Methodology to Develop the Airport Terminal Building Energy Use Intensity (ATB-EUI) Benchmarking Tool (2016)

DETAILS

34 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-44222-0 | DOI 10.17226/23495

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SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine 2016. *Methodology to Develop the Airport Terminal Building Energy Use Intensity (ATB-EUI) Benchmarking Tool*. Washington, DC: The National Academies Press. https://doi.org/10.17226/23495.

ACKNOWLEDGMENT

This work was sponsored by the Federal Aviation Administration (FAA). It was conducted through the Airport Cooperative Research Program (ACRP), which is administered by the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine.

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This Web-Only Document complements *ACRP CD-ROM 178: Airport Terminal Building Energy Use Intensity (ATB-EUI) Benchmarking Tool* available at http://www.trb.org/Main/Blurbs/173795.aspx.

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Author Acknowledgments

The research reported herein was performed under the ACRP project 09-10, "*Benchmarking and Profiling Airport Terminal Energy End Uses*", sponsored by the Transportation Research Board (TRB), Airport Cooperative Research Program (ACRP). The project was conducted by the Energy Systems Laboratory (ESL), of the Texas A&M Engineering Experiment Station (TEES), in collaboration with the Building Energy Technology Laboratory (BETlab), College of Design, North Carolina State University, and Energy Commissioning Group, Inc.

The research team would like to thank the ACRP project manager, Ms. Marci A. Greenberger, AAE, for her professional and efficient administration of this research effort, and her helpful insights into the ACRP project process. We would also like to thank the ACRP 09-10 review board for their valuable and continued guidance along the project development.

The research team appreciates the participation of the ten airports that have taken part in this research, and the time and effort invested by their administrative and technical personnel. We especially would like to recognize the following individuals from these airports: Robert (Bob) Barker, CFM, Executive Representative for ITRP, Scott B. Hill, Senior Business Analyst and Interim Division Manager, Asset Management, PDC - Planning Design and Construction, Houston Airport System, Troy Donahue, Sr. superintendent, City of Houston, Kathy Brakeville, Superintendent Facilities Management, George Bush Intercontinental Airport (IAH), Ron Turtzo, Airport Superintendent, William P. Hobby Airport (HOU), Steven V. Brian, C.M., Director, and Miguel Escalon, Airport Security Sergeant, Easterwood Airport (CLL), Patrick Cerri, EI, EMIT, CDT, LEED Green Associate, CLT Sustainability Program, Charlotte Douglas International Airport (CLT), Rusty T. Hodapp, Vice President, Energy & Transportation Management, and Larry Kramer, P.E., LC, CEM, Energy Engineer, Dallas/Fort Worth International Airport (DFW), Nathaniel Kimball, Environmental and Sustainability Specialist at Port Authority of NY & NJ, Newark Liberty International Airport (EWR), Franko Martinec, P.E., Port of Portland Facilities Services Division Manager, Portland International Airport (PDX), Scott W. Snoke, Utility Program Manager, Harrisburg International Airport (MDT), Ronak Patel, P.Eng., Manager, Energy Management & Recoveries, Toronto Pearson International Airport (YYZ), Heather Kendrew, PE, former Director of Maintenance / Engineering /Environment, and Rick Brown, Director of Maintenance, Burlington International Airport (BTV).

We would also like to acknowledge the City of College Station Utilities and Bryan Texas Utilities for supplying us with anonymous data on restaurants, and fast-food establishments, and the owners of the restaurants in Raleigh, North Carolina.

1. Overview of the Data Collection and Analysis Process

The overall data collection and analysis process for developing the Airport Terminal Buildings (ATBs) benchmarks is shown in Figure 1. This figure is divided into three main tasks: 1) developing the individual benchmarks in the upper portion of the figure and making comparisons between participating ATBs; 2) comparing estimated benchmarks with actual measured data from the ATBs; and 3) developing the Representative Airport Terminal Buildings (RATBs) benchmarks in the lower part of the figure.

To develop the individual ATB benchmark, two different procedures were created: one based on specific zones/functions within the ATB, each with a certain square footage; and one, based on the mechanical systems that can be found in an ATB and their particular parameters (not based on square footage). The cumulative result from the application of these two procedures produces the overall annual energy use intensity baseline for the ATB.

In the first procedure, the ATB is sub-divided into specific Zones (i.e., concession, office, transient space, etc.) and each of these Zones is assigned an Energy Use Intensity (EUI) based on the best available published EUIs that are appropriate for that type of space. Each ATB Zone EUI is then converted to an Energy Use (EU), by multiplying the EUI value with the square footage of that particular Zone. The EUs of all the various Zones are then added up to a subtotal EU for ATB Zones. Each ATB Zone EU is also divided by the total square footage of the buildings, which provides a normalized EUI for each ATB Zone. The EUIs of all the various Zones are then added up to a subtotal EUI for all ATB Zones.

In the second procedure, specific systems that are common to ATBs are identified and their annual EU is determined based on their specific parameters and the best available procedures for determining the annual EU of such systems. The Systems' EUs are summed up to a subtotal EU for all ATB systems. Each ATB system EU is also divided by the total square footage of the building, which provides a normalized EUI for each ATB system. The EUIs of all the various systems are then added up to a subtotal EUI for all ATB systems.

The overall ATB benchmark is the combination of the two subtotals: the annual EUI for all the ATB Zones and annual EUI for all the ATB Systems. This process is applied to each of the participating airports to determine the annual estimated EU and EUI of the individual ATB. The measured EUI, based on utility information is then calculated, and comparisons can be made between the estimated EU and EUI and the measured EU and EUI for each individual ATB, as well as comparisons between participating ATBs.

Once the process has been applied to the participating ATBs, comparisons can be performed, the Representative Airport Terminal Buildings (RATBs) can be defined, and their benchmarks can be set.

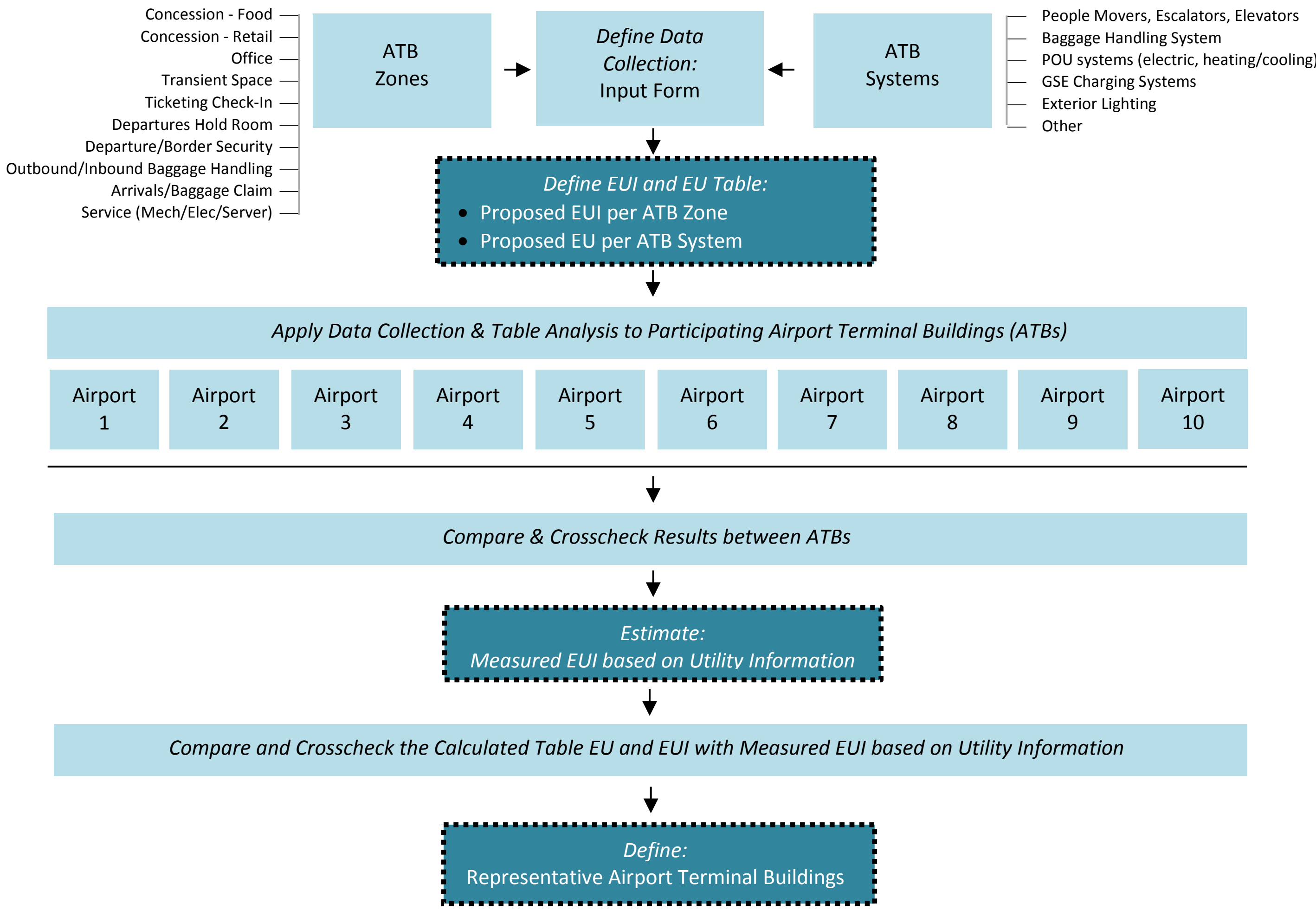


Figure 1. The Process of Data Analysis and Development of EUI Benchmarks

2. Defining Annual EUI per ATB Zone

Figure 2 shows the process used to determine the proposed Energy Use Intensity (EUI) for the Airport Terminal Building (ATB) Zones. In this process, published EUIs were gathered and compared to determine the most representative EUI for the expected Zones in the ATB. As shown in the upper portion of the figure, various sources were reviewed to determine if suitable EUIs were available. The result of this review produced the Preliminary EUIs.

