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Prototype Courthouse Building Energy Model: Building Characteristics and Energy Simulation Results

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July 2022

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Energy and Transportation Science Division

PROTOTYPE COURTHOUSE BUILDING ENERGY MODEL: BUILDING CHARACTERISTICS AND ENERGY SIMULATION RESULTS

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ABSTRACT

To coordinate commercial building energy research activities, the US Department of Energy uses a suite of commercial prototype building models, which includes 16 building types and covers 80% of US commercial floorspace. Efforts are underway to expand this suite by developing prototype models for additional building types, including a courthouse.

Informed by building design guides, databases, documented projects, and personal communication with courthouse design experts, a 3-story, 4-courtroom, 69,324 ft^2 building was considered as the prototype courthouse to represent an average-sized courthouse in the United States. This report documents the building and system characteristics of the prototype courthouse model combined with climate-specific and construction vintage–specific requirements for the building envelope and systems from ASHRAE Standard 90.1. The energy simulation results are presented for 4 construction vintages (2004, 2007, 2010, and 2013) and 15 ASHRAE climate zones. To verify the energy simulation results, energy use statistics of existing courthouses from different building database are also presented. Based on the simulated energy use, the site energy use intensity of the prototype courthouse ranged from 45 to 159 $kBtu/ft^2$ compared with the average energy use intensity of 94.7 $kBtu/ft^2$ for the courthouse building type in the 2012 Commercial Building Energy Consumption Survey (CBECS) Data.

1. INTRODUCTION

The US Department of Energy (DOE) supports the development of commercial building energy codes and standards. As part of DOE's support of ASHRAE Standard 90.1 and the International Energy Conservation Code (IECC), a suite of commercial prototype building models was developed, covering 80% of the commercial building floor area in the United States for new construction. The prototype models include 16 commercial building types in 17 climate locations (across all 8 US climate zones) for recent editions (2004, 2007, 2010, and 2013) of Standard 90.1 and recent editions (2006, 2009, 2012, and 2015) of the IECC.

To determine the building types and prioritize the model development for this suite, the Commercial Building Energy Consumption Survey (CBECS) building type subcategories (EIA 2016a) and relevant survey data were used. For the selected building types, building and system characteristics were researched using a variety of resources to develop building descriptions, thermal zone internal loads, schedules, and other key modeling input information necessary to create a canonical building energy model (Deru et al. 2011).

Continuous efforts are being made to update the suite of commercial prototype building models as Standard 90.1 and the IECC evolve. Recent efforts also focus on being able to create the EnergyPlus model through OpenStudio. Parallel efforts have begun to expand the prototype building suite to cover 90% of the commercial building floor area in the United States by developing prototype models for additional building types.

The courthouse building type was chosen as the first prototype building to add since DOE's Oak Ridge National Laboratory (ORNL) has ready access to data on several federal courthouses that are undergoing energy retrofits through energy savings performance contracts under DOE's Federal Energy Management Program. Additional resources, including building design guides, databases, and documented courthouse projects, supplemented by personal communication with courthouse facility planning and design experts were used to systematically conduct research on the courthouse building characteristics to define a prototype courthouse building and, most importantly, to develop the area program and floor layout. Malhotra et al. (2018) documents the research conducted for the courthouse building type, reports building and system characteristics.

This report documents the second phase for development of the prototype courthouse model. Based on the building characteristics determined by Malhotra et al. (2018), detailed modeling specifications—including thermal properties of the building envelope and characteristics of the HVAC system, water heating system, lighting, and equipment—were developed according to the requirements for ASHRAE Standard 90.1–2004, 2007, 2010, and 2013 for 15 ASHRAE climate zones (ASHRAE 2013) to develop 60 versions of the model. Section 2 documents the building and system characteristics of the prototype courthouse model combined with climate-specific and construction vintage–specific requirements for the building envelope and systems from ASHRAE Standard 90.1. Section 3 presents the energy simulation results for 4 construction vintages (2004, 2007, 2010, and 2013) and 15 ASHRAE climate zones. In addition, to verify the energy simulation results, energy use statistics of existing courthouses from different building databases are also presented.

2. BUILDING DESCRIPTION

The prototype courthouse is a 69,324 ft^2, 3-story, 4-courtroom building to represent an average-sized courthouse in the United States. The building and system characteristics of the prototype courthouse were determined through systematic research documented by Malhotra et al. (2018). The resources used include building design guides, databases, and documented courthouse projects, supplemented by personal communication with courthouse facility planning and design experts. The size and shape of the courthouse were determined from courthouse databases. The floor layout and area programming were developed in consultation with courthouse design experts and courthouse design guides. The occupancy, construction, and systems characteristics were determined based on courthouse databases and documented projects. The following sections describe the prototype courthouse modeling characteristics in detail.

2.1 FORM

The prototype courthouse model is a 3-story, 69,324 ft^2 (i.e., 218 ft × 106 ft) building as shown in Figure 1. The floor area, number of floors, aspect ratio of the footprint, and overall window-to-wall ratio of the building were determined based on the average and/or predominant characteristics of the courthouse building type in the CBECS data (EIA 1996, 2015).

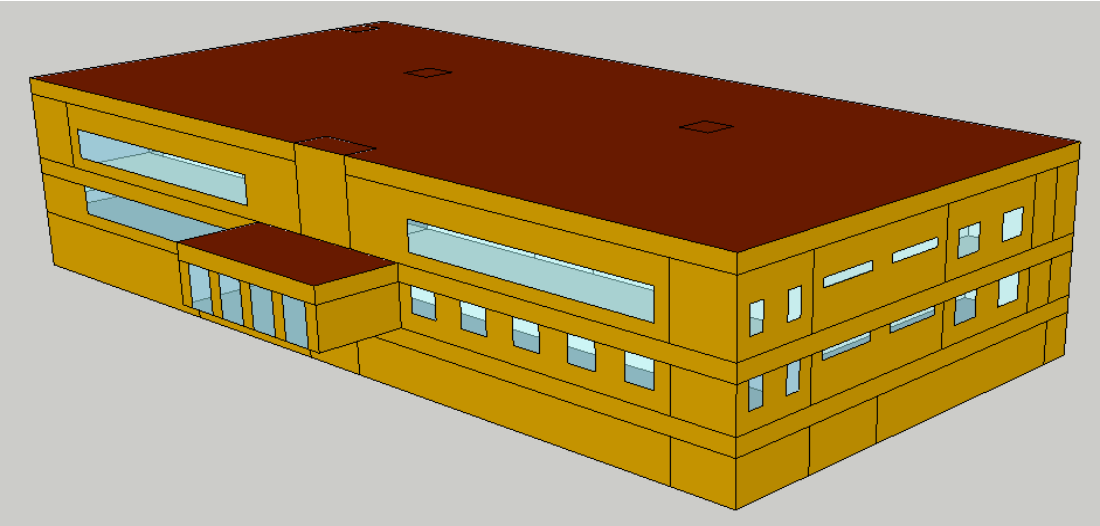


Figure 1. Prototype courthouse building massing and window placement.

The floor layout and area programming were developed in consultation with courthouse facility planning and design experts, adhering to the courthouse organizational concepts and space requirements. The entrance and high-volume public and general office spaces were housed on the first floor, the courtrooms and supporting spaces on the second floor, and the secured parking and central detention area on the basement floor. The floor layout of the court floor was developed first, based on the space, location, and adjacency requirements for the courtroom and supporting spaces. The remaining functional spaces were then housed on other levels inside the building footprint.

