business". The Atlantic Monthly Group. http://www.theatlantic.com/doc/200512/slot-machines. Retrieved 2008-04-21.

Cummings Associates, 2005, “The Density of Casinos, Slot Machines and Table Games in Iowa Compared to Other States,” Report to Iowa Racing and Gaming Comission, April. Available on-line at: http://www.iowa.gov/irgc/cummstudyDensity.pdf

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EMG Green, 2008, “Green Slot Project”, October, Downloaded in September 2009 at: http://egmgreen.com/blog/

6.9.9 Televisions

Table 162: Detailed findings for Televisions in Lodging Buildings

	Comments/Values
AEC (TWh/yr)	0.6
Installed Base (1,000s)	5.5
Units per 100,000 ft^2	108
UEC (kWh/yr)	115
UEC Variability	High based on variability active usage and active power draw
Best in Class	22% savings from typical unit (90 kWh/yr UEC)
Lodging Energy Savings Potential	0.2
Lodging Trends and Notes	

Unit Energy Consumption

The unit energy consumption for televisions is generally dominated by active mode, and the active mode power draw is mainly a function of screen area. In lodging buildings, there is very little data regarding the installed base, power draw, or usage of televisions. TIAX has estimated that installed TVs are generally in hotels, motels, nursing homes, and dormitories, and the average UEC was calculated to be 115 kWh/yr. The average UEC was calculated by estimating the UEC of TVs in two key applications. First, TVs in hotels and motels are estimated to consume 80 kWh/yr, the equivalent of average 32 inch, 125 W TVs on for one hour per day. Second, TVs in dormitories and nursing homes were estimated to have usage more like that of residential TVs. TIAX estimates that to be the equivalent of a 30 inch, 125 W televisions that operate for four hours per day, corresponding to a UEC of 210 kWh/yr. Installed televisions are estimated to consume approximately 4 W in off mode. (TIAX 2007) Based on the estimate of four million TVs in hotels and motels and 1.5 million TVs in nursing homes and dormitories, we calculated the weighted average TV UEC in lodging buildings to be 115 kWh/yr.

Annual Energy Consumption

Because of the lack of data, there is significant uncertainty in the estimate of TV energy consumption in lodging buildings. However, the estimated overall AEC of 0.6 TWh/yr, is relatively low, and will have little effect on the overall study results.

References

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/ .

TIAX, 2008, "Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2006 and Scenario-based Projections for 2020," Final Report by TIAX LLC for the U.S. Department of Energy, Building Technologies Program, April

TIAX, 2007, "Energy Consumption by Consumer Electronics (CE) in U.S. Residences," Final Report by TIAX LLC to the Consumer Electronics Association (CEA), January

6.9.10 Vertical Transport – Elevators and Escalators

Table 163: Detailed findings for Vertical Transport in Lodging Buildings

	Elevators	Escalators
AEC (TWh/yr)	0.4	~ 0
Installed Base (1,000s)	77	1
Units per 100,000 ft^2	1.5	~ 0
UEC (kWh/yr)	5,800	20,000
UEC Variability	High variability based on usage and elevator type	High based on variability in usage and escalator rise
Best in Class	30% savings from typical unit (4,100 kWh/yr UEC)	30% savings from typical unit (14,000 kWh/yr UEC)
Lodging Energy Savings Potential	0.1	~ 0
Lodging Trends and Notes		

Unit Energy Consumption

The UEC for elevators is based on the breakdown of low-, medium-, and high-rise buildings for the particular building type, an assumed elevator type, the average energy consumption per elevator start, and the number of elevator starts per year. For lodging buildings, the UEC was calculated to be 5,800 kWh/yr, as shown in Table 164.

Table 164: Calculation of the average UEC of elevators in lodging buildings

	# Floors	# of buildings w/ elevators	# of Elevators	Avg. Starts/year	Avg. (kWh/start)	UEC (kWh/yr)
Low-rise	<7	25,000	50,000	200,000	0.017	3,420
Mid-rise	7-24	5,000	25,000	400,000	0.026	10,440
High-rise	25+	0	2,000	500,000	0.017	8,500
Weighted Avg.			77,000			5,810
Comments/ Sources		EIA, 2006	EIA, 2005 scaled to 2008	Enermodal, 2004	Enermodal, 2004	

The UEC for escalators is calculated based on an escalator energy formula derived by an industry expert. (Al-Sharif 1997) The model was developed from actual measurements of in situ escalator rise, usage, and energy consumption. The model outputs energy as a function of escalator rise and operating time. The average escalator rise based on a distribution of rises for a sample of in situ escalators. (Enermodal 2004) TIAX estimates the average usage to be approximately twelve hours per day. It is also assumed that there is an equal number of up and down escalators installed in buildings.

Annual Energy Consumption

In lodging buildings, there are 77,000 elevators and 1,000 escalators installed, which consume 0.4 and less than 0.1 TWh/yr, respectively.

References

EIA, 2006, "2003 Commercial Building Energy Consumption Survey", DOE/EIA. Downloaded from http://www.eia.doe.gov/emeu/cbecs/ .

Enermodal Engineering Limited, 2004, "Market Assessment for Energy Efficient Elevators and Escalators," Report for the Office of Energy Efficiency, Natural Resources Canada, September.

Al-Sharif, L., 1997, "The General Theory of Escalator Energy Consumption," *Lift Report*, May/June.

6.10 Other Buildings and Non-Key Buildings

Key MELs for other buildings and non-key buildings are shown in Figure 48. The total annual energy consumption for key MELs in other buildings and non-key buildings is about 200 TWh/yr.