In the lower portion of Figure 2, an ongoing process is indicated to crosscheck EUIs with representative data from actual facilities (i.e., utility billing data, square footage, etc.). The result of this crosscheck was intended to produce the Proposed EUIs for use in the final report for this project.

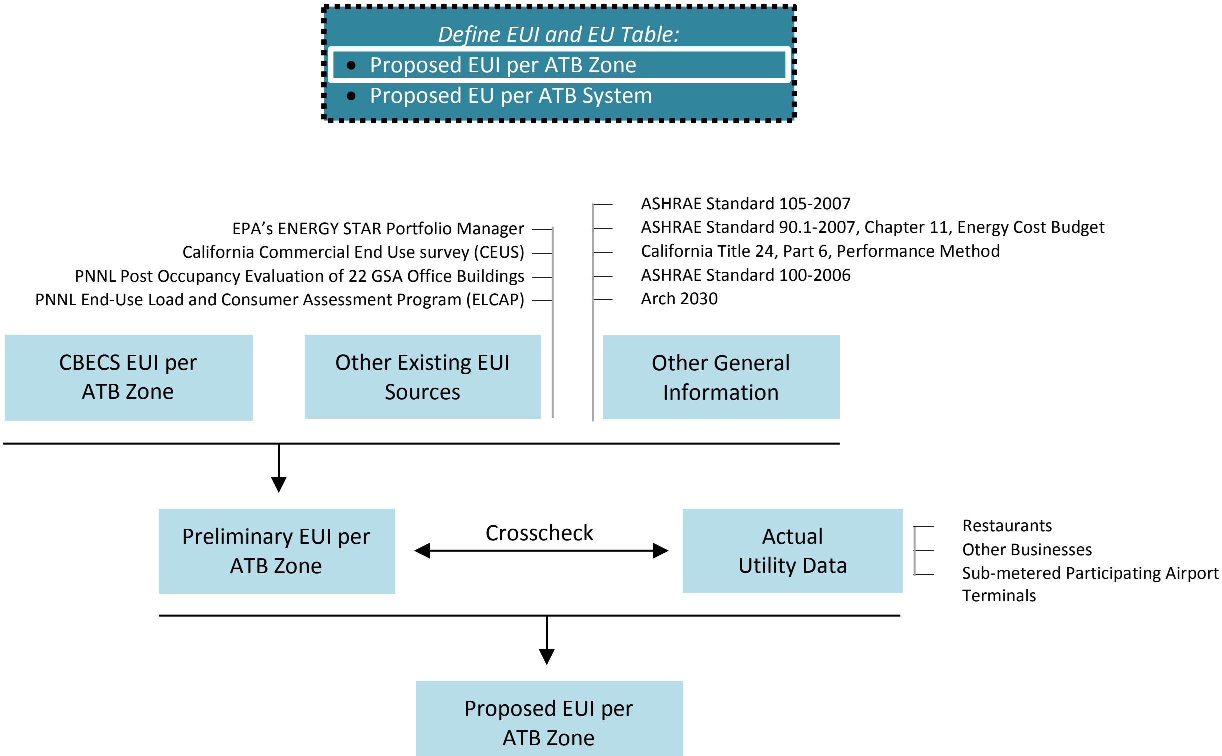


Figure 2. Defining Proposed EUI per Airport Terminal Building Zone

Some of the existing sources for EUI values focus on EUI for one specific building type/Zone (e.g., the PNNL Post Occupancy Evaluation of 22 GSA Office Buildings). Other sources provide values for several different building types/Zones (e.g., CBECS 2003, EPA Portfolio Manager, California Commercial End Use Survey). Each of the sources considered in this study relies upon a previous survey of existing building performance to establish EUI benchmark values for a specific building type or a group of building types. These sources established benchmarking values for building performance measured by EUI, which are relevant to this study because they provide a context for establishing the Preliminary EUIs per ATB Zone. The following is a brief review of the EUI sources.

2.1 Comparison of EUI Sources per Function/Zone

Table 1 summarizes the differences and similarities between the three main EUI sources; i.e., 2003 CBECS, EPA Portfolio Manager, and the California Commercial End Use Survey (CEUS). In Table 1, the varying values of ten (10) Zones identified in ATBs are shown.

Six (6) building types from the 2003 CBECS database were used to represent the ten (10) ATB Zones. Five (5) ATB Zones were represented using the 2003 CBECS "Public Assembly" category, (i.e., Transient Space, Ticketing Check-In, Departures Hold Room, Outbound/Inbound Baggage Handling, and Arrivals/Baggage Claim) (U.S. EIA 2003).

In the case of the EPA Portfolio Manager, six (6) building types were also used to represent the ten (10) ATB Zones. The EPA Portfolio Manager's "Public Services-Transportation Terminal/Station" building type represented the five (5) ATB Zones: Transient Space, Ticketing Check-In, Departures Hold Room, Outbound/Inbound Baggage Handling, and Arrivals/Baggage Claim (U.S. EPA 2013).

The 2003 CEUS' building types are the same as CBECS' building types except for the "Public Order & Safety." The CEUS data does not include this building type (LBNL 2008).

Table 1. Comparison of EUIs for Building Types from Difference Sources associated with ATB Zone

No.	Airport Terminal Building Zone	CBECS Data (2003)		EPA Portfolio Manager (Using 2003 CBECS Data)		California Commercial End Use Survey - CEUS (2008)	
		Building Type	Mean EUI (kBtu/ft^2-yr)	Building Type	Median EUI (kBtu/ft^2-yr)	Building Type	Median EUI (kBtu/ft^2-yr)
1	Concession Food	Food Service	258	Food Sales & Service - Fast-Food Restaurant & Restaurant (CBECS Fast-Food & CBECS – Restaurant Cafeteria)	304	Food Services - Restaurant	333
2	Concession Retail	Enclosed Mall	102	Retail - Enclosed Mall	94	Enclosed Shopping Center - Mall	80
3	Office	Office	93	Office - Office (CBECS - Office &Bank/Financial)	67	Office - Professional	53
4	Transient Space	Public Assembly	94	Public Services - Transportation Terminal/Station	45	Public Assembly	72
5	Ticketing Check-In	Public Assembly	94	Public Services - Transportation Terminal/Station	45	Public Assembly	72
6	Departures Hold Room	Public Assembly	94	Public Services - Transportation Terminal/Station	45	Public Assembly	72
7	Departure/Border Security	Public Order & Safety	116	Public Services - Police Station (CBECS - Fire Station/Police Station)	88	NA	NA
8	Outbound/Inbound Baggage Handling	Public Assembly	94	Public Services - Transportation Terminal/Station	45	Public Assembly	72
9	Arrivals / Baggage Claim	Public Assembly	94	Public Services - Transportation Terminal/Station	45	Public Assembly	72
10	Service (Mech/Elec/Server)	Other	164	Other - Utility (CBECS - Other)	79	Other - Unknown	89

In general, as illustrated in Figure 3, the EUI sources compared in this study showed a wide variation in the EUIs for each of the ATB Zones due to several reasons, such as the EUI calculation methods (mean vs. median), the different building types/Zones, and the data sources (national vs. state-based). However, several trends can be observed. First, with the exception of the “Concession Food” category, the 2003 CBECS EUI values are above all other values, which is considered acceptable for the purposes of this study since the 2003 CBECS values are the most widely used EUI values in the HVAC industry. Second, several of the EPA Portfolio Manager values appear to be unreasonably low for average values for existing facilities (i.e., Public Services).