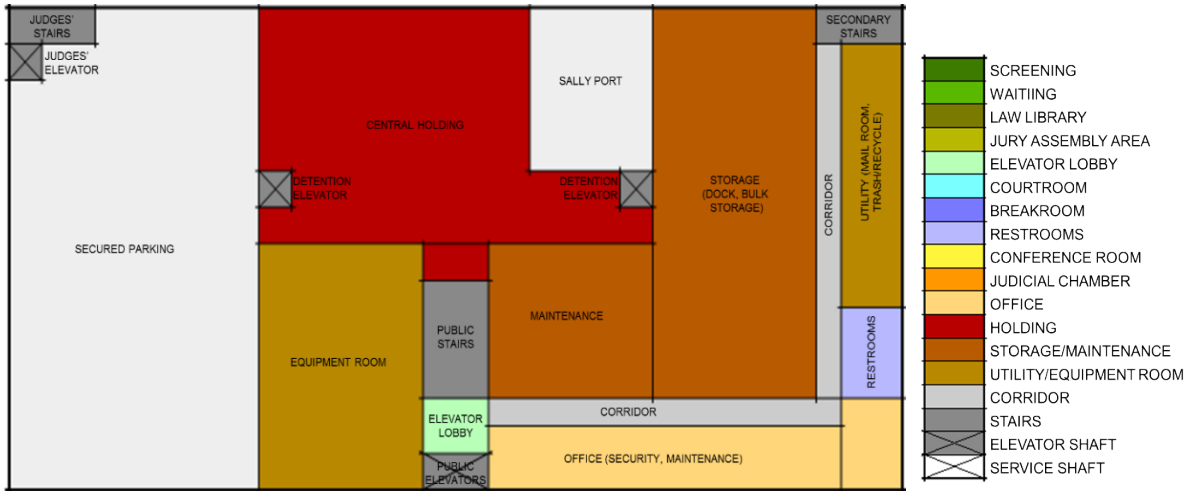
The floor heights were determined based on the dominant space-specific height requirements on each floor. A floor-to-ceiling height of 10 ft was selected for the first floor, 16 ft for the second floor, and 10 ft for the basement floor. However, to determine the floor-to-floor height, an additional 4 ft height was considered on each floor to house building services in the ceiling cavity without interference with each

other and to allow adequate access for maintenance. The basement floor is below the ground with one side exposed for separate entrances for secured parking, services, and escorting in-custody defendants.

A 15%–18% window-to-wall ratio was targeted. The distribution of windows on different orientations was determined after placement of windows for different spaces. To allow daylight in deep peripheral spaces while avoiding direct sight line from the outside, 6 ft high punched windows with 4 ft sill height were selected. This resulted in a 16% overall window-to-wall ratio—24.7% in the front, 9.4% on the right, 11.2% on the left, and 19.3% on the back (13.6% considering exterior wall area at the back of the basement).

2.2 THERMAL ZONES

Figure 2 shows the layout of the basement, first floor, and second floor with the thermal zones marked distinctly. The second floor is the courtroom floor housing courtrooms and supporting spaces, judges' chambers, and court-floor holding areas. The first floor has a public entrance lobby, clerk's office, court administration office, other offices (for the prosecuting attorney, public defender, probation, and parole), jury assembly area, and law library. The basement houses secured parking for judges, a central holding area, and building management and support areas. The screening area for the public entrance of the building on the first floor is located outside the main building mass in line with the recommendations for security in courthouse design guides (Malhotra et al. 2019). Separate sets of stairs and elevators are provided for the public and general staff, judges, and in-custody defendants. Except for the secured parking, sally port, and service shafts, all spaces are conditioned. Table 1 shows the floor area and area fractions of different space types in the prototype courthouse.



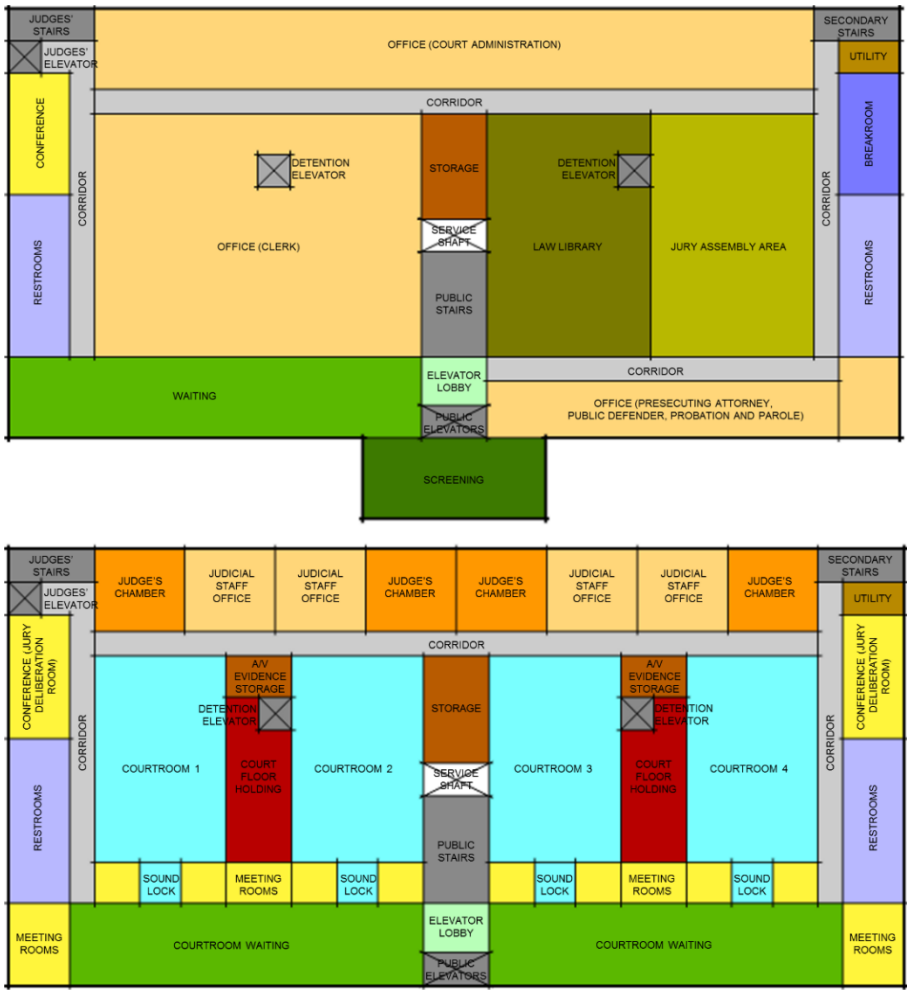


Figure 2. Prototype courthouse layout of the basement (top), first floor (middle), and second floor (bottom).

Table 1. Floor area and area fraction of courthouse spaces

Space type	Floor area (ft^2)	Percent of total (%)
Break room	450	0.6
Cell	5,064	7.3
Conference	1,370	2.0
Corridor	5,596	8.1
Courtroom	7,680	11.1
Courtroom waiting	3,440	5.0
Elevator lobby	576	0.8
Elevator shaft	320	0.5
Entrance lobby	2,020	2.9
Judge's chamber	1,760	2.5
Jury assembly	2,400	3.5
Jury deliberation	900	1.3
Library	2,336	3.4
Office	13,024	18.8
Parking	7,314	10.6
Restrooms	2,700	3.9
Security screening	893	1.3
Service shaft	—	—
Stairs	2,256	3.3
Storage	5,952	8.6
Utility	3,270	4.7
Total	69,321	100.0

2.3 CONSTRUCTION

The prototype courthouse was modeled with mass wall construction, built-up roof, concrete basement walls and slab floor, steel frame for interior partition walls, and concrete walls for vertical shafts and detention areas. The thermal properties of the building envelope components, including the windows, were determined based on the requirements in ASHREAE Standard 90.1.

The design air infiltration rate of 0.2016 cfm/ft^2 of above-grade exterior wall surface area was selected. Additional infiltration (6,871 or 4,704 cfm) was modeled through building entrance without vestibule or with vestibule based on the ASHRAE Standard 90.1 requirements.

2.4 MECHANICAL SYSTEMS

Based on the predominant system types for the courthouse building type in the CBECS data (EIA 2015), the HVAC system selected for the prototype courthouse included natural gas–fired boilers, water-cooled chillers, and variable air volume terminal units with hot water reheat, and a natural gas water heater for service hot water. The system efficiency and auxiliary equipment requirements (i.e., economizers, demand control ventilation, energy recovery, and pumps) were determined from the requirements in ASHRAE Standard 90.1. These systems were autosized to design days.

For the HVAC system, the thermostat set points of 74°F for cooling and 72°F for heating were selected. The setback temperature was 85°F for cooling season and 60°F for heating season. Supply air temperature was a maximum of 104°F and a minimum of 55°F. The chilled water supply temperature was 44°F, and the hot water supply temperature was 180°F.