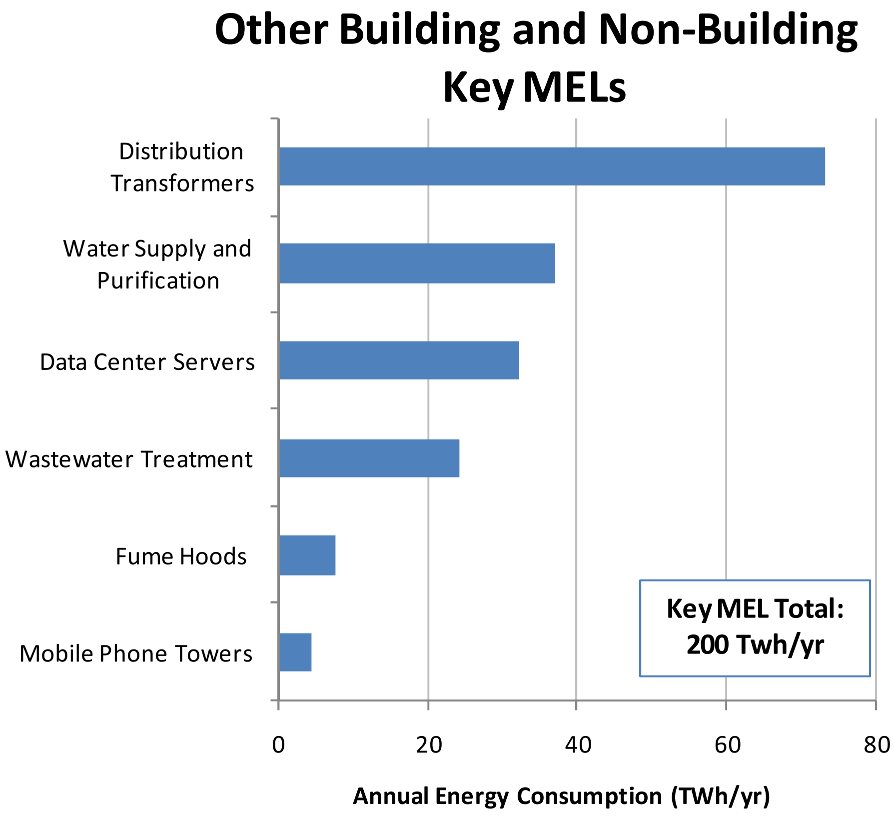

Figure 48: Key MELs for other buildings and non-key buildings

6.10.1 Distribution Transformers

Table 165: Detailed findings for Distribution Transformers outside of buildings (Utility owned)

	Comments/Values
AEC (TWh/yr)	73
Installed Base (1000s)	46,000
Units per 100,000 Sq Ft	**N/A**
UEC (kWh/yr)	1,600
UEC Variability	Transformer efficiencies are primarily affected by their rated capacity, average load and temperature.
Best in Class	20% savings from typical unit (1,300 kWh/yr UEC)

	Comments/Values
Energy Savings Potential	14.6 TWh/yr
Data Uncertainties	Uncertainties exit with average load and the distribution of transformer types and their rated capacities
Trends and Notes	90% of all liquid-immersed type and around 10% of dry-type distribution transformers are found outside of buildings

Unit Energy Consumption

TIAX assumes the UEC for distribution transformers outside of buildings to be similar to the UEC for a "typical" distribution transformer in commercial buildings. This type of unit has a typical capacity of 75kVA and average load of 16% as per the Cadmus Group (1999) study. This includes transformers that are owned by utilities only and are on the grid-side of the meter. The installed base was obtained by dividing the AEC by the UEC.

Annual Energy Consumption

Typically, distribution transformer efficiencies are in the range of 97% to 99.5% (LBNL's Energy Efficiency Standards, 2009). The aggregate energy loss attributed to distribution transformers outside of buildings is 73TWh. This value was derived from energy consumption rate per year from 1996 and from the fact that in 1996, distribution transformers used by utilities account for about 61TWh of annual energy lost in the delivery of electricity (ORNL, 1996). Around 90% of all liquid-immersed transformers are owned by electric utilities with the remaining owned by commercial and industrial customers (ORNL, 1996).

References

Cadmus Group, 1999, "Metered Load Factors for Low-Voltage, Dry-Type Transformers in Commercial, Industrial, and Public Buildings," Report for Northeast Energy Efficiency Partnerships and Boston Edison Company, December.

LBNL Energy Efficiency Standards, 2009, "Distribution Transformers," Downloaded in November 2009 at: http://ees.ead.lbl.gov/projects/current_projects/distribution_transformers

ORNL, 1996, "Determination Analysis of Energy Conservation Standards for Distribution Transformers," Report for the DOE, July.

6.10.2 Fume Hoods

Table 166: Detailed findings for Distribution Transformers in **non-key building types** (mainly offices and education buildings)

	Comments/Values
AEC (TWh/yr)	7.5
Installed Base (1000s)	375
Units per 100,000ft^2	170

	Comments/Values
UEC (kWh/yr)	20,000
UEC variability	Fume hoods sizes are fairly consistent and thus UEC variability is relatively low.
Best in Class	50% Savings from typical unit (10,000 kWh/yr UEC)
Energy Savings Potential	3.8
Trends and Notes	Fume hoods are predominantly concentrated in laboratory environments such as in buildings are that dedicated laboratory buildings or in buildings where there are inter-dispersed lab space.

Unit Energy Consumption

To be consistent with the MEL-centric nature of this study, TIAX is only concerned with the energy consumption of the air-handling component of fume hoods, i.e. the energy used to drive fans and not the energy used for conditioning of replacement air. The UEC and best in class UEC values are taken directly from (LBNL, 2009) and (LBNL, 2003) respectively.

Annual Energy Consumption

The AEC for all fume hoods in the U.S. was calculated by multiplying the UEC with the total installed base of approximately 750,000 according to LBNL (2003). Since there is an appreciable amount of uncertainty on how the fume hoods are distributed among building types, TIAX assumes a 50% split in distribution of fume hoods in laboratory buildings and in non-key building types (mainly offices and education buildings that contain laboratories).

References

LBNL, 2003, "Energy use and savings potential for laboratory fume hoods," Article supported by DOE contract No. DE-AC03-76SF00098 and California Energy Commission, July.