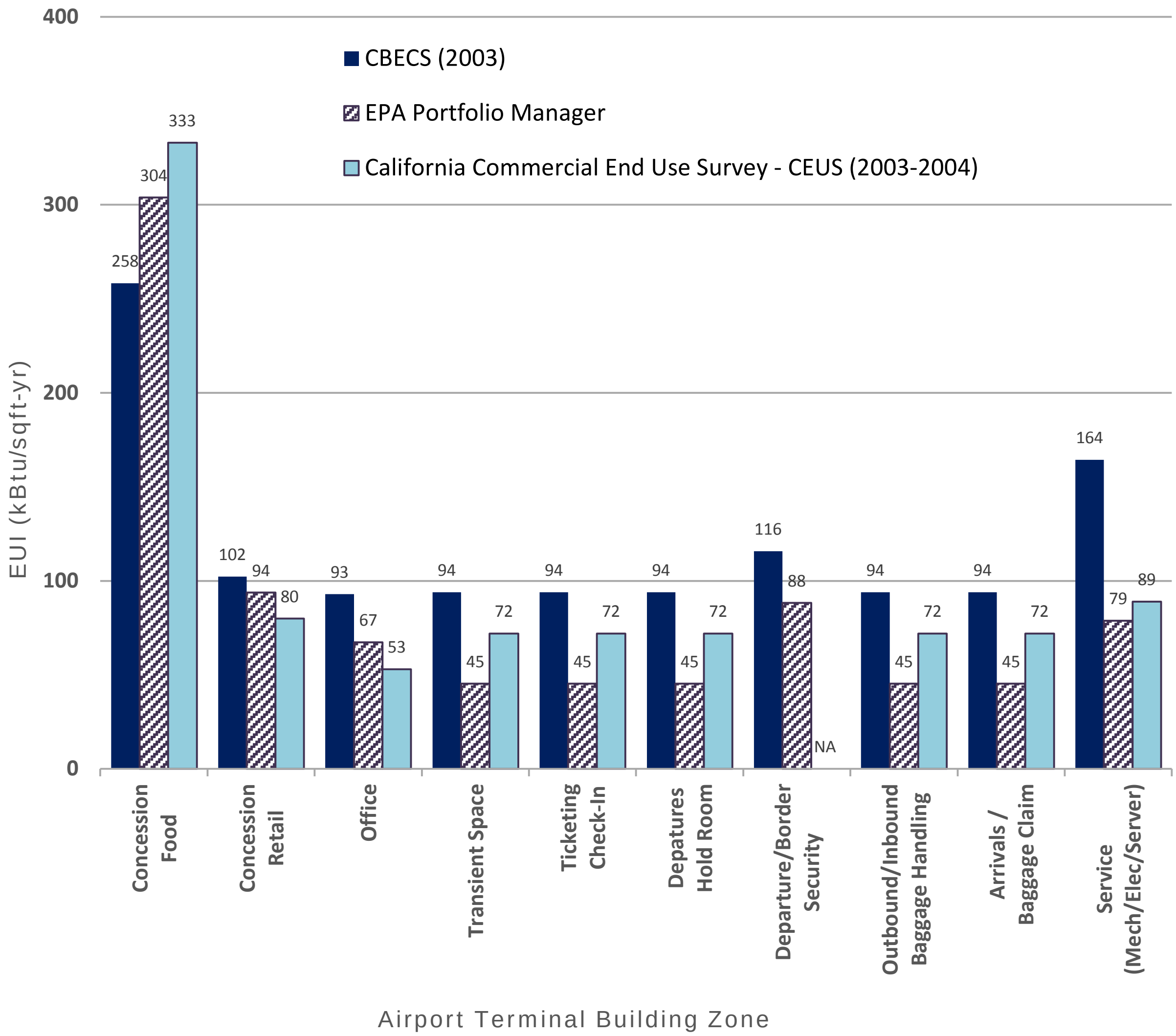


Figure 3. EUIs Comparison between Different Sources

2.2 Crosscheck with Actual Utility Data

The study included several efforts to crosscheck the Preliminary EUIs per ATB Zone with the Actual Utility Data from businesses similar to those found in ATBs (such as full-service restaurants and fast-food establishments, etc.), or sub metered data from the participating airports.

2.2.1. Crosscheck Efforts

The crosscheck efforts include the following:

- An EUI Analysis of full-service restaurants in Raleigh, North Carolina (2014):
  This restaurant analysis is based on a survey of six (6) full-service restaurants in the area surrounding Raleigh, NC. This analysis was completed with the intent of informing this study by providing a EUI reference for the Concession - Food ATB Zone. This analysis includes annual whole-building energy consumption based on electricity and natural gas consumption for twelve month utility bills.

- An EUI Analysis of full-service and fast-food restaurants in Bryan/College Station, Texas (2013-2014):
  This analysis consists of surveying and analyzing full-service and fast-food restaurants located in Bryan/College Station, TX, with the intention of providing a reference EUI for the Concession - Food ATB Zone. The survey included full-service Mexican and Asian restaurants, and fast-food establishments serving burger, sandwich, pizza, donut, coffee, and yogurt. The analysis includes annual whole-building energy consumption based on electricity and natural gas consumption, whenever was available, for twelve month utility bills.

2.2.2. Summary and Discussion of Results

The restaurant types included in the Energy Use Intensity (EUI) statistics were full-service and fast-food restaurants in Raleigh, NC and College Station, TX. Twelve month energy consumption data was considered. Both electricity and natural gas utility bills were included when possible. The analysis results are shown in Figure 4.

The full-service and fast-food restaurants data was grouped and averaged: Full service, 485 kBtu/ft^2-yr, and fast-food, 530 kBtu/ft^2-yr. The CBECS EUI for the restaurant category is 258 kBtu/ft^2-yr, a difference of 87.9% and 105.4% are observed. This large discrepancy can be due to the small sample of this study compared to the one used by CBECS, which includes nationwide spread of food-serving facilities. Therefore, for this study's reliability, the research team decided to use the reported 2003 CBECS EUI values in determination of the ATB EUI values per Zone.

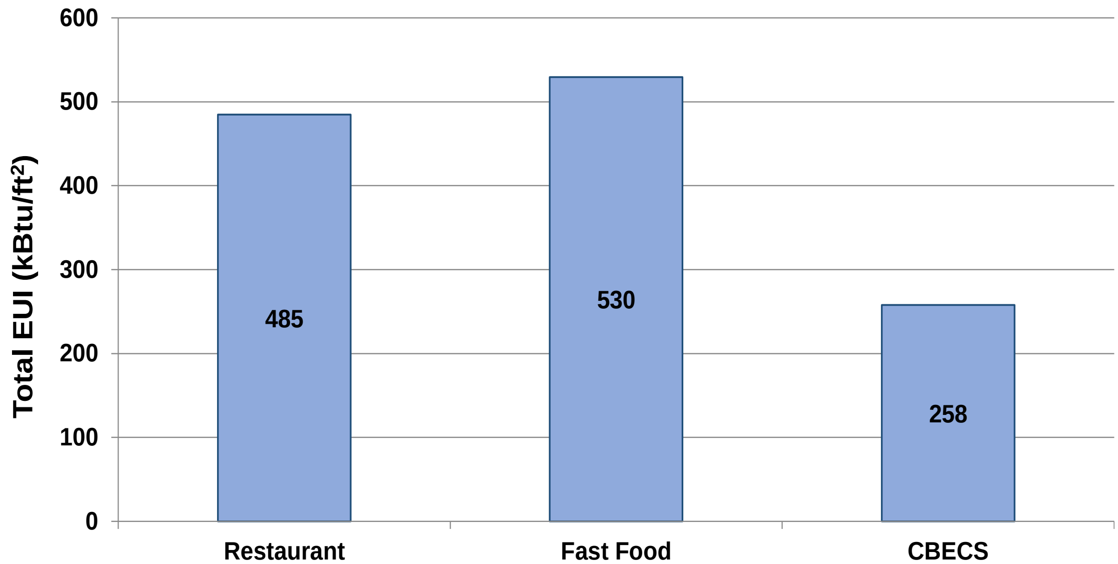


Figure 4. EUIs Comparison among Actual Utility Data Sources and CBECS Values

2.3 Final Annual EUI per ATB Zone

The research team's recommendation was to adopt the 2003 CBECS values as the Final EUI per ATB Zone. The recommendation was made despite the fact that the 2003 CBECS values for "Concession Food" are the lowest of the values among other EUI sources, so all the EUI values are consistent with the remaining categories, and to avoid the need for additional variables as required by the EPA Portfolio Manager for these categories.

Table 2. Final EUI per ATB Zone

	Airport Terminal Building (ATB) Zones	Final EUI per Zone (kBtu/sqft-yr)
1	Concession - Food	258.3
2	Concession - Retail	73.9
3	Office	92.9
4	Transient Space	93.9
5	Ticketing Check-In	93.9
6	Departures Hold Room	93.9
7	Departure/Border Security	115.8
8	Outbound/Inbound Baggage Handling	93.9
9	Arrivals/Baggage Claim	93.9
10	Service (Mech/Elec/Server)	164.4

3. Annual EU Calculation per ATB System

Figure 5 shows the process for determining the Energy Use (EU) per system that is located in an ATB or that receives energy from the ATB. In this process, systems that are specific to ATBs were identified and relevant literature was reviewed. The sources we identified assisted in the development of the method for determining the annual EU per system. The ATB Systems identified in this study include:

- People movers, escalators, elevators,
- Baggage handling systems,
- Alternative Systems (i.e., electric, heating/cooling),
- Airport Ground Support Equipment (GSE), and
- External/parking lighting.

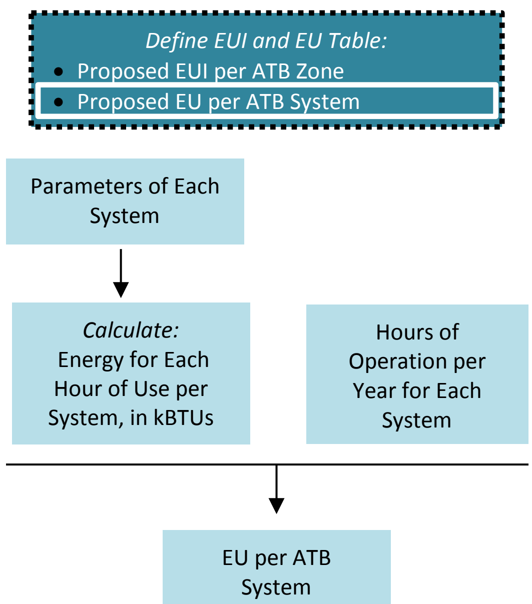


Figure 5. Defining EU per ATB System

For an Airport Terminal Building (ATB), the overall energy use of all systems would be:

$$
\begin{aligned}
EU_{\text{all-systems, total}} = \; & EU_{\text{escalator-total}} + EU_{\text{people-mover-total}} \\
& + EU_{\text{baggage handling-total}} + EU_{\text{elevator-total}} \\
& + EU_{\text{alternative systems-total}} + EU_{\text{ground support equipment}} \\
& + EU_{\text{external/parking lighting}} \\
& + EU_{\text{other}}
\end{aligned}
$$

Where:

$EU_{\text{all-systems, total}}$ = Annual energy use of all systems (kBtu/yr).

3.1 Annual EU of Escalator, People-mover and Baggage Handling Systems.

Figure 6 illustrates the process of calculating the total annual energy use for escalators, people movers (moving walkways), and baggage handling systems (TIAX, 2006).