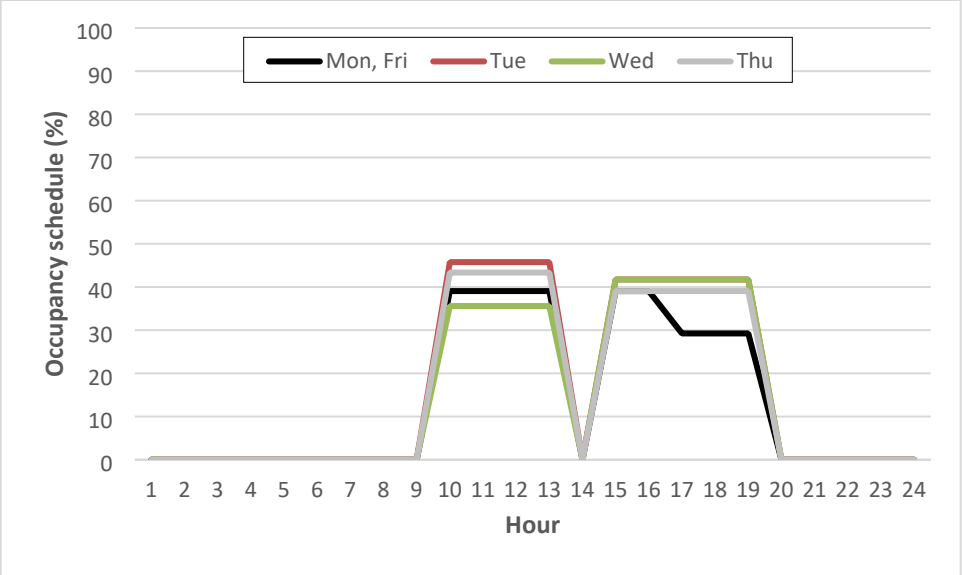
2.5 OCCUPANCY AND VENTILATION REQUIREMENTS

The occupant density for different spaces in the prototype courthouse was determined from ASHRAE Standard 62.1-2004, as shown in Table 2. The occupant density was the same across the vintages.

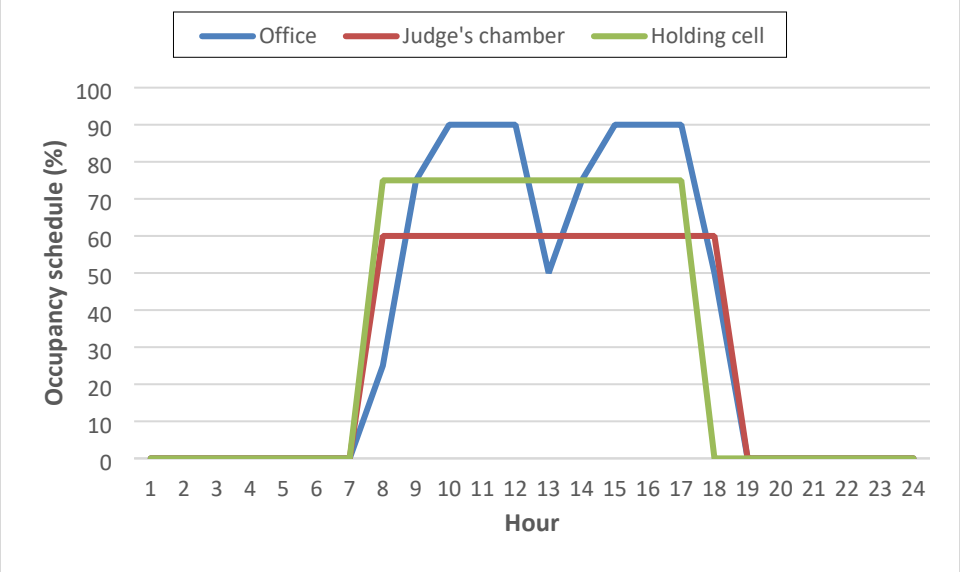
Table 2. Occupant density

Space	Occupant density (#/1,000 ft²)	Space	Occupant density (#/1,000 ft²)
Break room	5	Jury deliberation	50
Cell	25	Library	10
Conference	50	Office	5
Corridor	—	Parking	—
Courtroom	70	Restrooms	—
Courtroom waiting	10	Security screening	10
Elevator lobby	10	Service shaft	—
Elevator shaft	—	Stairs	—
Entrance lobby	10	Storage	—
Judge's chamber	5	Utility	—
Jury assembly	120		

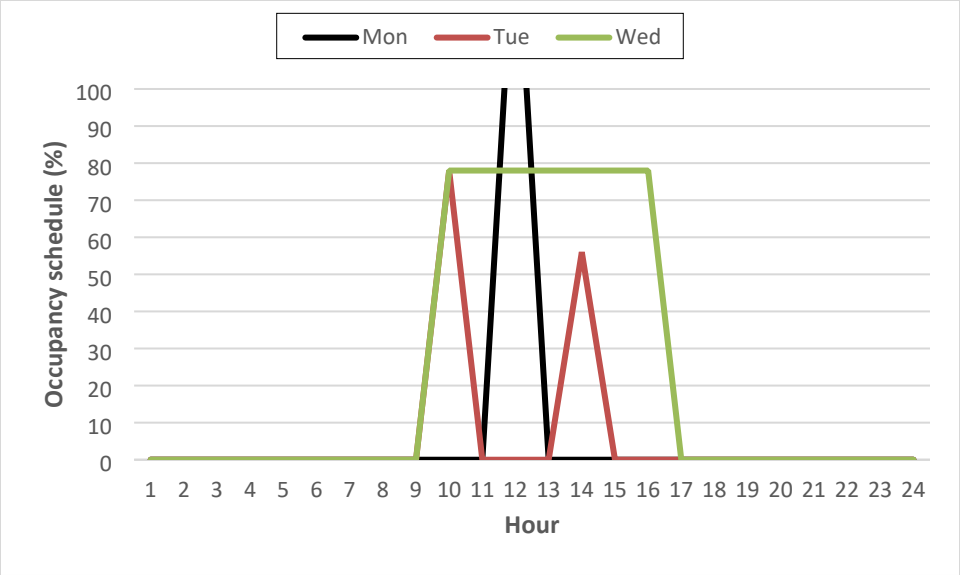
The occupancy schedules were adopted from the courthouse energy model used for the US General Services Administration (GSA) Leadership in Energy and Environmental Design (LEED) cost study (GSA 2004). The GSA model used multiple weekly and annual schedules for the courtrooms and jury deliberation rooms to model the diversity of use over the year. For the prototype model, a single weekly schedule was derived from the multiple weekly schedules of the GSA model, taking into account the frequency of use of different courtrooms and jury deliberation rooms in the annual schedules of the model. Figure 3 shows the space-specific weekly occupancy schedules used for the prototype courthouse.



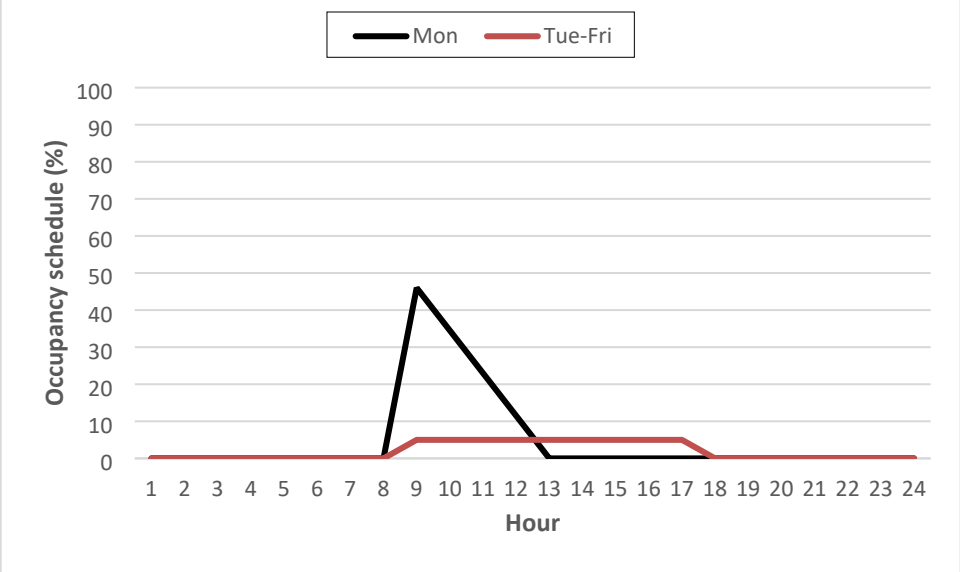
(a) Courtroom



(b) Office, judge's chamber, and holding cell



(c) Jury deliberation room



(d) Jury assembly area

Figure 3. Occupancy schedules.

