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A Process for Defining Prototype Building Models: Courthouse Case Study for U.S. Commercial Energy

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Abstract: Buildings currently consume 36% of the world's energy and contribute nearly 40% of CO_2 emissions. Many countries desire to generate virtual models of their nation's buildings in order to coordinate research activities and inform market opportunities for a more sustainable built environment. The United States Department of Energy uses a suite of Commercial Prototype Building Models, which currently 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. In this paper, we outline a systematic approach to defining the building, collecting relevant information and creating a flexible model while doing so in the pragmatic context of a courthouse building. Informed by building design guides, databases, documented projects and inputs from courthouse design experts, we define a small, 69,324 ft^2 (6440 m^2), four-courtroom, low-rise courthouse as the prototype to represent an average-size courthouse in the US. We present building characteristics relevant for energy model development and provide the rationale for their selection. These details combined with climate- and construction-vintage-specific requirements for the building envelope and systems from building standards will be used for developing the courthouse model for the Commercial Prototype Building Models suite. The comprehensive information presented will also guide model modification to capture the dynamics of smaller or larger courthouses more accurately for building or system size-specific research.

Keywords: commercial prototype building models; courthouse building characteristics; building codes and standards; Commercial Building Energy Consumption Survey (CBECS)

1. Introduction

The United States (US) Department of Energy (DOE) has set aggressive goals for energy-efficiency in buildings—a 30% reduction in average energy use intensity of all US buildings by 2030 compared to a 2010 baseline [1]. To coordinate commercial building research across multiple disciplines, Commercial Reference Building Models were developed for the most common buildings [2,3] and later adapted as Commercial Prototype Building Models for use in code update development [4]. The current suite of Commercial Prototype Building Models covers 16 common building types—offices, hotels, schools, mercantile, food service, healthcare, apartments and warehouse—in 17 ASHRAE climate zones [5] and represents different construction vintages (pre-1980, 1980–2004) and building energy standards (ASHRAE Standards 90.1-2004, 2007, 2010, 2013 and 2016; and International Energy Conservation Code 2006, 2009, 2012 and 2015). The current combination results in an overall set of 2448 building models that covers 80% of the US commercial floorspace [4]. These models have been used to analyze the energy savings and cost impacts of energy-efficiency code updates [4,6]; develop prescriptive new construction and retrofit design guides [7,8]; create technical potential scales for building asset scores [9,10]; develop typical energy-conservation measures savings estimates for up-front incentives through utility programs [11]; create performance, cost, lifetime and time-to-market

targets for new technologies to inform DOE's technology investment portfolio [12]; and many other applications [13–18].

DOE is focused on expanding commercial floorspace coverage by developing prototype models for additional building types [14]. To determine prototype building types, the Commercial Building Energy Consumption Survey (CBECS) building type subcategories [19] and relevant survey data have been used. Through discussions among DOE, ASHRAE, American Institute of Architects (AIA) and DOE's national laboratories, additional building types are proposed for prototype model development, which includes food sales, public assembly, public order and safety, religious worship and other. 'Courthouse' is a subcategory that represents 30% of buildings under the CBECS 'Public Order and Safety' building type category; other subcategories include police station; fire station; and jail, reformatory or penitentiary [19].

Many previously published articles and reports thoroughly document the energy-related parameters of prototypical building models and sometimes even the data sources, statistical findings or assumptions underlying those models [2–4]. However, a scientific process is needed to enable the definition, collection and modeling of buildings in a way that eliminates errors (i.e., lead to objections for use in building codes, standards or decision-making). The authors attempt to incorporate existing best practices and lessons-learned in proposing a more scientific process employable by any country, while demonstrating this on a practical case study using country-specific data sources for a specific prototype building. The U.S. courthouse building type defined in the process of this study will be included in the Commercial Prototype Building Models suite.

Objectives

This paper describes a systematic approach for creating prototype building models, while doing so in the pragmatic context of a courthouse building. This is accomplished by demonstrating a comprehensive review of building databases, design guides and case studies of courthouses and determining building characteristics relevant for energy model development while providing the rationale for these determinations.

The comprehensive information presented in this paper will also guide model modification to more accurately capture the dynamics of smaller or larger courthouses for building or system size-specific research and allow modifications that can accommodate country-specific differences [20,21].

While demonstrated in the context of real-world data sources for a U.S. courthouse, the authors encourage readers to leverage, extend or institute similar data collection processes that capture the unique operational characteristics of your built environment.