LBNL, 2009, "Laboratory Fume Hood Energy Model," Available online at: http://fumehoodcalculator.lbl.gov/index.php

Bell G., Sartor, D., Mills, E., 2002, "The Berkeley hood: development and commercialization of an innovative high-performance laboratory fume hood," Brochure available online at: http://ateam.lbl.gov/hightech/fumehood/fhood.html

6.10.3 Mobile Phone Towers

Mobile Phone Towers are classified as a "non-building" MEL. See Section 5.11.1 for detailed discussion.

6.10.4 Servers in Data Centers

Table 167: Detailed findings for Servers in Data Centers

	Comments/Values
AEC (TWh/yr)	32
Installed Base (1000s)	16,000
Units per 100,000 Sq Ft	unknown
UEC (kWh/yr)	2,100 (weighted average of various sizes)
UEC Variability	Depending on purpose, a data center may hold tens to tens of thousands of servers – Power consumption can vary by 1000's of watts
Best in Class	19% Savings from typical unit (1,700 kWh/yr UEC)
Energy Savings Potential	6 TWh/yr
Trends and Notes	Internet growth is spurring rapid, large scale expansion, forcing efficiency to be a top economic priority

Unit Energy Consumption

While specific energy consumption estimates are not published, Koomey estimates that a typical "volume" server of this style may consume approximately 250 Watts with an equivalent load factor of 100% (i.e. continuous operation) for a UEC of 1,800 kWh/yr (Koomey, 2007). In practice, the actual load factor will be less than 100% and the power consumption will be higher than the assumed value. Using a weighted average of volume servers and the much less common mid-range and high-end servers drives the UEC estimate 10% higher to 2,100 kWh/yr.

Annual Energy Consumption

The UEC was assumed to be consistent across all data centers. Therefore, the AEC is calculated as the installed base multiplied by the UEC. The 16 million servers in data centers in the US (Koomey, 2007) consume 32 TWh/yr.

References

Koomey, 2007, *"Estimating Total Power Consumption by Servers in the U.S. and the World,"* Lawrence Berkeley National Laboratory, February 2007.

Web Servers, 2009, Miller, Rich, *"Who Has the Most Web Servers?"* Data Center Knowledge, May 2009, downloaded on October 12, 2009 from http://www.datacenterknowledge.com/archives/2009/05/14/whos-got-the-most-web-servers/

6.10.5 Wastewater Treatment

Wastewater Treatment is classified as a "non-building" MEL. See Section 5.22 for detailed discussion.

6.10.6 Water Supply and Purification

Water Supply and Purification is classified as a “non-building” MEL. See Section 5.23 for detailed discussion.

7 CONCLUSIONS AND RECOMMENDATIONS

To support its strategic planning efforts, DOE/BT contracted TIAX to characterize commercial MELs (C-MELs) by commercial building type, analyze their unit and annual electricity consumption (for the 2008 calendar year), and carry out an initial assessment of the energy-saving potential for C-MELs using best-available devices and practices. This study:

- Provides estimates of U.S. commercial MEL electricity consumption by commercial building type
- Provides estimates of non-traditional commercial MELs found outside (i.e., before the electric meter) of buildings (e.g., water supply, distribution transformers)
- Establishes preliminary technical energy-saving potential estimates of C-MELs using currently available, energy efficient devices and technologies
- Guides energy efficiency research and activities by aggregating the results and comparing them with main load, sector, and national energy consumption totals.

TIAX's assessment of the 28 different loads was approached as a bottom-up study. That is, as opposed to beginning from total energy consumption in the U.S. and breaking down that number step by step until each category had been filled, the team collected various pieces of data and built up the estimates from the basic components. The key commercial MELs selected for further investigation are as follows:

Refrigeration

1. Unit Coolers
2. Central
3. Residential Type
4. Ice Machines
5. Warehouse
6. Walk-in

Consumer Electronics

7. PCs
8. Monitors
9. Other Office Equipment
10. Televisions

Other Building MELs

11. Slot Machines
12. ATMs
13. Vending Machines
14. Vertical Transport
15. Non-Road Vehicles
16. Landscape Irrigation
17. Fitness Equipment
18. Laundry
19. Fume Hoods
20. Arcade Machines

Non-Building MELs

21. Water Supply & Purification
22. Waste Water Treatment
23. Distribution Transformers
24. Mobile Phone Towers

Medical

25. Medical Imaging
26. Other Medical Equip.

27. Cooking

28. Data Center Servers

The key building MELs are those from the list of 28 that are used inside buildings. The 'other key MELs' include loads such as mobile phone towers or waste water treatment, which are not specifically associated with a building type, but are considered commercial MELs in this analysis.

The nine building types considered include: office, retail & service (non-food), food service, food sales, education, warehouse, healthcare, lodging, and public assembly, order, and religion (AOR). These building types are consistent with the main types defined in the Commercial Building Energy Consumption Survey (CBECS), which was most recently published for 2003 by the DOE Energy Information Administration. This consistency allows for straightforward comparisons with other data sources. The CBECS definitions included three individual categories, public assembly, public order, and religious, but given their lower energy consumption, TIAX combined them to form the public AOR category.

The amount of information available varied from load to load, but in most cases, not all required pieces of the information were available to complete a full bottom-up analysis. TIAX made assumptions based on the best available information and our general knowledge of the loads and load trends to estimate the average UECs and installed base for the key loads. Measurements and the collection of new data were outside the scope of this report. Rather this report is intended to serve as a broad overview of C-MELs energy consumption by building type, identify data gaps and uncertainties, and guide further focused energy consumption analysis and reduction research.

The uncertainty of the energy consumption and savings potential estimates varies from load to load, and at times from building type to building type. We have stated our key assumptions in Section 5 and Section 6. In generally, there is significant uncertainty in the usage patterns of MELs, and how the usage varies from one building type to the next. More power draw and installed base data is available for some of the more energy intensive MEL categories (e.g., PCs, office equipment, refrigeration, cooking), although some of the information is dated. The installed base estimates and average UEC estimates (i.e., statistically representative of the installed base) were more uncertain for the less energy intensive key building MELs that have not received as much research attention (e.g., medical equipment, fitness equipment, elevators) and for non-building MELs which historically have not been considered MELs (e.g., water supply and treatment, mobile phone towers, distribution transformers).