The ventilation requirements of different spaces in the prototype courthouse were determined from ASHRAE Standard 62.1, as described in Table 3.

Table 3. Ventilation requirement by vintage

Zone category	90.1-2004 (based on ASHRAE Standard 62-1999)		90.1-2007 (based on ASHRAE Standard 62.1-2004)		90.1-2010 (based on ASHRAE Standard 62.1-2007)		90.1-2013 (based on ASHRAE Standard 62.1-2007)	
	cfm/person	cfm/ ft^2	cfm/person	cfm/ ft^2	cfm/person	cfm/ ft^2	cfm/ person	cfm/ ft^2
Break room	15	—	5	0.06	5	0.06	5	0.06
Cell	20	—	5	0.12	5	0.12	5	0.12

Conference	20	—	5	0.06	5	0.06	5	0.06
Corridor	—	0.05	—	0.06	—	0.06	—	0.06
Courtroom	16.95	—	10	0.12	10	0.12	10	0.12
Courtroom waiting	15	—	5	0.06	5	0.06	5	0.06
Elevator lobby	15	—	5	0.06	5	0.06	5	0.06
Elevator shaft	—	—	—	—	—	—	—	—
Entrance lobby	15	—	5	0.06	5	0.06	5	0.06
Judge's chamber	20	—	5	0.06	5	0.06	5	0.06
Jury assembly	15	—	5	0.06	5	0.06	5	0.06
Jury deliberation	20	—	5	0.06	5	0.06	5	0.06
Library	16.95	—	5	0.12	5	0.12	5	0.12
Office	20	—	5	0.06	5	0.06	5	0.06
Parking	—	1.50	—	—	—	—	—	—
Restrooms	—	—	—	0.06	—	0.06	—	0.06
Security screening	15	—	5	0.06	5	0.06	5	0.06
Service shaft	—	—	—	—	—	—	—	—
Stairs	—	0.05	—	0.06	—	0.06	—	0.06
Storage	—	0.15	—	0.12	—	0.12	—	0.12
Utility	—	0.05	—	0.12	—	0.12	—	0.12

2.6 LIGHTING

The lighting power densities were determined from ASHRAE Standard 90.1 and are described in Table 4. The difference between the vintages is shown in Figure 4.

Table 4. Lighting power density by vintage

Zone category	90.1-2004	90.1-2007	90.1-2010	90.1-2013
	Lighting power density (W/ft^2)			
Break room	1.2	1.2	0.73	0.73
Cell	0.9	0.9	1.1	0.81
Conference	1.3	1.3	1.23	1.23
Corridor	0.5	0.5	0.66	0.66
Courtroom	1.9	1.9	1.72	1.72
Courtroom waiting	1.3	1.3	0.9	0.9
Elevator lobby	1.3	1.3	0.64	0.64
Elevator shaft	—	—	—	—
Entrance lobby	1.3	1.3	0.9	0.9
Judge's chamber	1.3	1.3	1.17	1.11
Jury assembly	1.4	1.4	1.24	1.24
Jury deliberation	1.3	1.3	1.23	1.23
Library	1.2	1.2	0.93	1.06
Office	1.1	1.1	1.11	1.11
Parking	0.2	0.2	0.19	0.19
Restrooms	0.9	0.9	0.98	0.98
Security screening	1.3	1.3	0.9	0.9
Service shaft	—	—	—	—
Stairs	0.6	0.6	0.69	0.69
Storage	0.8	0.8	0.63	0.63
Utility	1.5	1.5	0.95	0.42

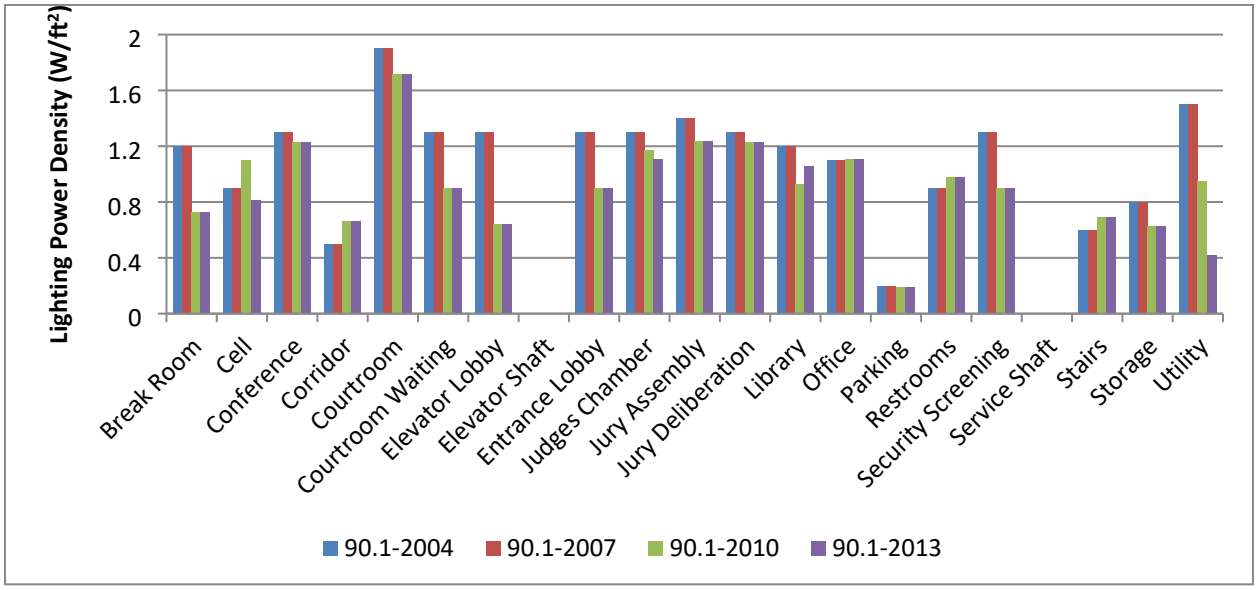
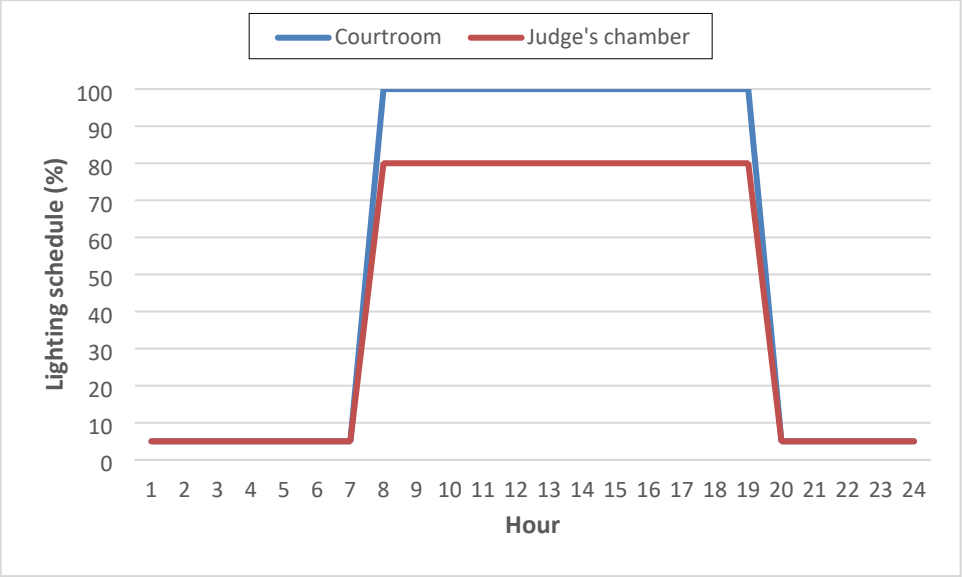
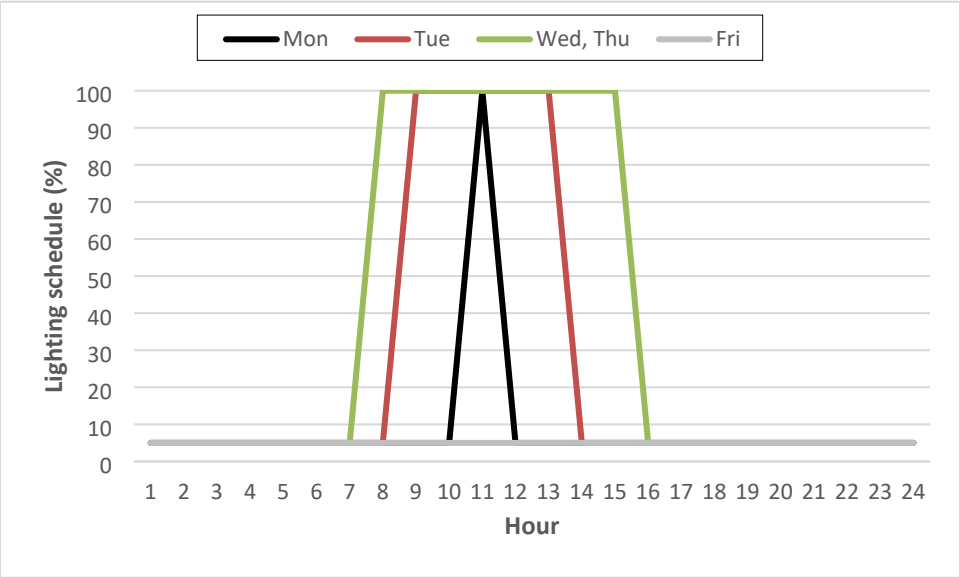