2. Methodology

Figure 1 shows the overall workflow of prototype model development for the Commercial Prototype Building Models suite through the context of courthouse building. The work involves (a) building characteristics research (Steps 1 and 2), which is the focus of this paper and (b) model development (Steps 3 and 4), which will follow this research.

2.1. Step 1: Defining a Narrative for Prototype Building

Buildings exhibit a large variation in terms of physical characteristics (i.e., scale and size, building form and geometry, construction, etc.) as well as operational characteristics (function of the building, occupancy, schedule of use, etc.). The first and foremost step to creating a prototype building model for use in national scale R&D is to define a narrative or a context for the building that could represent majority of cases across the country. This is demonstrated in the context of courthouse building, as below.

The US court system consists of a federal court system and the state and territorial court systems of the individual US states and territories. These court systems differ in terms of jurisdiction, court structure, case definitions, court rules, statutes or terminology [22]. To define a narrative for

the prototype courthouse that could represent most, if not all, types of court, we reviewed the US court system and the statistics of different types of courts. We reviewed court operations to define the space types, usage, occupancy characteristics and schedule of use for those spaces.

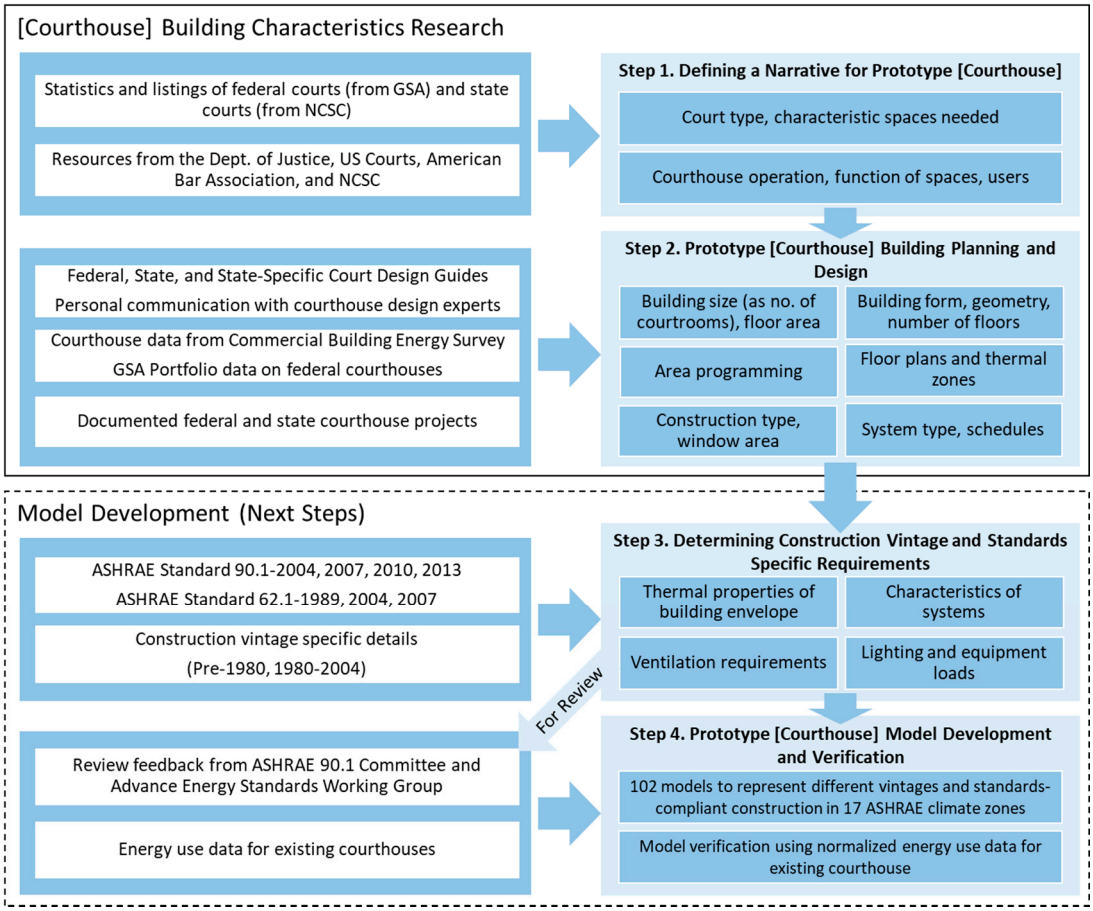


Figure 1. Workflow of prototype model development (context: Courthouse building).