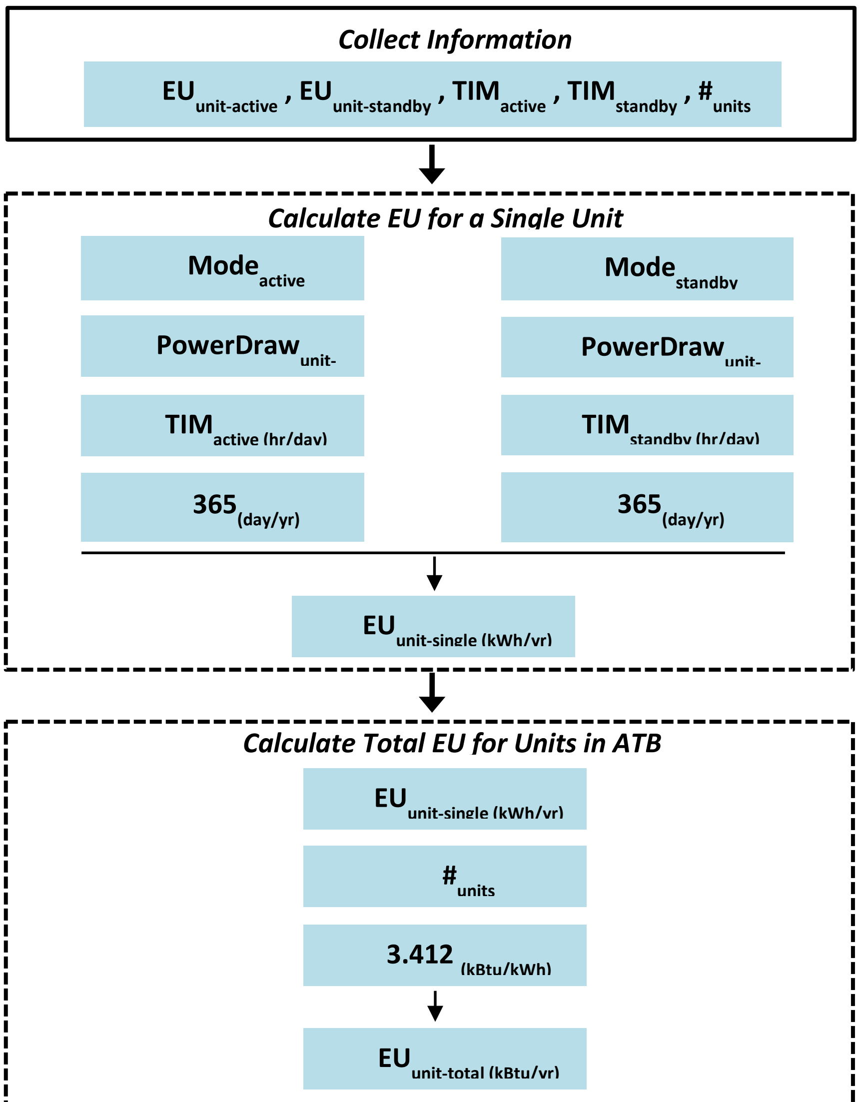


Figure 6. Calculating Total Annual Energy Use for Escalators, Moving Walkways, and Baggage Handling Systems in ATB

3.1.1 Annual EU of Escalator Systems:

$$EU_{escalator\text{-}total} = \{(EU_{escalator\text{-}active} \text{ x } TIM_{active} \text{ x } 365) + (EU_{escalator\text{-}standby} \text{ x } TIM_{standby} \text{ x } 365)\} \text{ x } \#_{units} \text{ x } 3.412$$

Where:

$EU_{escalator\text{-}total}$ = Annual electricity use of all units in the ATB (kBtu/yr),
$EU_{escalator\text{-}active}$ = Power Draw per Unit in mode; active (kW),
TIM_{active} = Time in mode; active (hr/day),
$EU_{escalator\text{-}standby}$ = Power Draw per Unit in mode; standby (kW),
$TIM_{standby}$ = Time in mode; standby (hr/day),
$\#_{units}$ = Number of Escalators in Airport Terminal Building.
1 kWh = 3.412 kBtu

In TIAX 2006, pg. 30, the Commercial Loads – Escalators – Key Assumptions are:

Table 3. Commercial Loads, Escalators—Key Assumptions

		2005	2010	2015	2020	2030
Installed Base [thousands]		35	38	41	44	51
Power Draw [W]	**Avg. Operating**	4,671	4,671	4,671	4,671	4,671
	Off*	0	0	0	0	0
Annual Usage [hours]	**Avg. Operating**	4,380	4,380	4,380	4,380	4,380
	Off	4,380	4,380	4,380	4,380	4,380
UEC [kWh/year]		20,500	20,500	20,500	20,500	20,500
AEC [TWh/year]		0.7	0.8	0.8	0.9	1.0

Assuming standard Power Draw per unit (TIAX 2006, pg. 30, Commercial Loads – Escalators – Key Assumptions):

$EU_{escalator\text{-}active}$ = 4.671 kW
$EU_{escalator\text{-}standby}$ = 0 kW

$$EU_{escalator\text{-}total} = \{(4.671 \text{ kW x } TIM_{active} \text{ x } 365) + (0 \text{ kW x } TIM_{standby} \text{ x } 365)\} \text{ x } \#_{units} \text{ x } 3.412$$

Assuming standard Annual Unit usage (TIAX 2006, pg. 30, Commercial Loads – Escalators – Key Assumptions):

TIM_{active} = 4380 hr/yr / 365 = 12 hr/day
$TIM_{standby}$ = 4380 hr/yr / 365 = 12 hr/day

$$EU_{escalator\text{-}total} = \{(4.671 \text{ kW x } 12 \text{ hr/day x } 365 \text{ day/yr}) + (0 \text{ W x } 12 \text{ hr/day x } 365 \text{ day/yr}) \text{ x } \#_{units} \text{ x } 3.412$$

$$EU_{escalator\text{-}total} = 20{,}458 \text{ kWh/yr x } \#_{units} \text{ x } 3.412 \text{ kBtu/kWh}$$

$$EU_{escalator\text{-}total} = 69{,}806 \text{ kBtu/yr x } \#_{units}$$

3.1.2 Annual EU of People-Mover Systems:

$$EU_{people\ mover\text{-}total} = \{(EU_{people\ mover\text{-}active} \times TIM_{active} \times 365) + (EU_{people\ mover\text{-}standby} \times TIM_{standby} \times 365)\} \times \#_{units} \times 3.412$$

Where:

$EU_{people\ mover\text{-}total}$ = Annual electricity use of all units in the ATB (kBtu/yr),
$EU_{people\ mover\text{-}active}$ = Power Draw per Unit in mode; active (kW),
TIM_{active} = Time in mode; active (hr/day),
$EU_{people\ mover\text{-}standby}$ = Power Draw per Unit in mode; standby (kW),
$TIM_{standby}$ = Time in mode; standby (hr/day),
$\#_{units}$ = Number of Units in Airport Terminal Building.
1 kWh = 3.412 kBtu

Assuming a standard Power Draw per unit (Otis 2000):

$EU_{people\ mover\text{-}active}$ = 10.4 hp = 7.755 kW
$EU_{people\ mover\text{-}standby}$ = 0 kW

$$EU_{people\ mover\text{-}total} = \{(7.755\ kW \times TIM_{active} \times 365) + (0\ kW \times TIM_{standby} \times 365)\} \times \#_{units} \times 3.412$$

Assuming the people movers standard Annual Unit usage is similar to the escalators (TIAX 2006, pg. 30, Commercial Loads – Escalators – Key Assumptions):

TIM_{active} = 4380 hr/yr / 365 =12 hr/day
$TIM_{standby}$ = 4380 hr/yr / 365 =12 hr/day

$$EU_{people\ mover\text{-}total} = \{(7.755\ kW \times 12\ hr/day \times 365\ day/yr) + (0\ kW \times 12\ hr/day \times 365\ day/yr)\} \times \#_{units} \times 3.412$$
$$EU_{people\ mover\text{-}total} = 33{,}966.900\ kWh/yr \times \#_{units} \times 3.412\ kBtu/kWh$$
$$EU_{people\ mover\text{-}total} = 115{,}895\ kBtu/yr \times \#_{units}$$

3.1.3 Annual EU of Baggage Handling Systems:

$$EU_{baggage\ handling\text{-}total} = \{(EU_{baggage\ handling\text{-}active} \times TIM_{active} \times 365) + (EU_{baggage\ handling\text{-}standby} \times TIM_{standby} \times 365)\} \times \#_{units} \times 3.412$$

Where:

$EU_{baggage\ handling\text{-}total}$ = Annual electricity use of all units in the ATB (kBtu/yr),
$EU_{baggage\ handling\text{-}active}$ = Power Draw per Unit in mode; active (kW),
TIM_{active} = Time in mode; active (hr/day),
$EU_{baggage\ handling\text{-}standby}$ = Power Draw per Unit in mode; standby (kW),
$TIM_{standby}$ = Time in mode; standby (hr/day),
$\#_{units}$ = Number of Units in Airport Terminal Building.
1 kWh = 3.412 kBtu

Using an example from Harrisburg International Airport (MDT) for Power Draw per unit:

$EU_{baggage\ handling\text{-}active} = 1.5\ hp = 1.119\ kW$
$EU_{baggage\ handling\text{-}standby} = 0\ W$

$$EU_{baggage\ handling\text{-}total} = \{(1.119\ kW \times TIM_{active} \times 365) + (0\ kW \times TIM_{standby} \times 365)\} \times \#_{units} \times 3.412$$

Using an example case of Harrisburg International Airport (MDT) for Annual Unit Usage:

$TIM_{active} = 16\ hr/day$
$TIM_{standby} = 8\ hr/day$

$$EU_{baggage\ handling\text{-}total} = \{(1.119\ kW \times 16\ hr/day \times 365\ day/yr) + (0\ kW \times 8\ hr/day \times 365\ day/yr)\} \times \#_{units} \times 3.412$$

$$EU_{baggage\ handling\text{-}total} = 6{,}532.333\ kWh/yr \times \#_{units} \times 3.412\ kBtu/kWh$$

$$EU_{baggage\ handling\text{-}total} = 22{,}288\ kBtu/yr \times \#_{units}$$

3.2 Annual EU of Elevators

Figure 7 illustrates the process of calculating the total annual energy use for elevators (TIAX, 2006).