7.1 Energy Consumption in 2008

The evaluated key C-MELs consume a total of 504 TWh of electric energy in commercial buildings per year, or 5.5 quads of primary energy. This is 30% of the 18.3 quads consumed by the commercial energy sector, as shown in below in Table 49. 3.3 quads are associated with key building MELs while an additional 2.2 quads were consumed by other key loads not associated with specific building types (a.k.a., other key MELs).

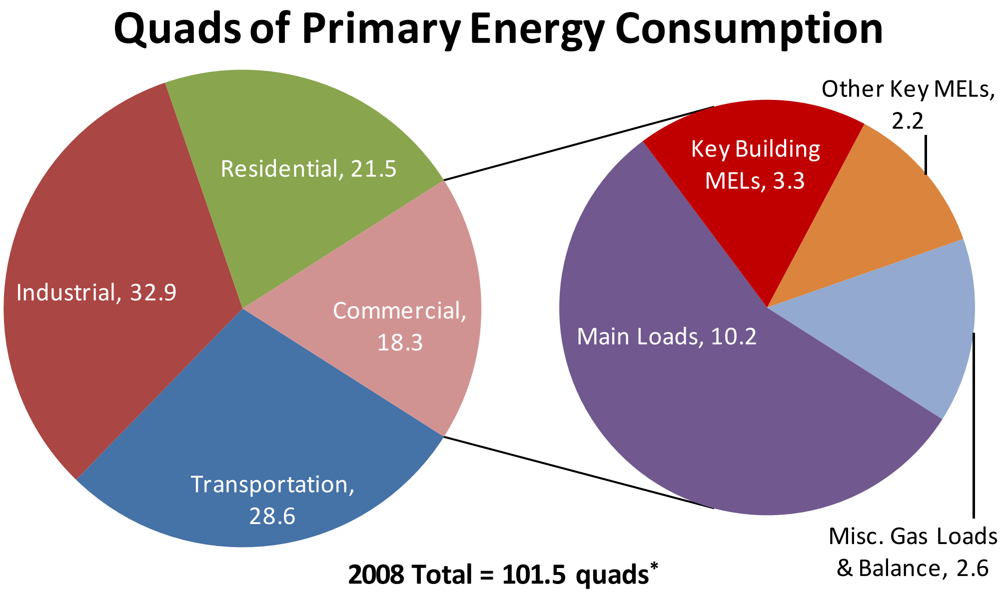

Figure 49: TIAX addressed 5.5 quads of C-MELs identified as both "Key Building MELs" and "Other Key MELs"[12]

The “miscellaneous gas loads” shown in Table 49 include things such as gas heated laundry dryers and gas cooking. There is also a remaining “balance” after adding main loads, MELs, and miscellaneous gas loads, which may come from unaccounted for miscellaneous loads, uncertainty in the energy consumption in any category, or may be a statistical artifact resulting from summing of values from different sources.

Given that 92 TWh of site electric energy is approximately equivalent to one quad of primary energy, and that a one gigawatt power plant delivers approximately eight TWh/yr of electricity, TIAX’s key MELs consume the output of more than 11 one gigawatt power plants. They account for approximately 30% of the commercial primary energy and 5.5% of the U.S. primary energy.

In aggregate, the evaluated C-MELs consume more electric energy than any of the traditional building main loads, as shown below in Table 50.

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[12] EERE, 2009, “2009 Building Energy Data Book,” U.S. DOE. For U.S. Commercial, and main load totals

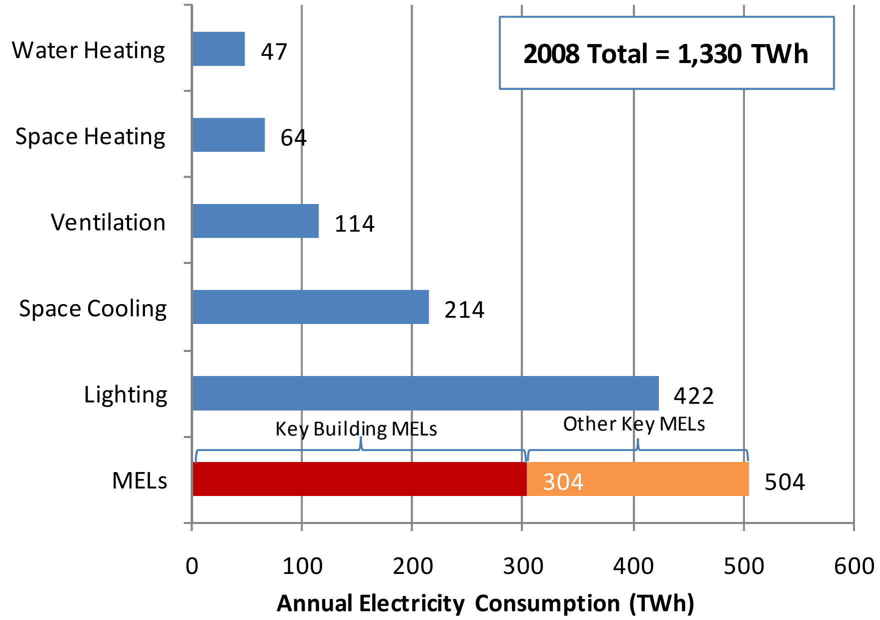

Figure 50: The U.S. Commercial Electricity Consumption, broken down by load, shows that TIAX's Key MELs are greater in aggregate than another other single load.[13]

The key building C-MELs, which consume approximately 300 TWh/yr, account for between 10% and 60% of the electric energy consumption of each building type. The breakdown between key C-MEL energy and main load energy consumption[14] by building type is shown below in Table 51.