2.2. Step 2: Prototype Building Planning and Design

A typical process of energy model development begins with collecting relevant physical and operational data. Most of these details are/can be well-defined for an actual building (proposed or existing). However, for a prototype building model to be a representative of a specific building type, it must align with the established organizational concepts, space-specific requirements, operational characteristics and prevalent design and construction practices. This is demonstrated in the context of courthouse building, as below.

Courthouses have unique building and occupancy characteristics, which differentiate them from office and government administration buildings [23]. These characteristics vary widely depending on the type and size of court. To understand the organizational concepts and space-specific requirements and to recognize the commonalities and variations, we reviewed the US Courts Design Guide (USCDG) for federal courts [24], state court design guide by the National Centers for State Courts [23] and several state-specific court design guides (California Trial Court Facilities Standards [25], Minimum Courtroom Standards in the State of Illinois [26], Kentucky Court Facilities Design Guide [27], The Michigan Courthouse [28]; Nebraska Courts Facility Planning [29], Guidelines for New York State Court Facilities [30], Utah Judicial Facility Design Standards [31] and Virginia Courthouse Facility Guidelines [32]). We examined the implementation of these concepts and the extent of variation using the following resources:

- General Services Administration (GSA) Unit Cost Study [33,34], which provides area programs and floor plans of representative low-rise, mid-rise and high-rise federal courthouses and the GSA LEED Cost Study [35], which provides energy-modelling inputs of the mid-rise courthouse;
- Courthouse Retrospective book series [36–38], which collectively documents 236 federal and state courthouse projects designed in three decades—1980s, 1990s and 2000s;
- GSA Portfolio Data [39], which provides building area statistics for all 158 federal courthouses; and
- Investment-grade audit documentation of 31 federal courthouses [40], which describes their overall building characteristics, construction, occupancy and systems.

To determine the prototype courthouse building characteristics (e.g., size of the courthouse, building geometry, construction type and system type), we reviewed the 2012 CBECS data [41] that includes a detail dataset for a statistical sample of 26 courthouses, which combined with sample weights, represents 6278 courthouses in the United States (2012 CBECS used a sample size of 6720 buildings under 53 building type subcategories to provide statistical information about energy consumption, expenditures and energy-related characteristics of 5.6 million commercial buildings in the US). In consultation with several courthouse facility planning and design experts, we condensed all these findings to define a prototype courthouse building and complete with area program and floor layout.

2.3. Step 3: Determining Construction Vintage and Standards-Specific Requirements

Based on the building characteristics determined in Step 2, detailed modelling specifications—including thermal properties of the building envelope and characteristics of the heating, ventilation and air conditioning (HVAC) system, water heating system, lighting and equipment—are developed according to the requirements for pre-1980 and 1980–2004 construction vintages and ASHRAE Standard 90.1-2004, 2007, 2010, 2013 and 2016 for 17 ASHRAE climate zones [5] to develop 119 versions of the model (i.e., two construction vintages plus five standards multiplied by 17 climate zones). The modelling specifications are submitted for review by building energy codes and standards experts (currently, the ASHRAE Advanced Energy Standards Working Group).

2.4. Step 4: Prototype Model Development and Verification

The energy models are developed for the OpenStudio Standards library [42], which allows users to readily create prototype courthouse models for desired ASHRAE climate zones, construction vintages and ASHRAE standards in OpenStudio format and EnergyPlus [4] and conduct a range of analysis as discussed in Section 1 [13]. For model verification, simulated energy consumption is compared with available measured energy use and utility data from existing building datasets.

3. Prototype–Specific Building Characterization

The following Sections demonstrate Steps 1 and 2 of the methodology for prototype building characterization (i.e., defining a building narrative and building planning and design) through the context of courthouse, beginning with a comparison of floor space and energy use of the building population it would represent among other US commercial buildings.