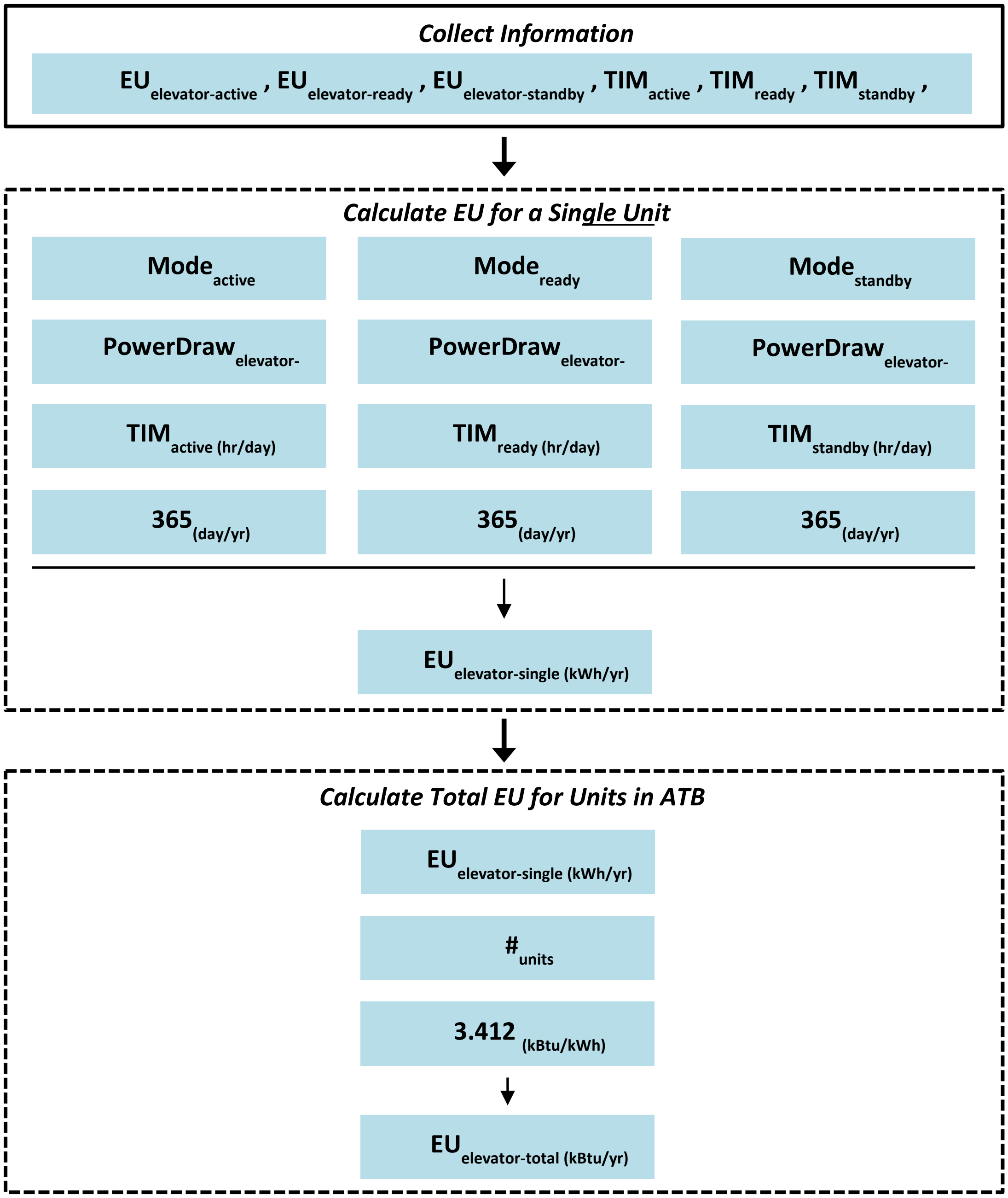


Figure 7. Calculating Total Annual Energy Use for Elevators in ATB

The annual Energy Use (EU) of elevators is calculated using (TIAX 2006):

$$EU_{elevator\text{-}total} = \{(EU_{elevator\text{-}active} \times TIM_{active} \times 365) + (EU_{elevator\text{-}ready} \times TIM_{ready} \times 365) + (EU_{elevator\text{-}standby} \times TIM_{standby} \times 365)\} \times \#_{units} \times 3.412$$

Where:

$EU_{elevator\text{-}total}$ = Annual electrical energy use of all elevators in the ATB (kBtu/yr),
$EU_{elevator\text{-}active}$ = Power Draw per Unit in mode; active (kW),
TIM_{active} = Time in mode; active (hr/day),
$EU_{elevator\text{-}ready}$ = Power Draw per Unit in mode; ready (kW),
TIM_{ready} = Time in mode; ready (hr/day),
$EU_{elevator\text{-}standby}$ = Power Draw per Unit in mode; standby (kW),
$TIM_{standby}$ = Time in mode; standby (hr/day),
$\#_{units}$ = Number of elevator Units in Airport Terminal Building.
1 kWh = 3.412 kBtu

In TIAX 2006, pg. 28, the Commercial Loads – Elevators – Key Assumptions are:

Table 4. Commercial Loads, Elevators – Key Assumptions

		2005	2010	2015	2020	2030
Installed Base [thousands]		590	640	700	760	900
Power Draw [W]	**Active**	10,000	10,000	10,000	10,000	10,000
	Ready	500	500	500	500	500
	Standby	250	250	250	250	250
Annual Usage [hours]	**Active**	300	300	300	300	300
	Ready	8,460	7,365	6,270	5,175	4,080
	Standby	0	1,095	2,190	3,285	4,380
UEC [kWh/year]		7,400	7,000	6,700	6,400	6,200
AEC [TWh/year]		4.4	4.5	4.7	4.9	5.5

Assuming standard Power Draw per unit (TIAX 2006, pg. 28, Commercial Loads – Elevators – Key Assumptions):

$EU_{elevator\text{-}active}$ = 10 kW
$EU_{elevator\text{-}ready}$ = 0.5 kW
$EU_{elevator\text{-}standby}$ = 0.25 kW

$$EU_{elevator} = \{(10\text{ kW} \times TIM_{active} \times 365) + (0.5\text{ kW} \times TIM_{ready} \times 365) + (0.25\text{ kW} \times TIM_{standby} \times 365)\} \times \#_{units} \times 3.412$$

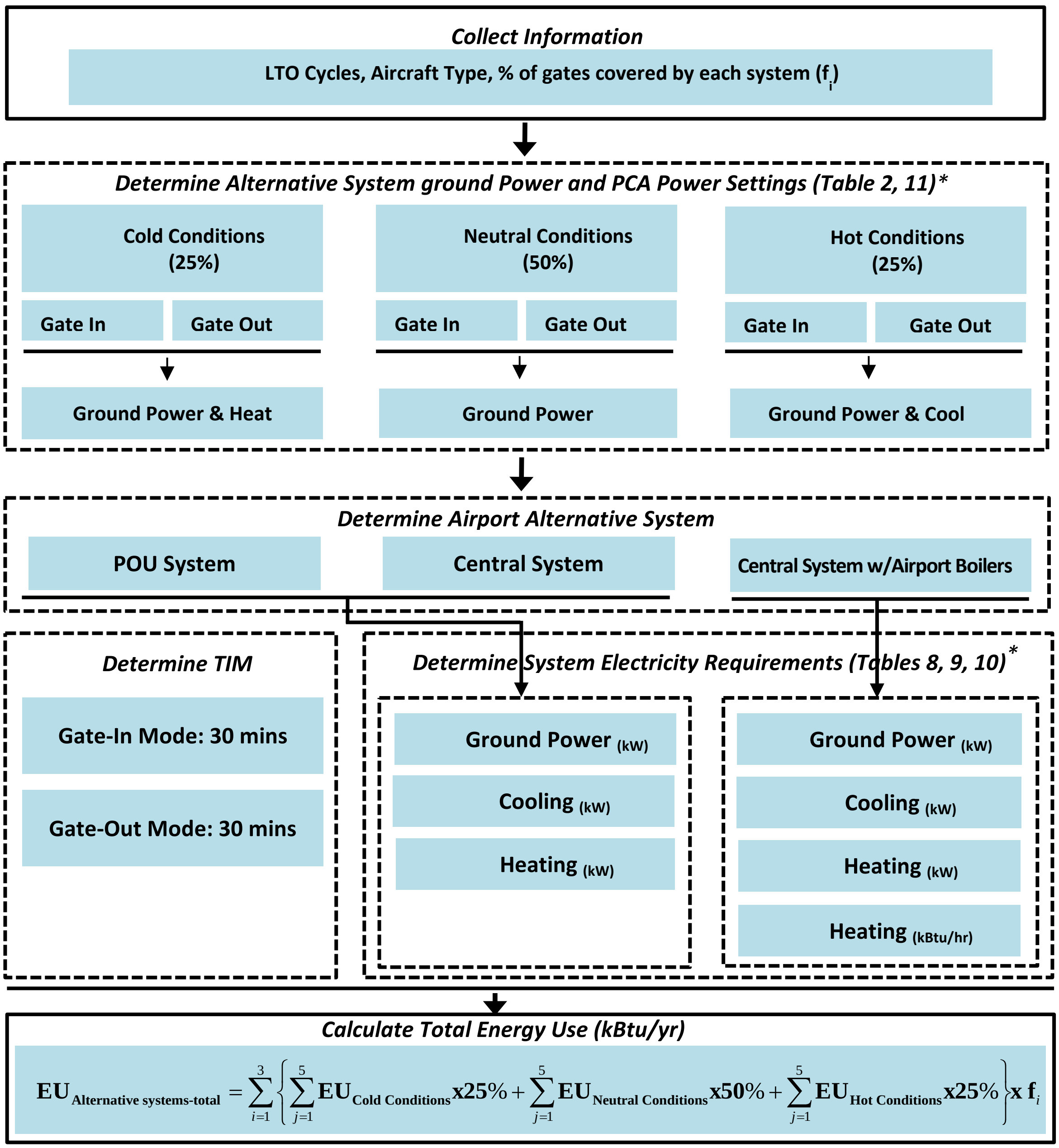
Assuming standard Annual Unit Usage (TIAX 2006, pg. 28, Commercial Loads – Elevators – Key Assumptions):