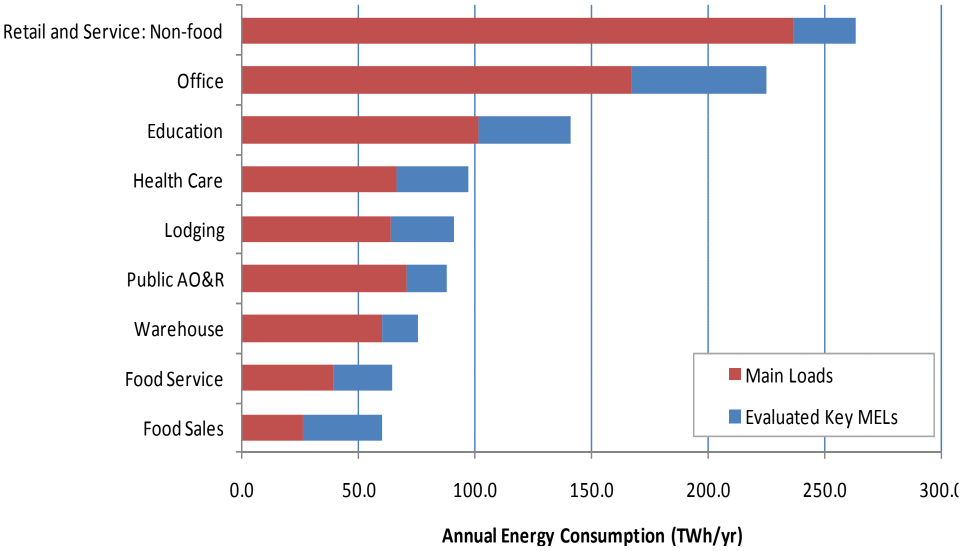

Figure 51: The key MELs are between 10% and 60% of the electric energy consumption of each building type.

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[13] EERE, 2009, "2009 Building Energy Data Book," U.S. DOE. For U.S. Commercial, and main load totals

[14] EIA, 2003, "Commercial Building Energy Consumption Survey," Main load energy from Table 5a.

Food sales buildings have a high MEL energy consumption (about 60% of the total energy) because of refrigeration loads. MELS account for 26% and 28% of office building energy and education building energy, respectively, largely because of PCs, monitors, and other office equipment.

The total energy consumption for each key C-MEL across all building types is plotted in Figure 52.

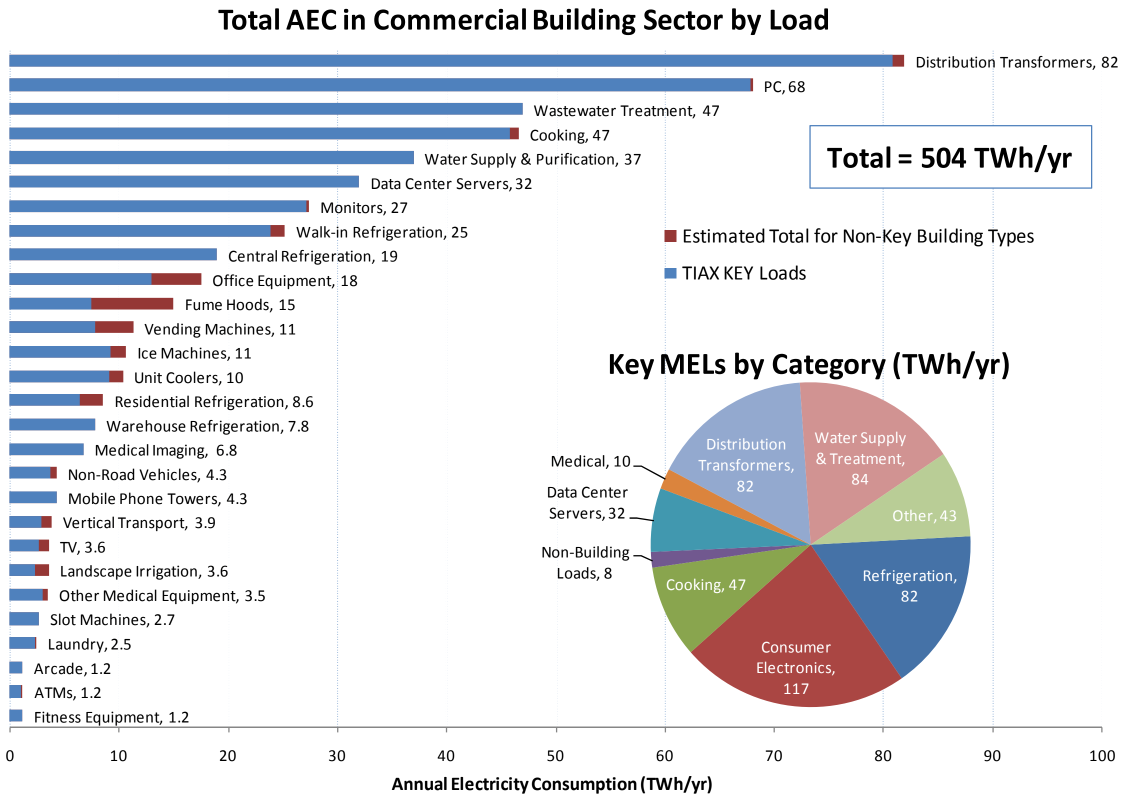

Figure 52: Consumer electronics and refrigeration, in aggregate, account for nearly 40% of the evaluated MELs.

Each bar represents the energy consumption in the commercial sector for the stated key MEL. Key C-MELs were evaluated in building types in which they represented a significant load. Bars in Figure 52 that are only blue indication that for any building type in which the load was not key, it was a negligible load. The bars that also include red sections (“estimated total for non-key building types”), are an indication that a portion of the load’s energy consumption is in building types in which it is not considered a key load, but, in aggregate, is noteworthy.

The pie chart in Figure 52 groups the key C-MELs into appropriate categories. Office electronics consume nearly 25% of the total. Refrigeration equipment, water supply and treatment equipment (namely, pumps), and distribution transformers (both inside and outside of buildings) each used over 80 TWh in 2008, or 16% each.