Figure 4. Comparison of space-specific lighting power density by vintage.

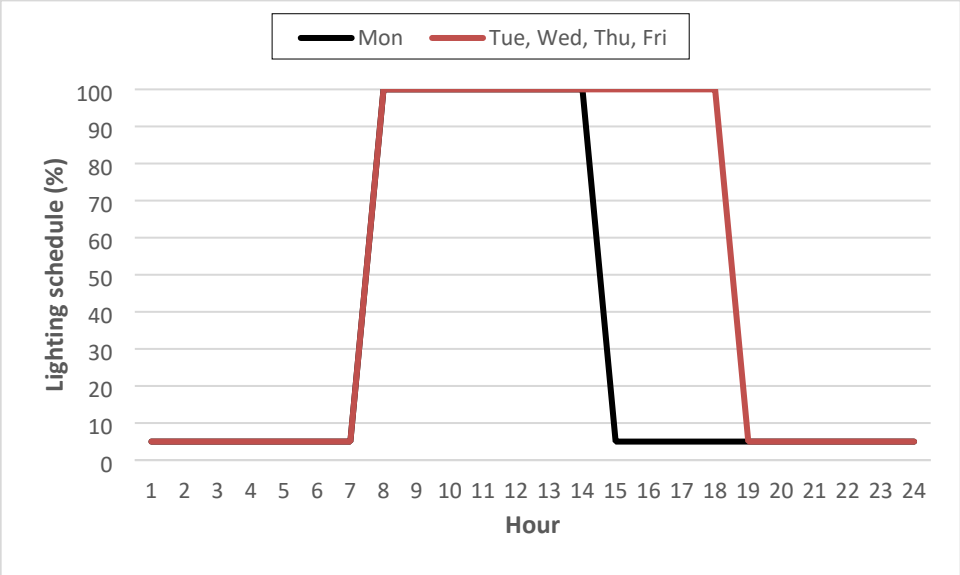
The lighting schedules were adopted from the GSA LEED cost study (GSA 2004). Figure 5 shows the lighting schedules during weekdays for key space types of the prototype courthouse.



(a) Courtroom and judge's chamber



(b) Jury deliberation room



(c) Jury assembly area

Figure 5. Lighting schedules.

2.7 EQUIPMENT

The equipment power densities were adopted primarily from the medium office prototype, which was supplemented by other prototype models for spaces that do not exist in the medium office prototype. The space-specific equipment power densities are shown in Table 5. The difference between the vintages is shown in Figure 6.

Table 5. Equipment power density by vintage

Zone category	90.1-2004	90.1-2007	90.1-2010	90.1-2013
	Equipment power density (W/ft²)			
Break room	5.58	4.46	4.46	4.46
Cell	—	—	—	—
Conference	1	0.37	0.37	0.37
Corridor	0.29	0.16	0.16	0.16
Courtroom	0.5	0.5	0.5	0.5
Courtroom waiting	0.27	0.07	0.07	0.07
Elevator lobby	0.27	0.07	0.07	0.07
Elevator shaft	—	—	—	—
Entrance lobby	0.27	0.07	0.07	0.07
Judge's chamber	0.87	0.64	0.64	0.64
Jury assembly	1	0.37	0.37	0.37
Jury deliberation	1	0.37	0.37	0.37
Library	0.93	0.93	0.93	0.93
Office	0.87	0.64	0.64	0.64
Parking	—	—	—	—
Restrooms	0.27	0.07	0.07	0.07
Security screening	0.27	0.07	0.07	0.07
Service shaft	—	—	—	—
Stairs	—	—	—	—
Storage	—	—	—	—
Utility	0.27	0.27	0.27	0.27

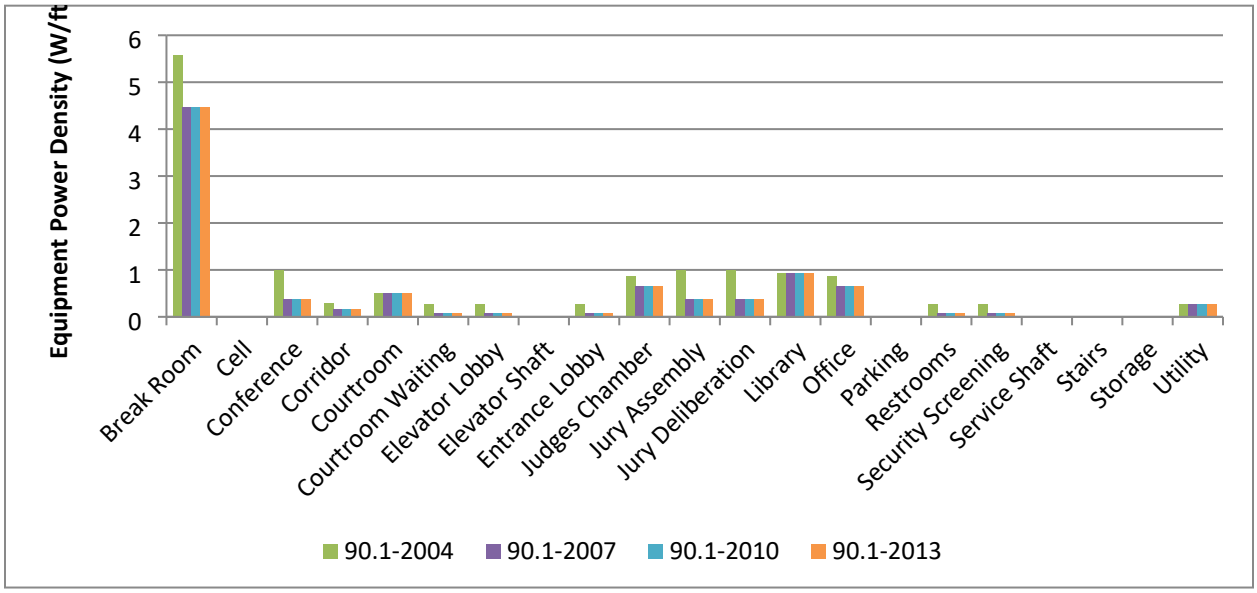


Figure 6. Comparison of space-specific equipment power density by vintage.