3.1. Common Statistics for Prototype Comparison

According to the 2012 CBECS data [41], courthouses occupy a total of 436 million ft^2 (40.5 million m^2) of floorspace, which represents 0.5% of US commercial floorspace–the same order as fast-food (0.35%), grocery store or food market (0.88%) and restaurant or cafeteria (1.2%) buildings included in the Commercial Prototype Building Model suite (Figure 2a). They consume a total of 41 trillion Btu of fuel, which represents 0.6% of total fuel consumption in US commercial buildings (Figure 2b). Further, the average floor area for courthouses is 69,400 ft^2 (6447 m^2)—significantly larger than the 15,800 ft^2 (1468 m^2) average for offices and the 15,700 ft^2 (1459 m^2) average for all commercial buildings combined;

while, the average fuel consumption intensity is 94.7 kBtu/ft^2 (300 kW/m^2)—comparable to 77.8 kBtu/ft^2 (245 kW/m^2) for offices and 80 kBtu/ft^2 (252 kW/m^2) for all commercial buildings combined (Figure 2c). Further, as shown in Figure 2d, the range of variation of fuel consumption intensity for courthouses in 2012 CBECS data is much narrow compared to most other building types. The right skewed distribution (i.e., the median smaller than the mean) indicates higher number of building in the lower than average fuel consumption intensity regime.