Figure 53 compares the TIAX results for several key MELs or MEL categories to other past estimates, the 2009 Building Energy Data Book (EERE 2009) and the 2003 CBECS results (EIA 2006).

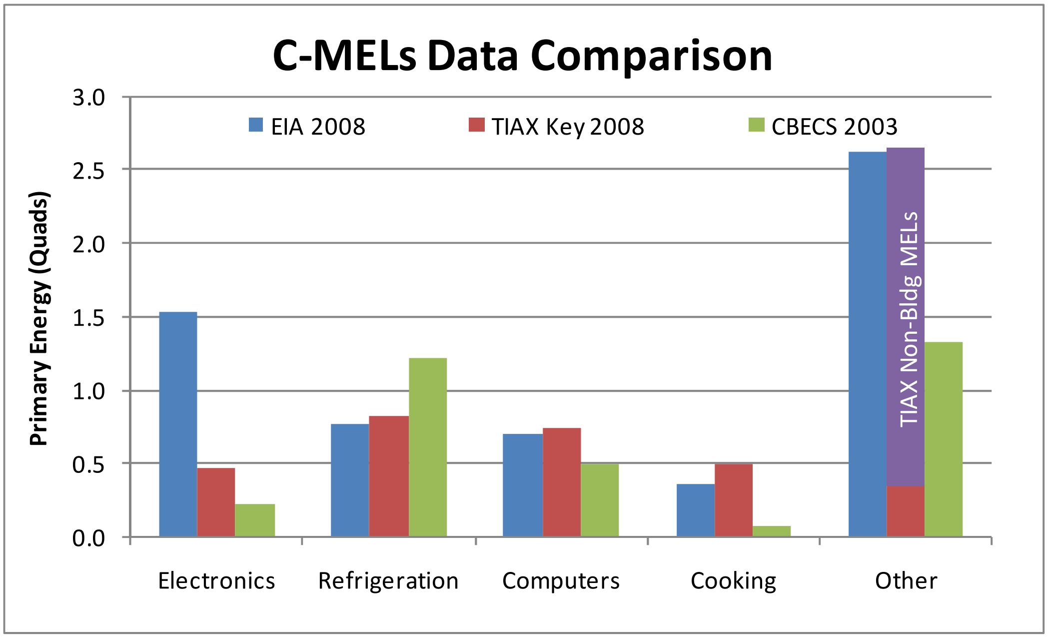

Figure 53: Comparison of several TIAX key MELs with other information sources

There is noticeable discrepancy among the estimates for electronics. Part of the difference may be explained by the vintage of the estimates (i.e., CBECS estimates for electronics and computers may be lower because they are for 2003), and part of the difference may be due to devices included in the estimates (i.e, CBECS only includes office equipment and TIAX only includes key consumer electronics). However, it is unlikely that this fully explains the differences.

There are also appreciable differences among the estimates for the 'other' category. It is understandable that the TIAX estimate for 'other' category is lower since we only addressed a set of key C-MELs, while the other estimates may include an estimate for the many smaller MELs not included in the TIAX study. The TIAX estimate for non-building MELs is likely not accounted for in the other estimates.

The differences by building type between the TIAX key building MELs and the 2003 CBECS data are also shown on a per floor area basis in Figure 54 and on a per building basis in Figure 55. TIAX MEL energy intensity estimates relative to the CBECS data range from 89% higher for lodging to 37% lower for public AOR. TIAX MEL energy intensities are also higher for education and healthcare buildings, while the TIAX MEL energy intensities are lower for warehouse, food sales, food service, and office buildings. There are many potential reasons for the discrepancies seen (e.g., loads analyzed, methodology, references, vintage, etc.), that have not been addressed under this scope of work.

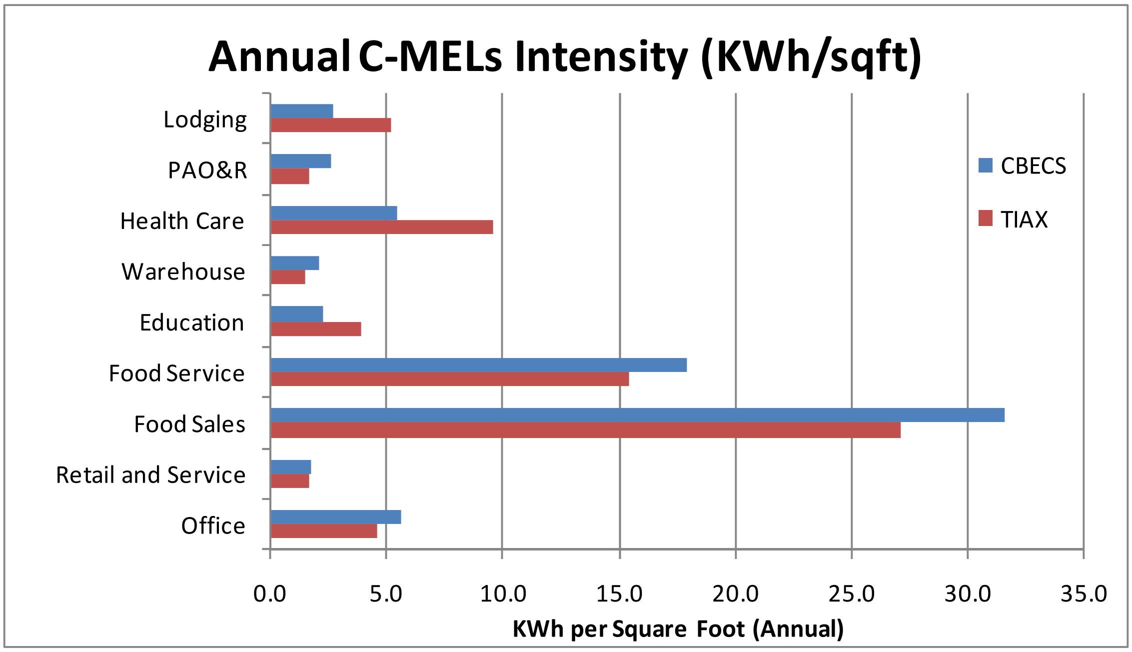

Figure 54: Comparison of C-MEL energy intensity (kWh/sqft) estimates by building type between TIAX key C-MELs and 2003 CBECS data for refrigeration, cooking, PCs, office equipment, and other miscellaneous loads