A single whole-building equipment schedule was adopted from the medium office protype, as shown in Figure 7.

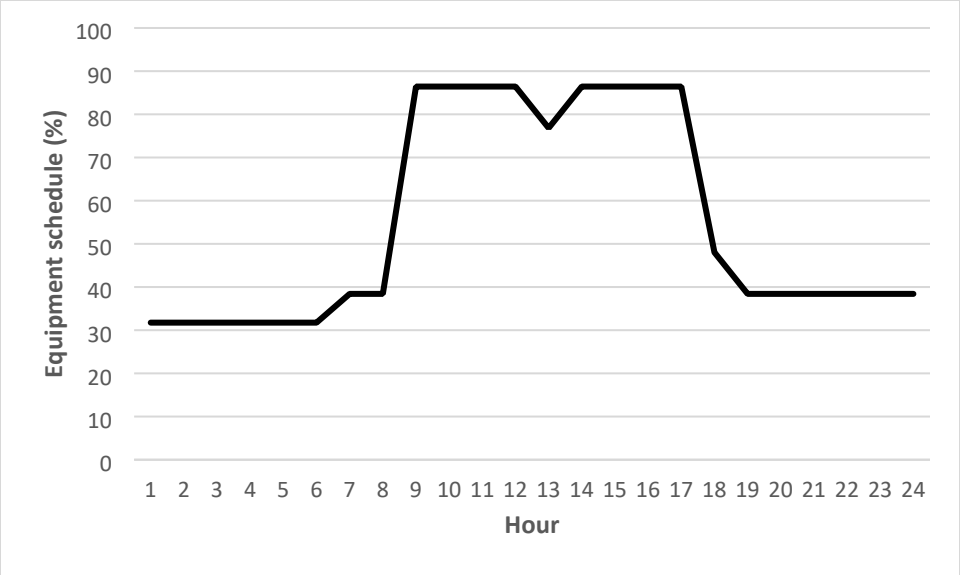


Figure 7. Equipment schedule.

3. COURTHOUSE ENERGY USE

For model verification, the simulated energy consumption for the prototype courthouse was compared with reported energy use for existing courthouses obtained from different building data sets. Also, the impact of the requirements of ASHRAE Standard 90.1 for different vintages and climate zones on the energy use was observed to verify the expected trend.

3.1 ENERGY USE IN EXISTING COURTHOUSES

For the courthouse building type, two primary sources include the CBECS data and ENERGY STAR Portfolio Manager. The energy use in buildings is typically reported as energy use intensity (EUI) calculated as total energy use divided by the gross floor area—either as site EUI or source EUI.

3.1.1 2012 CBECS Data

The 2012 CBECS data (EIA 2015) include a detailed set of data for a statistical sample of 26 courthouses ranging from 1,300 to 800,000 ft^2. Combined with sample weights, they represent 6,278 courthouses in the United States.

Figure 8 plots the fuel consumption intensity (i.e., site EUI) against the mean floor area of courthouses and other buildings based on the 2012 CBECS data. The clusters indicate building types that are similar in terms of average size and energy use. The courthouse is a large building type with a mean floor area of 69,400 ft^2 compared with 15,700 ft^2 for all commercial buildings. It is among the smaller fuel consumption intensity building types with an average of 94.7 kBtu/ft^2, next to 77.8 kBtu/ft^2 for offices and 80 kBtu/ft^2 for all commercial buildings.

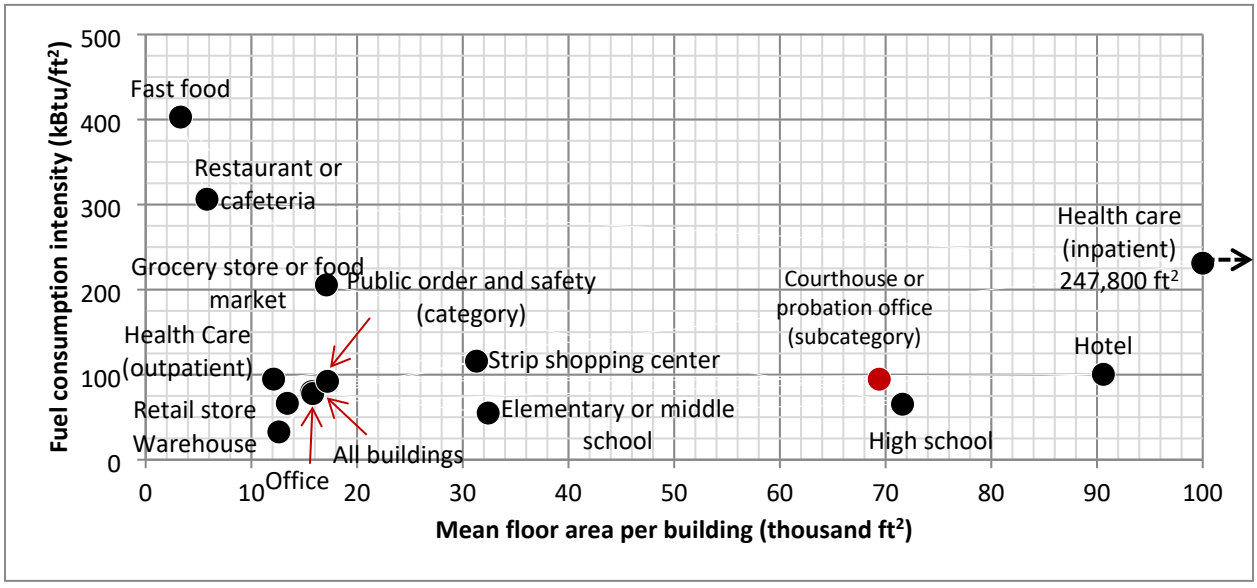


Figure 8. Fuel consumption intensity plotted against mean floor area for courthouses and other buildings.
Source: EIA 2015. Based on the CBECS data (year unspecified), ENERGY STAR (2018) reports the median source EUI and site EUI for courthouse to be 211.4 kBtu/ft^2 and 101.2 kBtu/ft^2, respectively.

Furthermore, as shown in Figure 9, the range of variation of fuel consumption intensity for the courthouse building type in 2012 CBECS data is much narrow than for most other building types. The right-skewed distribution (i.e., the median 92 kBtu/ft^2 is smaller than the mean of 94.7 kBtu/ft^2) indicates a higher

number of buildings in the regime with a lower than average fuel consumption intensity, and most energy-intensive courthouses are further away from the median than courthouses that are less energy-intensive.