TIM_{active} = 300 hr/yr / 365 = 0.82 hr/day
TIM_{ready} = 8,460 hr/yr / 365 = 23.18 hr/day
$TIM_{standby}$ = 0 hr/day

$EU_{elevator\text{-}total}$ = {(10 kW x 0.82 hr/day x 365 day/yr) + (0.5 kW x 23.18 hr/day x 365 day/yr) + (0.25 kW x 0 hr/day x 365 day/yr)} x $\#_{units}$ x 3.412 kBtu/kWh
$EU_{elevator\text{-}total}$ = 7,223 kWh/yr x $\#_{units}$ x 3.412
$EU_{elevator\text{-}total}$ = 24,646 kBtu/yr x $\#_{units}$

3.3 Annual EU of Alternative Systems (Ground Power and PCA)

Figure 8 illustrates the process of calculating the total annual energy use of Alternative Systems, including Ground Power and PCA Power (Environmental Science Associates 2012). Following our site visits and further research, the Time In Mode (TIM) for both the gate-in mode and the gate-out mode were set to 30 minutes. Due to the lack of a definitive study of US airlines, the TIM for all aircraft types are assumed to be the same. However, to refine this, the survey form allows new users from airports to input more accurate TIM per aircraft type according to their knowledge for better predictions. If no new information is provided, the calculation will use the default value of 30 minutes for gate-in and for gate-out modes, which means 60 minutes for a full Landing/Takeoff (LTO) cycle, regardless of the aircraft type.



Source: Tables from ACRP Report 64 (Environmental Sciences Associates 2012)

Figure 8. Calculating Total Annual Energy Use of Alternative Systems in ATB

The annual Energy Use (EU) of Alternative Systems is calculated using (Environmental Science Associates 2012):

$$\mathbf{EU}_{\textbf{Alternative systems-total}} = \sum_{i=1}^{3}\left\{\sum_{j=1}^{5}\mathbf{EU}_{\textbf{Cold Conditions}}\mathbf{x25\%} + \sum_{j=1}^{5}\mathbf{EU}_{\textbf{Neutral Conditions}}\mathbf{x50\%} + \sum_{j=1}^{5}\mathbf{EU}_{\textbf{Hot Conditions}}\mathbf{x25\%}\right\}\mathbf{x\ f}_i$$

Where:

$EU_{\text{Alternative systems-total}}$ = Annual electrical energy use of all Alternative System units in the ATB (kBtu/yr),
$EU_{\text{Cold Conditions}}$ = $EU_{\text{ground power}}$ + EU_{heating},
$EU_{\text{Neutral Conditions}}$ = $EU_{\text{ground power}}$,
$EU_{\text{Hot Conditions}}$ = $EU_{\text{ground power}}$ + EU_{cooling} ,
i = 1,2,3, representing three alternative system types, including POU system, Central system, and Central system with Airport Boilers,
j = 1,2,3,4,5, representing up to five aircraft types, including narrow body, wide body, jumbo-wide body, regional jet, and turbo prop,
f_i = Percentage of gates using this system to deliver ground power, heating and cooling.

Then, the $EU_{\text{Alternative systems-total}}$ expression can be simplified as:

$$\boxed{\mathbf{EU}_{\textbf{Alternative systems-total}} = \sum_{i=1}^{3}\left\{\sum_{j=1}^{5}\mathbf{EU}_{\textbf{ground power}} + \sum_{j=1}^{5}\mathbf{EU}_{\textbf{heating}}\mathbf{x25\%} + \sum_{j=1}^{5}\mathbf{EU}_{\textbf{cooling}}\mathbf{x25\%}\right\}\mathbf{x\ f}_i}$$

Where:

$EU_{\text{ground power}}$ = EP x (TIM/60) x $LTO_{\text{cycles/yr}}$ x 3.412

Where:

$EU_{\text{ground power}}$ = Annual electricity used by the alternative systems (kBtu/yr),
EP = Electric power (kW); values from ACRP Report 64, Tables 8, 9, or 10 (below),
TIM = Time in mode (min/LTO); values from ACRP Report 64, Table 3 (below),
$LTO_{\text{cycles/yr}}$ = Number of Landing and Takeoff cycles per year (Number of cycles/yr).

EU_{heating} = (HP x3.412+HR) x (TIM/60) x $LTO_{\text{cycles/yr}}$

Where:

EU_{heating} = Annual heating energy used by the alternative systems (kBtu/yr),
HP = Heating power (kW); values from ACRP Report 64, Tables 8, 9, or 10 (below),
HR=Heating rate (Btu/hr) for natural gas; if any, values from ACRP Report 64, Table 10 (below),
TIM = Time in mode (min/LTO),
$LTO_{\text{cycles/yr}}$ = Number of Landing and Takeoff cycles per year (Number of cycles/yr).

EU_{cooling} = CP x (TIM/60) x $LTO_{\text{cycles/yr}}$ x3.412

Where:

EU_{cooling} = Annual cooling energy use of the alternative systems (kBtu/yr),
CP = Cooling Power (kW),
TIM = Time in mode (min/LTO),
$LTO_{\text{cycles/yr}}$ = Number of landing and takeoff cycles per year (Number of cycles/yr).

The above calculations use the following Tables (Environmental Science Associates 2012):

Table 3. APU activity information—default times in mode (TIM).

Aircraft Category	APU Start (min/LTO)	Gate Out (min/LTO)	Main Engine Start (min/LTO)	Gate In (min/LTO)	Total APU Use (min/LTO)	Total Ground-Based Infrastructure Use (min/LTO)
Narrow Body	3	3.60	0.58	15	22.18	18.6
Wide Body	3	3.60	0.58	15	22.18	18.6
Jumbo-Wide Body	3	5.30	2.33	15	25.63	18.6
Regional Jet	3	3.60	0.58	15	22.18	18.6
Turbo Prop	3	3.60	0.58	15	22.18	18.6

APU TIM data source: ICAO, 2007. Note that consistent with the FAA's VALE Technical Report, the alternative systems would only be used during the Gate Out TIM and the Gate In TIM.

Table 8. POU system electricity requirements.

Aircraft Category	Ground Power (KW)	Cooling (KW)	Heating (KW)
Narrow Body	23.88	68.64	46.71
Wide Body	37.12	174.04	96.71
Jumbo-Wide Body	53.21	189.95	113.73
Regional Jet	13.30	39.33	16.68
Turbo Prop	26.60	31.16	12.72

SOURCE: ASE, 2011.

Table 9. Central system electricity requirements.

Aircraft Category	Ground Power (KW)	Cooling (KW)	Heating (KW)
Narrow Body	23.88	48.84	46.71
Wide Body	37.12	130.49	96.71
Jumbo-Wide Body	53.21	152.64	113.73
Regional Jet	13.30	27.15	16.68
Turbo Prop	26.60	21.20	12.72

SOURCE: ASE, 2011.

Table 10. Central system with airport boilers electricity requirements.

Aircraft Category	Ground Power (KW)	Cooling (KW)	Heating (KW)	Heating (1,000 BTU/hr)
Narrow Body	23.88	48.84	6.68	128.31
Wide Body	37.12	130.49	16.41	258.33
Jumbo-Wide Body	53.21	152.64	17.96	309.00
Regional Jet	13.30	27.15	3.74	42.90
Turbo Prop	26.60	21.20	3.74	30.00

SOURCE: ASE, 2011.

Figure 9. Source: Environmental Sciences Associates. ACRP Report 64: Handbook for Evaluating Emissions and Costs of APUs and Alternative Systems. Tables 3, 8, 9, 10

3.4 Annual EU of Ground Support Equipment (GSE)

The annual Energy Use (EU) of Alternative Systems is calculated using:

$$\mathbf{EU_{Ground\ Support\ Equipment}} = \sum_{k=1}^{N} \mathbf{(GSx\ TIM_{active} + EU_{Standby}x\ TIM_{standby})\ x\ 365\ x3.412}$$

Where:

$EU_{Ground\ Support\ Equipment}$ = Annual energy use of the ground support equipment (kBtu/yr),
GS = Ground Support power (kW),
TIM_{active} = Time in mode, active (hr/day),
$EU_{Standby}$ = Electric power in standby mode (kW),
$TIM_{standby}$= Time in mode, standby (hr/day),
k=1,2,…,N, representing N types of ground support equipment.