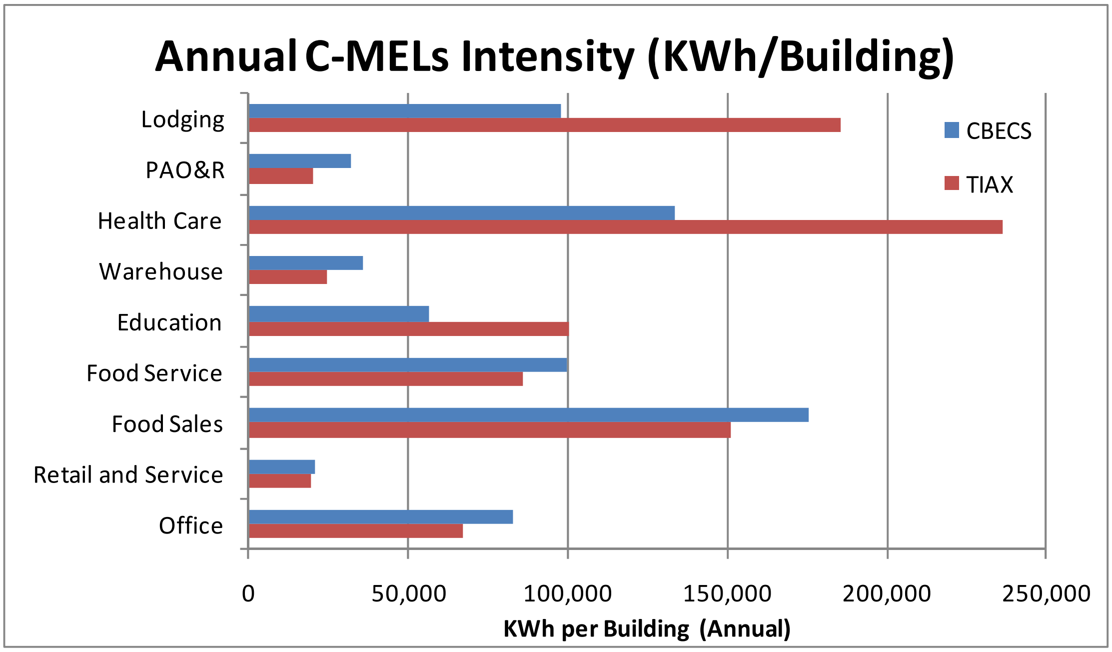

Figure 55: Comparison of C-MEL energy intensity (kWh/building) estimates by building type between TIAX key C-MELs and 2003 CBECS data for refrigeration, cooking, PCs, office equipment, and other miscellaneous loads

7.2 Energy Savings Potential Using Best in Class Devices

In order to identify energy savings opportunities, TIAX selected or estimated “best-in-class (BIC)” devices from each of the 28 selected load types. For the most part, the energy consumption associated with BIC units was derived directly from energy efficient units that are currently on the market.

By comparing the BIC to the typical unit used in the baseline calculations, TIAX generated a technical “energy savings potential (ESP)” for each load. Assumptions about the market penetration and impact of emerging technologies are not addressed in this study, and therefore the ESP is not necessarily fully achievable due to many market factors, but also may be more than 100% achievable in cases where new technologies are on the horizon.

It is assumed that all current units are replaced by the BIC unit. The “by load”, and “by load category” energy savings potential estimates, which include estimates for both key and non-key building types, are shown below in Figure 56.

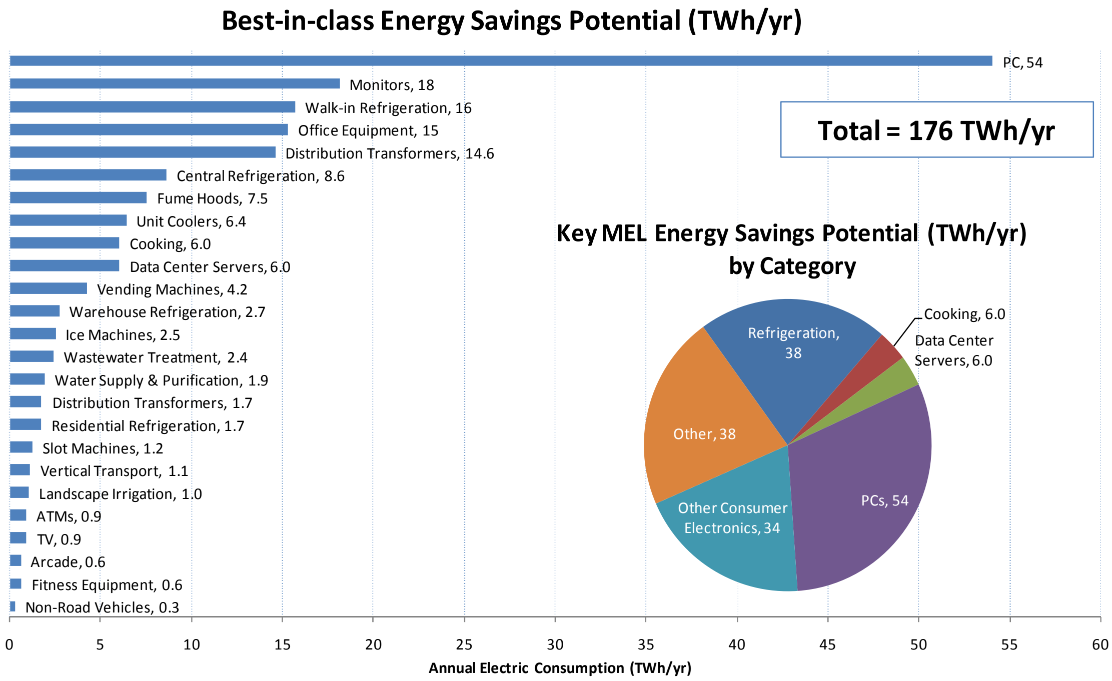

Figure 56: Achievement of this energy savings potential could reduce C-MEL energy consumption by 176 TWh/yr, thereby reducing C-MELs from approximately one third of commercial primary energy, one quarter.[15]