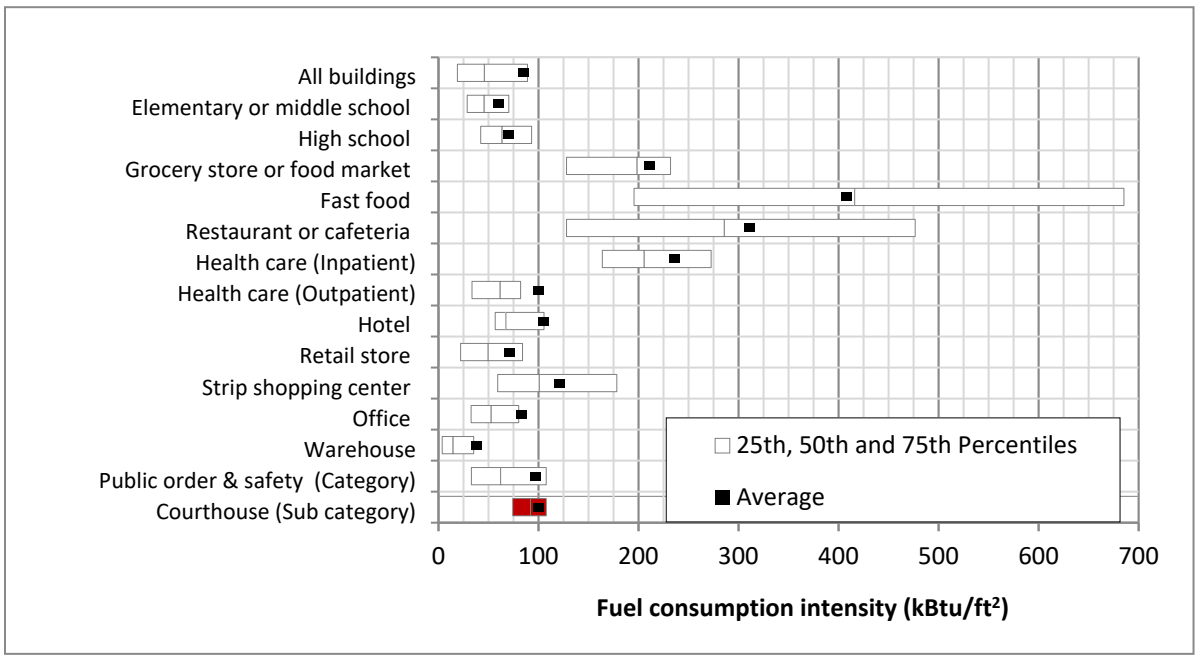


Figure 9. Fuel consumption intensity statistics for a courthouse and other buildings. Source: EIA 2016b.

3.1.2 ENERGY STAR Portfolio Manager

Based on the self-reported data for 1,290 courthouse properties benchmarked in the (then) most recent 5 years (~2010–2015) in ENERGY STAR Portfolio Manager (2015), the source EUI ranged from less than 100 kBtu/ft² to more than 700 kBtu/ft² across all courthouses, with a median of 167 kBtu/ft², as shown in Figure 10. This is smaller than the median source EUI of 211.4 kBtu/ft² based on the CBECS data.

Furthermore, courthouses in the 95th percentile used more than 4 times the energy of those in the 5th percentile. The distribution has a negative skew, similar to that found in the CBECS data, which means the most energy-intensive properties are further away from the median than the least energy-intensive ones.

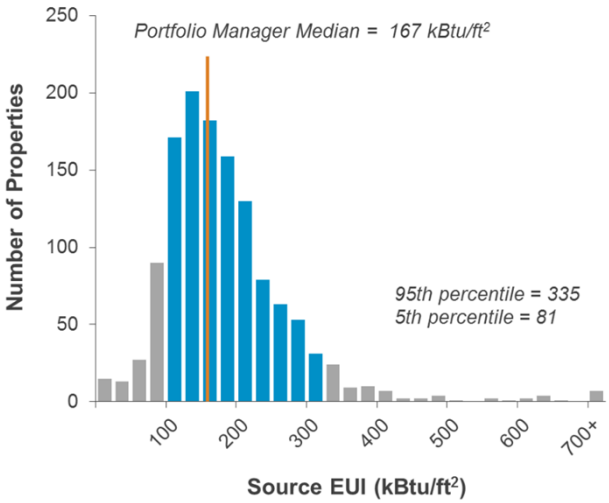


Figure 10. Fuel consumption intensity statistics for courthouses in ENERGY STAR Portfolio Manager.
Source: ENERGY STAR 2015.

3.2 SIMULATED ENERGY USE IN PROTOTYPE COURTHOUSE

With the building and system characteristics described in Section 2, the prototype courthouse model for different vintages was simulated in 15 ASHRAE climate zones. To see the overall trend of the impact of the requirements of ASHRAE 90.1 standards for different construction vintages and climate zones on energy use, the total site energy, heating energy, and cooling energy use are plotted in Figure 11, Figure 12, and Figure 13, respectively. ASHRAE 90.1 standards for different construction vintages included Standards 90.1-2004, 90.1-2007, 90.1-2010, and 90.1-2013. The horizontal axis shows the locations and climate zones, and different vintages are represented by different colors.

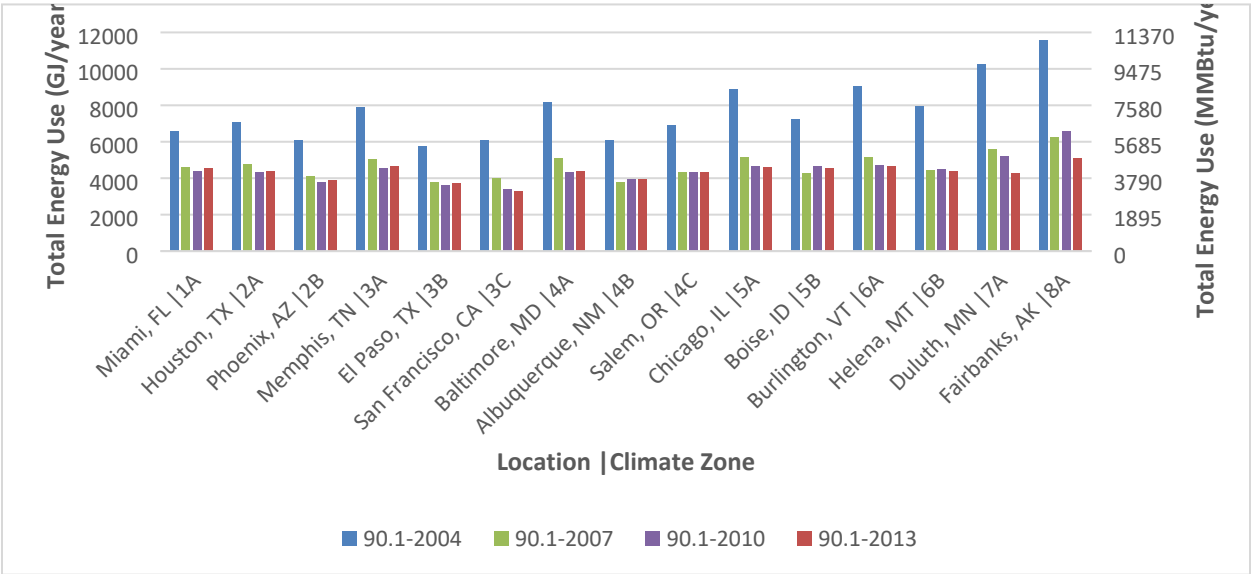


Figure 11. Total site energy use of prototype courthouse simulation model.

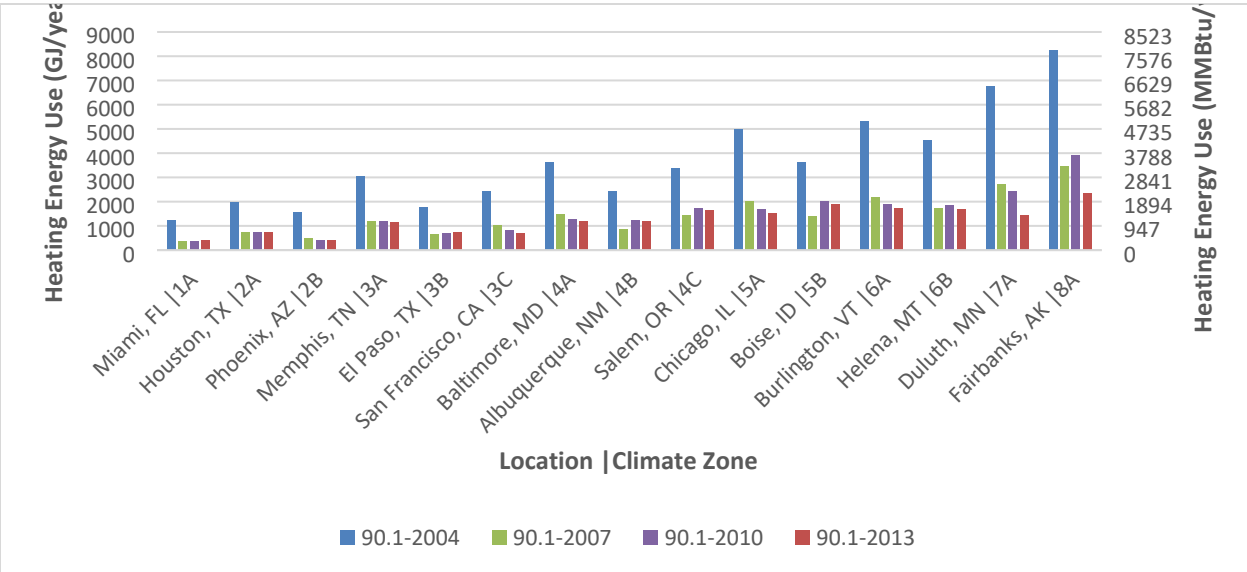


Figure 12. Heating energy use of prototype courthouse simulation model.