3.5 Annual EU of External Lighting and Parking Lighting

The total annual Energy Use (EU) of Exterior Lighting is calculated using:

$EU_{exterior\ lighting} = EU_{exposed\ lighting} + EU_{covered\ lighting}$

Where:

$EU_{exposed\ lighting}$ (kBtu) = (LPD/1000) x A (ft^2) x 12 (hr/day) x 365 (day/yr) x 3.412 (kBtu/kWh)

$EU_{covered\ lighting}$ (kBtu) = (LPD/1000) x A (ft^2) x 24 (hr/day) x 365 (day/yr) x3.412(kBtu/kWh)

Where:

LPD = Lighting Power Density (W/ft^2),
A= Area illuminated (ft^2).

4. Estimation of ATB's Measured Annual EU based on Utility Information

The utility bills are used to calculate the (measured) Energy Use (EU) of an individual Airport Terminal Building (ATB). The utility bills usually consist of electricity consumption (kWh) and gas consumption (MCF or therms) data. The utility bills should include all of the energy consumption of an ATB, such as lighting, equipment, heating, and cooling. The total EU is then estimated by:

$EU_{Total} = EU_{ATB\ Electricity} + EU_{ATB\ Natural\ Gas}$

Where

$EU_{ATB\ Electricity}$, is the EU that corresponds to the total electricity use in the ATB,
$EU_{ATB\ Natural\ Gas,}$ is the EU that corresponds to the total natural gas use in the ATB

However, there are certain cases where the utility information includes the heating and cooling energy consumption (i.e., chilled water and heating hot water). This often occurs at a large airport, when a thermal plant provides Chilled Water (CHW) and Heating Hot Water (HHW) for cooling and heating to multiple ATBs that are metered. In these cases, the total EUI for an ATB becomes:

$EU_{Total} = EU_{CHW} + EU_{HHW} + EU_{ATB\ Electricity\text{-}non\ CHW} + EU_{ATB\ Natural\ Gas\text{-}non\ HHW}$

Where

$EU_{CHW,}$ is the EU that corresponds to the chilled water use in the ATB,
$EU_{HHW,}$ is the EU that corresponds to the heating hot water use in the ATB,
$EU_{ATB\ Electricity\text{-}non\ CHW}$, is the EU that corresponds to the electricity use in the ATB for lighting and equipment,
$EU_{ATB\ Natural\ Gas\text{-}non\ HHW,}$ is the EU that corresponds to the natural gas use in the ATB that is not for heating.

For these cases, it is necessary to adjust the heating and cooling energy portion of the utility information in order to estimate the electricity or natural gas that would be required to generate the CHW and HHW. To accomplish this, the recommended thermal plant efficiencies are 1.0 kW/ton for the CHW production (Ostendorp 2010), and 80% for the HHW generation (Durkin 2006). In such cases the metered CHW and HHW consumption data are adjusted by the above factors to calculate the ATB's EUI. The equations to calculate the corresponding Energy Use (EU) for CHW and HHW are as follows.

EU_{CHW} (kBtu/yr) = 3.412 (kBtu/kWh) x CHW (kBtu/yr) x 1.0 (kW/ton) x 1 (ton) / 12 (kBtu/h)

EU_{HHW} (kBtu/yr) = HHW (kBtu/yr) / 80 (%)

5. The Complete ATB Annual EU/EUI Table

Table 5 summarizes the results of the various estimations that together combine the baseline of the total annual EU and EUI for the ATB building. As described in section 1. Overview of the Data Collection and Analysis Process, the total annual EU estimations include: the calculations of the EU per ATB Zone, which are rooted in square footage parameters of each Zone and the CBECS EUI values associated with each type of Zone (see subsection 2.3 Final Annual EUI per ATB Zone); and the estimations of the annual EU per ATB system, which are based on individual parameters of each system and its particular annual EU estimation method (see section 3. Annual EU Calculation per ATB System). The separate line below the table includes the estimated measured ATB annul EU, which is based on the ATB utility information provided by the airport (see section 4. Estimation of ATB's Measured Annual EU based on Utility Information). All individual EU values as well as the two subtotals and the two total EUs are then converted to EUI values by dividing them by the total square footage of the ATB.

Table 5. The Complete ATB Annual EU/EUI Table

				Terminal Gross Area (sq.ft.):		
		Airport Terminal Building (ATB) Zones / Systems	**EUI per Zone (kBtu/sqft-yr)**	**Floor Area (sqft)**	**EU (kBtu/yr)**	**Total EUI (kBtu/sqft-yr)**
ATB Zones	1	Concession - Food	258.3			
	2	Concession - Retail	73.9			
	3	Office	92.9			
	4	Transient Space	93.9			
	5	Ticketing Check-In	93.9			
	6	Departures Hold Room	93.9			
	7	Departure/Border Security	115.8			
	8	Outbound/Inbound Baggage Handling	93.9			
	9	Arrivals/Baggage Claim	93.9			
	10	Service (Mech/Elec/Server)	164.4			
		Subtotal for all ATB Zones				
ATB Systems	11	People Movers, Escalators, Elevators				
	12	Baggage Handling Systems				
	13	Alternative Systems (Ground Power and PCA)				
	14	Airport Ground Support Equipment (GSE) Charging Systems				
	15	External Lighting, Parking Lighting				
		Subtotal for all ATB Systems				
		Total for ATB Zones and Systems				

Total for ATB based on Utility Bills		

6. Input Form

The following pages present the final *Input Form* used for the collection of data from participating ATBs, on which the EUI benchmarking analysis is based. This form is being converted into a dynamic .pdf format, to be used in the prototype online system.

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TERMINAL ENERGY USE INDICES BENCHMARKING INPUT FORM

(Version 24)

Any information provided by the participants is confidential.

A separate input form should be filled in for each Airport Terminal Building.

Date of Survey Airport Name: Airport Code: State/Province: Alabama

Contact Information

Name:

Title:

Phone Number

Email:

Airport Terminal Building - General Information

Terminal Name:

Terminal Construction Year:

Terminal Renovation Year:

Number of Gates:

Number of Floors:

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Airport Terminal Building - Floor Space Information

The following table provides 10 zone categories.

(a) Please complete the "Total Airport Terminal Building Floor Area" in the last raw of the table for your Airport Terminal Building.

(b) Please complete the floor area breakdown per Airport Terminal Zone using the "Percentage of the Total Floor Area (%)" column or the "Floor Area (ft^2)" column.

Airport Terminal Building Conditioned Space Zone Information

No.	Airport Terminal Zones	Floor area (ft2)	Percentage of Total Floor Area
1	Concession - Food	0	0%
2	Concession - Retail	0	0%
3	Office	0	0%
4	Transient Space	0	0%
5	Ticketing Check-In	0	0%
6	Departures Hold Room	0	0%
7	Departure/Border Security	0	0%
8	Outbound/Inbound Baggage Handling	0	0%
9	Arrivals/Baggage Claim	0	0%
10	Service	0	0%
Total Airport Terminal Building Floor Area		0	

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Airport Terminal Building - Mechanical Systems

Please complete the following tables for the mechanical systems that exist in your Airport Terminal Building:

Airport Terminal Building - Baggage Handling Systems Information

	Model No. (optional)	Manufacturer (optional)	Power (kW) (required)	Avg. Operation Hours in active Mode (Hours/Day) (required)	Operation Days (Days/Year) (required)	No. of Units (required)
Add Row Delete Row						

Airport Terminal Building - People Mover Systems Information

	Model No. (optional)	Manufacturer (optional)	Power (kW) (required)	Avg. Operation Hours in active Mode (Hours/Day) (required)	Operation Days (Days/Year) (required)	No. of Units (required)
Add Row Delete Row						

Airport Terminal Building - Escalators Information

	Model No. (optional)	Manufacturer (optional)	Power (kW) (required)	Avg. Operation Hours in active Mode (Hours/Day) (required)	Operation Days (Days/Year) (required)	No. of Units (required)
Add Row Delete Row						

Airport Terminal Building - Elevators Information

	Model No. (optional)	Manufacturer (optional)	Power (kW) (required)	Avg. Operation Hours in active Mode (Hours/Day) (required)	Avg. Operation Hours in ready Mode (Hours/Day) (required)	Operation Days (Days/Year) (required)	No. of Units (required)
Add Row Delete Row							

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Airport Terminal Building - Airport Ground Support Equipment (GSE) Electricity Use

Please complete the following table on the GSE that are at your Airport Terminal Building:

Airport Terminal Building - GSE Information

GSE Type	Model No. (optional)	Manufacturer (optional)	Power (kW) (required)	Avg. Operation Hours in Active Mode (Hours/Day) (required)	Operation Days (Days/Year) (required)	No. of Units (required)
De-icing Cart						
Ramping Cart						
Jet Engine Airstart Cart						
Aircraft Tug						
Portable Ground Power						
Add Row Delete Row Other						

Airport Terminal Building - Alternative Systems (Ground Power & PCA Power)

Please mark all systems that apply for each gate with **X** and provide the annual Landing TakeOff (LTO) cycles for each aircraft type at each gate.

	Gate No.	400 Hz Ground Power	PCA					Annual LTO Cycles of Aircraft Types				
				Airport Central Terminal		Terminal Building Plant		Narrow Body	Wide Body	Jumbo-Wide Body	Regional Aircraft	Turbo Jet
			POU	Chiller	Boiler	Chiller	Boiler					
Add Row Delete Row												

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Please provide the Time In Mode for the gate in, gate out operation (default: 30 mins).

Time In Mode (TIM) for Different Aircraft Types

	Narrow Body	Wide Body	Jumbo-Wide Body	Regional Jet	Turbo Prop
Gate In (min./LTO)	30	30	30	30	30
Gate Out (min./LTO)	30	30	30	30	30

Table 1. Aircraft types and auxiliary power units grouped by aircraft category.