Overall, we have estimated a 35% (176 TWh/yr) energy savings potential by replacing the current installed base with best-in-class devices. The loads with highest savings potential include PCs, monitors, walk-in refrigeration, office equipment, and distribution transformers. Each of these loads has the technical potential for a reduction of approximately 15 TWh/yr or greater.

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[15] Source: 2009 Buildings Energy Data Book, DOE/EERE. 2008 values interpolated from 2006 data points and 2010 projected data points – See Tables 3.14, 3.15, and 3.17.

Electronics (namely, PCs, monitors, and other office equipment) account for about 50% (88 TWh/yr) of the estimated energy savings potential. For this reason, office and education buildings show a high potential for energy savings, as shown in Figure 57. This energy savings potential is mainly driven by the potential impact of power management. Other key drivers for this energy savings are the transition from desktops to laptops (or at least to equivalent components and power saving design strategies in a desktop form factor), and the transition from CRT monitors to efficient LCD monitors.

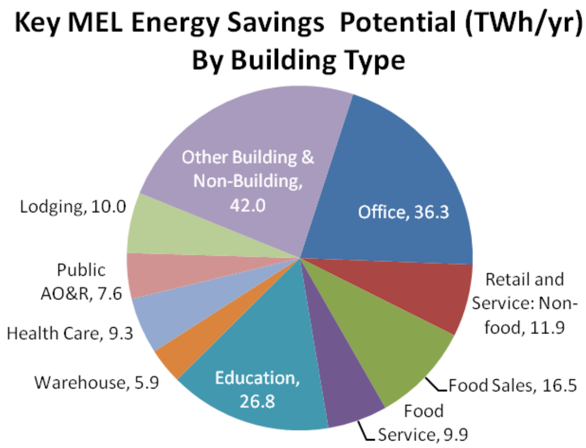

Figure 57: Energy savings potential estimate by building type

7.3 Recommendations

The insights gained from this characterization of commercial MELs point to several recommendations for further study. Each one is discussed separately in the following subsections.

Regular Evaluation of Rapidly Evolving MELs**:** A significant portion of the devices evaluated have – and, in many cases, continue to – undergone dramatic changes in their installed base, their usage, and their functionalities, characteristics, and underlying technologies (and, hence, their power draw by mode). This is particularly true of electronics (namely, office electronics and data servers), which have changed dramatically over the last couple of decades and tend to have much shorter average product lifetimes (i.e., on the order of a few years compared to ten or more for white goods), but also true of some other products as well (e.g., the increased installed base of mobile phone antennas). In all cases, it has significant ramifications for DOE's goal of net zero-energy buildings (NZEB) in the future.

Consequently, we recommend performing regular (e.g., every 3-4 years) evaluations of MEL energy consumption and energy savings potential to understand how the evolution of MELs are affecting the feasibility of cost-effectively attaining DOE's building efficiency goals. Furthermore, we recommend that brief annual updates (executive summary style) be performed in order to keep installed base and UEC estimates current and statistically representative of the installed stock.

***More Refined Evaluation and Characterization of MEL Energy-Saving Opportunities*:** Our initial characterization of energy-saving opportunities for commercial MELs primarily focuses on energy savings attainable using *existing* products. Although we found that this approach can yield overall reductions in MEL energy of about 35%, it probably is not realistic to rely on a large portion of the five million commercial buildings to purchase such "best-in-class" devices to realize large-scale savings. Furthermore, it is often very challenging to reduce the building energy consumption of many MELs via other pathways (e.g., automated controls) due to the low annual energy cost savings potential for most MELs and building owners'/operators' disdain for measures that might adversely affect device utility or usability or impact business operations.

We recommend that DOE perform a study focused on a thorough characterization of commercial MEL energy savings opportunities with an emphasis on a critical assessment of the likelihood that a large portion of real buildings would accept and effectively deploy different measures. Ultimately, this could be used to develop a roadmap for credibly achieving major (e.g., 35%) reductions in MELs that identifies the technologies and policies needed to reach realize those reductions.

We recommend two different potential approaches:

a) Focus on large (>50,000 square feet) buildings, which consume 50% of the key MEL energy, but are only 5% (~250,000) buildings. These buildings may also see appreciable reductions in operating costs from energy savings measures, and therefore may be more amenable to adopting such measures.

b) Focus on high impact technology categories. While the study analyzes tens of loads and the potential energy savings measures associated with each one, the technology used to achieve those savings can probably be summarized in approximately ten categories. By using this approach, DOE can facilitate greater energy savings by targeting core technologies that affect multiple loads at the same time. For example, by targeting high efficiency screens with advanced LED or even OLED backlighting, DOE can make an impact on the energy consumption of monitors, ATMs, slot machines, arcade games, and more.

***Data Gathering by Building Type to Fill Key Data Gaps*:** TIAX found a lack of current data, particularly by building type, for many C-MEL to develop accurate bottom-up estimates. We recommend that the DOE conduct power measurements by mode for a sample representative of the installed base for key C-MELs in key building types. Likewise, interviews, surveys, or actual measurements are needed to more accurately understand the usage patterns of key MELs in key building types. Obtaining real operating data can be time and budget intensive, and therefore a focused work plan is needed to fill the largest data gaps with the largest impact on energy consumption. We recommend starting with large commercial buildings (i.e., greater than 50,000 square feet).