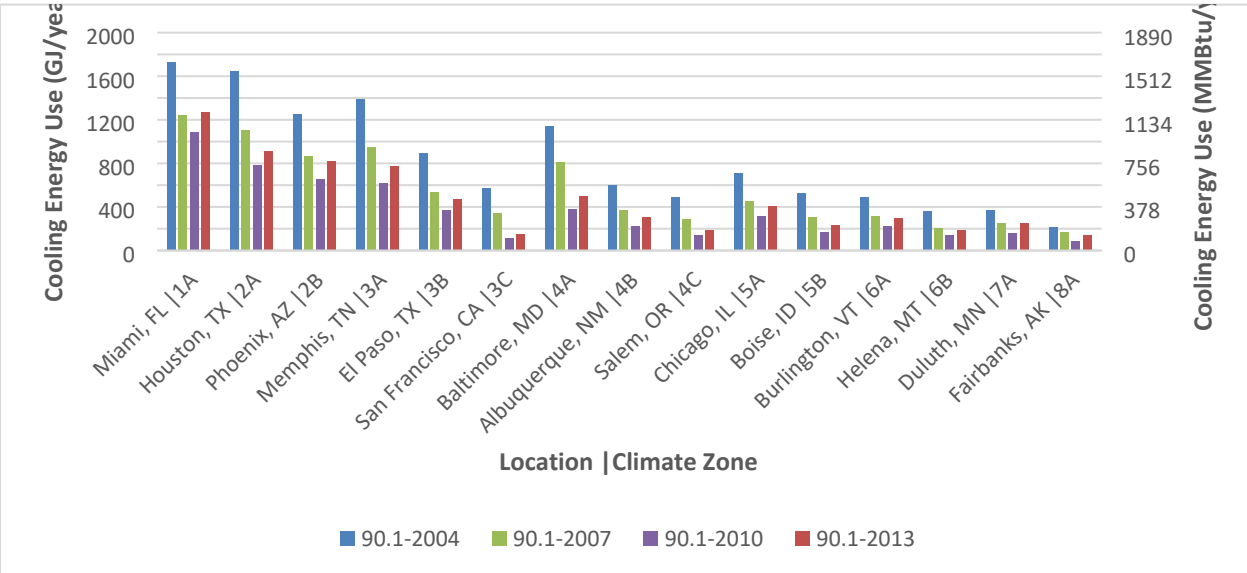


Figure 13. Cooling energy use of prototype courthouse simulation model.

Overall, compared with the energy consumption for the ASHRAE Standard 90.1-2013 model, the energy consumption for the ASHRAE Standard 90.1-2004 model was 138.2% higher for total site energy use, 369.8% higher for heating energy use, and 280.4% higher for cooling energy use. For the ASHRAE Standard 90.1-2007 model, the energy consumption was 29.8% higher for total site energy use, 89.4% higher for heating energy use, and 128.5% higher for cooling energy use. For the ASHRAE Standard 90.1-2010 model, the energy consumption was 29.5% higher for total site energy use, 69.7% higher for heating energy use, and 14.1% lower for cooling energy use. The significantly high ventilation requirements in Standard 90.1-2004 (as described in Table 3) resulted in increased heating energy use in cold climate zones, and increased cooling energy use in warm climate zones compared with other vintages. The difference among vintages is likely more pronounced in the prototype courthouse model than in other prototype models. The impact of climate on the energy use is also discernible from the expected trend of heating and cooling energy use in Figure 12 and Figure 13, respectively.

To compare the energy use of prototype courthouse with that of existing courthouse data sets, the site EUI was calculated from the simulated total energy use divided by the 69,324 ft^2 gross floor area of the prototype courthouse model. Figure 14 shows the calculated site EUI for different construction vintages and climate zones.

The site EUI of the courthouse was 79–159 kBtu/ft^2 for ASHRAE Standard 90.1-2004, 52–86 kBtu/ft^2 for ASHRAE Standard 90.1-2007, 47–90 kBtu/ft^2 for ASHRAE Standard 90.1-2010, and 45–70 kBtu/ft^2 for ASHRAE Standard 90.1-2013. Compared with the reported site EUI of 94.7 kBtu/ft^2 based on 2012 CBECS data and 101.2 kBtu/ft^2 by ENERGY STAR (2018), the range of site EUI for the prototype courthouse is reasonable.

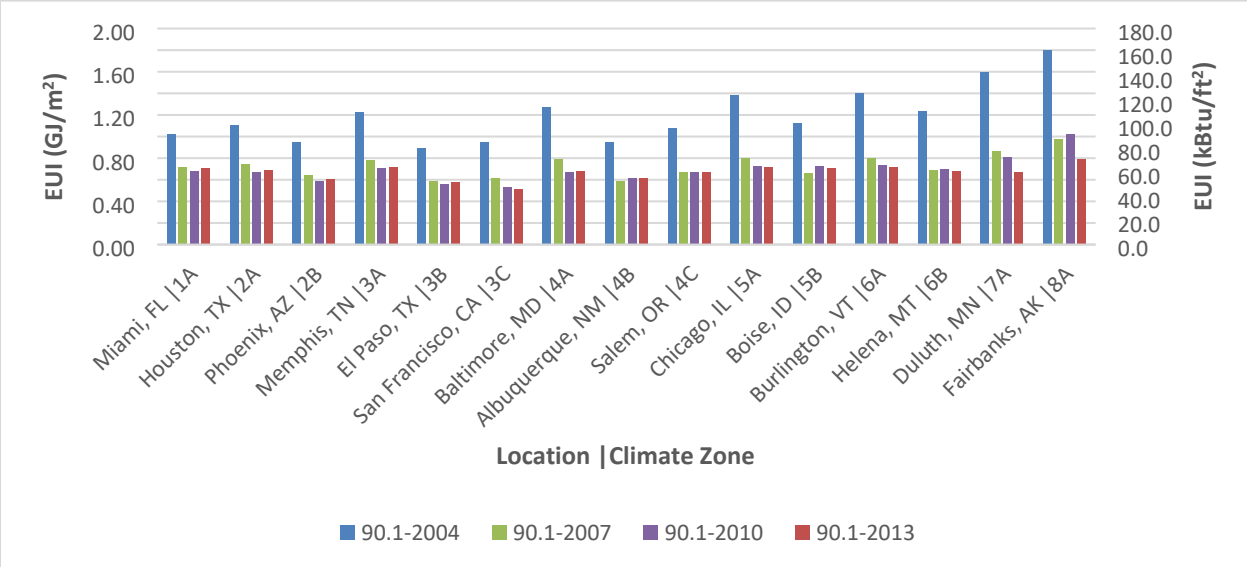


Figure 14. Site EUI of prototype courthouse simulation model.

4. DISCUSSION AND CONCLUSIONS

As an effort to expand the current suite of commercial building prototype models, this report presents the prototype courthouse building energy model and energy simulation results. The final set of prototype models includes the 60 models for different vintages of ASHRAE Standard 90.1 (i.e., 2004, 2007, 2010, and 2013) and for 15 ASHRAE climate zones, and the modeled energy uses are consistent with existing data from multiple sources. The site EUI of the courthouse was 79–159 kBtu/ft^2 for ASHRAE Standard 90.1-2004, 52–86 kBtu/ft^2 for ASHRAE Standard 90.1-2007, 47–90 kBtu/ft^2 for ASHRAE Standard 90.1-2010, and 45–70 kBtu/ft^2 for ASHRAE Standard 90.1-2013. Compared with the reported site EUI of 94.7 kBtu/ft^2 based on 2012 CBECS data and 101.2 kBtu/ft^2 by ENERGY STAR (2018), the site EUI for the prototype courthouse is in a reasonable range.

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