Aircraft Category	Example Aircraft Types	Representative APUs
Narrow Body	Boeing 737-700 Series, Boeing MD-80 Series, Airbus A320 Series, Boeing 757-200 Series, Airbus A319-100 Series, Boeing 737-800 Series, Boeing 737-300 Series, Boeing 717-200 Series, Embraer ERJ170, Embraer ERJ175.	GTCP 36-300 (80 HP), GTCP 85 (200 HP), GTCP85-98 (200 HP), GTCP85-129 (200 HP), GTCP-129H, GTCP 331-9B, GTCP 331-200, GTCP 85-98, GTCP 36-150, GTCP 36-4A.
Wide Body	Boeing 767-300 Series, Boeing 777-200 Series, Airbus A300B/C/F-600 Series, Boeing 767-200 Series, Boeing 767-400, Airbus A310-200 Series, Boeing 777-300 Series, Airbus A300B/C/F Series, Airbus A310-300 Series, Boeing 787-300 Series.	TSCP700-4B, GTCP331-200ER, GTCP331-500, APS 5000.
Jumbo - Wide Body	Boeing 747-400 Series, Airbus A330-200 Series, Airbus A340-200 Series, Boeing 747-200/300 Series, Airbus A330-300 Series, Airbus A340-600 Series, Airbus A340-300 Series, Airbus A340-500 Series, Boeing 747-100 Series, Airbus A380 Series.	GTCP 331-350, PW-980, GTCP 660, APU PW901A.
Regional Jet	Bombardier CRJ-200/400, Embraer ERJ145, Bombardier CRJ-700, Bombardier CRJ-900, Embraer ERJ140, Bombardier CRJ-100, Embraer ERJ135, Domier 328 Jet, BAE 146-100, BAE 146-200.	GTCP 36-100, GTCP 36-150, GTCP 85.
Turbo Prop	DeHavilland DHC-8-400, DeHavilland DHC-8-100, Embraer EMB120 Brasilia, DeHavilland DHC-8-300, DeHavilland DHC-8-200, Shorts 360-100 Series, DeHavilland DHC-7 Dash 7, Embraer EMB110 Bandeirante, Fokker F27-100 Series, Fokker F27-200 Series.	T-62T-40C7, APS 1000 T-62T-46C12, GTCP 36-150, GTCP 30-54.

SOURCE: Developed from the FAA's Emissions and Dispersion Modeling System (EDMS) fleet database (FAA 2010a).

Airport Terminal Building - External Lighting/ Parking Lighting

Is the energy consumption of the external lighting and/or parking lighting included in the Airport Terminal Building utility bill?

☐ Yes ☐ No

If "Yes", please provide the following information:

☐ Covered illuminated area (sq. ft.):

☐ Uncovered illuminated area (sq. ft.):

Note: include only that portion of the areas included in the ATB utility bill.

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Airport Terminal Building - Performance and Utilities Information

Please provide 12-month metered utility data for the Airport Terminal Building. If monthly utility data is not available, please provide the total annual utility data.

Airport Terminal Building - Annual Utility Information

	From (m/d/yy)	To (m/d/yy)	Electricity (kWh/month)	From (m/d/yy)	To (m/d/yy)	Natural Gas/ Fuel Oil ☐ MCF ☐ CCF ☐ Therms	From (m/d/yy)	To (m/d/yy)	Other: CHW (MMBtU/month)	Other: HHW (MMBtU/month)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
Total Annual				Total Annual			Total Annual			

Note: If a terminal has both Natural Gas and Fuel Oil, then please combine those bills into a single number. Please give fuel oil in therms.

Is monthly sub-metered utility data available for the Airport Terminal Building? ☐ Yes ☐ No

If "Yes", please check all that apply: ☐ Electricity ☐ Natural Gas ☐ Other (please specify):

Is the thermal plant energy use included in the Airport Terminal Building utility data? ☐ Yes ☐ No

If "No", please provide the average annual plant efficiency (defaults: shown)

Heating Efficiency	80%
Cooling Efficiency (kW/ton)	1

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7. Site Visits

The study included walk-throughs of the participating ATB facilities. This section describes the ideas behind the site visits and their contribution to this study.

7.1. Purpose

The walk-throughs were originally aimed at: (1) completing and verifying information collected on the ATB systems and zones that are required for the EU/EUI Table benchmarking analysis, (2) characterizing the building space utilization, building loads and occupancy, (3) developing baselines for indoor air quality, and (4) collecting configuration, nameplate and operational data on the installed lighting and mechanical equipment.

In reality, the site visits resulted in collecting missing information required for the EU/EUI Table benchmarking analysis and completing all fields of the *Input Form*, as well as confirming and further adjusting the *Input Form* to be more user friendly (please see the final *Input Form* in Section 5). Moreover, additional observations on each participating ATB were made while conducting the site visits, and general recommendations were developed on how to achieve greater energy efficiency, and better manage the energy consumption at an ATB.

7.2. Technical Resources

The whole-system engineering approach, which was followed at the ATBs walk-throughs, is based on the following technical resources:

Liu et al. 2002. The elements of Continuous Commissioning® assessment, under the Continuous Commissioning® (CC®) process, developed and trademarked by the ESL. The CC® process in its entirety focuses on the optimization of public, commercial, and institutional building operations, and has been implemented and achieved significant utility cost savings in hundreds of buildings around the world in various climates.

6.2.2. ASHRAE 2002. *ASHRAE Guideline 14.* This guideline provides methods for reliably measuring the energy and demand savings due to building energy management projects.

6.2.3. Lau et al. 2010. *ACRP Synthesis of Airport Practice 21: Airport Energy Efficiency and Cost Reduction*. The report documents low cost / short payback energy efficiency improvements implemented at 20 airports across the U.S. by means of a survey, interviews, and a literature review. The report identifies diverse strategies and relative costs to achieve energy efficiency at airports.

7.3. Visited ATBs

The original work plan included visiting seven of the ten participating ATBs. However, during the initial site visits the team found that the site visits were helpful in completing the required information for the EU/EUI analysis, particularly on the ATB mechanical systems, GSE and alternative systems (ground power and PCA). Therefore, the team expanded the plan to all participating ATBs, and at the end were able to visit nine of the ten ATBs. Seven of the site visits took a one- to two-full-day session, in which our research engineers met with the ATBs various systems operators or contractors, toured the facilities, verified equipment, and made additional observations.

Table 6. Site Visits Schedule of Participating ATBs

No.		Airport Size	Climate Zone
Warmer	1	L	2
	2	M	2
	3	Nonhub	2
Moderate	4	L	3
	5	L	3
	6	L	4
	7	M	4
	8	S	5
Colder	9	L	6
	10	S	6

References

ASHRAE. 2002. *ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

California Energy Commission. 2006. California Commercial End Use Survey (CEUS). Source Data.

Durkin, T. H. 2006. "Boiler system efficiency." *ASHRAE Journal*, 48(7), 51-57.

Environmental Science Associates. 2012. *ACRP Report 64: Handbook for Evaluating Emissions and Costs of APUs and Alternative Systems.* Transportation Research Board of the National Academies, Washington, D.C. http://www.trb.org/Publications/Blurbs/167070.aspx.

Lau, C.R., J.T. Stromgren, and D.J. Green. 2010. *ACRP Synthesis of Airport Practice 21: Airport Energy Efficiency and Cost Reduction*. Transportation Research Board of the National Academies, Washington, D.C. http://www.trb.org/Publications/Blurbs/164002.aspx.

LBNL (Lawrence Berkeley National Laboratory). 2008. CalArch – California Building Energy Reference Tool. Lawrence Berkeley National Laboratory. Accessed July 1. http://poet.lbl.gov/cal-arch/.

Liu, M., D.E. Claridge, and D.W. Turner. 2002. *Continuous Commissioning® Guidebook - Maximizing Building Energy Efficiency and Comfort.* Prepared by the Energy Systems Laboratory Texas A&M University System and the Energy Systems Laboratory, University of Nebraska for the Federal Energy Management Program, U.S. Department of Energy [Online].
http://www1.eere.energy.gov/femp/program/om_guidebook.html.

Ostendorp, C. 2010. "Chilled water plant optimization by resetting the condenser water temperature." *Energy Engineering*, 107(5), 9-23.

Otis. 2000. "606 NCT Trav-O-Lator Moving Walk – Specifications", Otis Elevator Company.
http://www.otis.com/site/us/OT_DL_Documents/OT_DL_DownloadCenter/Product%20information%20-%20Commercial%20applications/Otis%20606%20NCT%20Trav-O-Lator.pdf

TIAX. 2006. *Commercial and Residential Sector Miscellaneous Electricity consumption: Y2005 and Projections to 2030 - Final Report to the U.S. Department of Energy's Energy Information Administration (EIA) and Decision Analysis Corporation (DAC)*. September 22, Reference Number D0366. TIAX LLC, 15 Acom Park, Cambridge, MA, 02140-2390.http://wpui.wisc.edu/news/EIA%20Posts/TIAX_EIA_MiscElecReport.pdf

U.S. EIA (Energy Information Administration). 2003. "Commercial Buildings Energy Consumption Survey (CBECS)." Accessed July 1. http://www.eia.gov/consumption/commercial/data/2003/

U.S. EPA (Environmental Protection Agency). 2013. "Energy Star Portfolio Manager: Technical Reference – U.S. Energy Use Intensity by Property Type." Washington, D.C. Dated July.
https://portfoliomanager.energystar.gov/pdf/reference/ENERGY%20STAR%20Score.pdf?ff11-d8c6