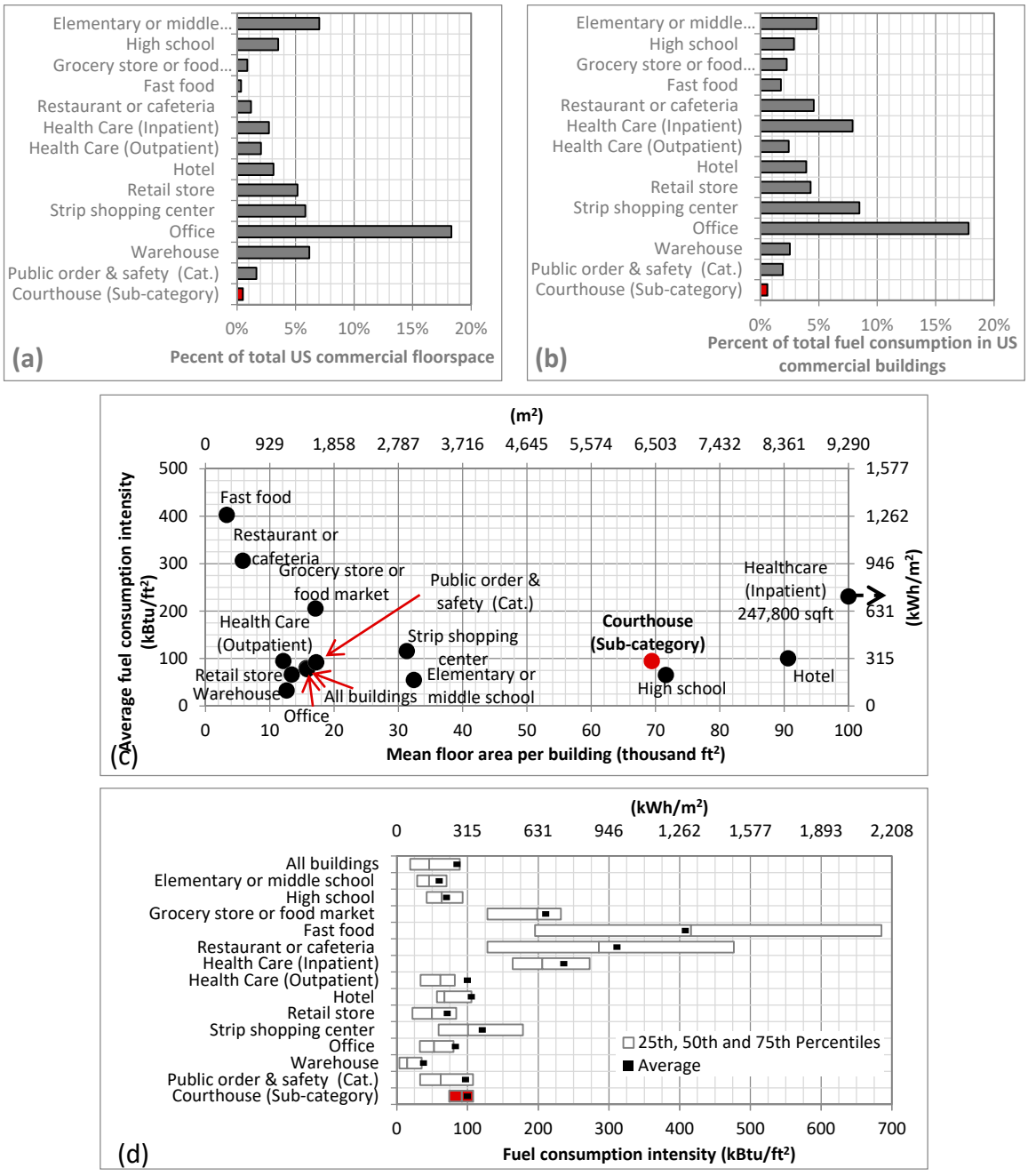


Figure 2. Courthouses in the US commercial building stock [41]. Courthouses account for 0.5% of US commercial floorspace (**a**); 0.6% of fuel consumption in US commercial buildings (**b**); are dissimilar to most other buildings in terms of average floor area but comparable in terms of average fuel consumption intensity (**c**) and have a narrower range of variation of fuel consumption intensity compared to most other building types (**d**).

3.2. Operational Context

The US court system consists of a federal court system and the state and territorial court systems of the individual US states and territories. Each court system is generally divided into three tiers—(i) trial or district court, the lowest tier at which a case starts; (ii) appellate court, where most appeals are first heard; and (iii) supreme court, which hears further appeals and has final authority in the cases heard. Some cases initiated in a state court system may ultimately end up in the federal court system (Figure 3) [24].

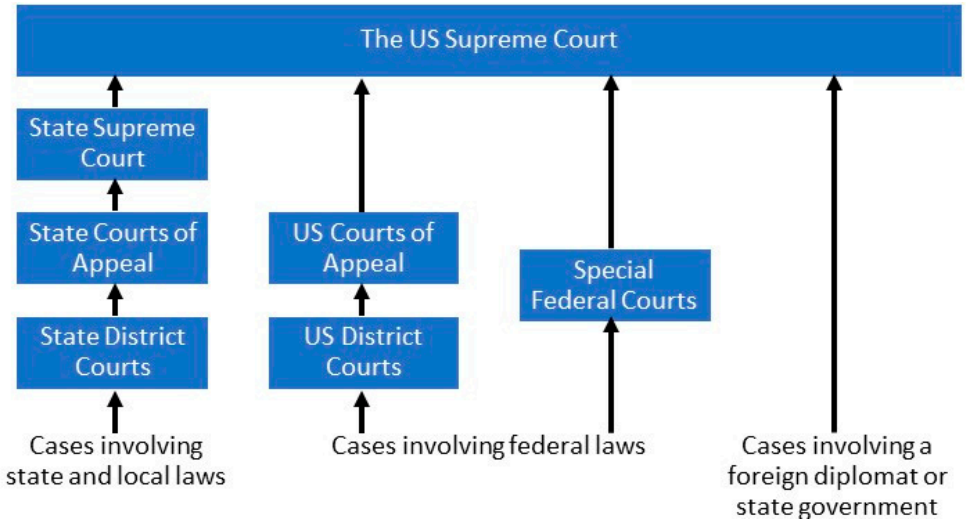


Figure 3. The US court system.

Federal and state courts are different in terms of the types of cases heard. Federal courts handle cases involving federal laws, foreign diplomats and disputes between two or more states or its citizens [24]. State courts, generally, have two levels of trial courts—(i) special jurisdiction courts with jurisdiction limited to specific types of cases (such as traffic cases, minor civil and criminal disputes, juvenile cases) and (ii) general jurisdiction courts with jurisdiction over all other cases, including serious criminal and civil cases [22,43].

Federal courts in the United States include 94 trial courts, 13 appellate courts and a supreme court [24]. State courts include 15,679 trial courts, 95 appellate courts and 57 supreme courts [44]. Federal courts, in most cases, are in multi-tenant buildings; other tenants may include the US Postal Service, the US Marshals Service, correctional facilities and juvenile facilities. State courts, in some cases, may be in an administrative building of the local government (such as a municipal building or a state or county office building).

The 2012 CBECS data represents 6278 courthouses, which is approximately 40% of the number of courthouses listed in References [23] and [43]. It should be noted that CBECS data includes only commercial buildings greater than 1000 ft^2. Further, the building type/subtype category in the CBECS data tables presents a classification of the commercial activity that occupies the most floor area in the building. Therefore, it is likely that many small courthouses or courthouses in multi-tenant buildings are not counted in CBECS data.

These distinctions between different court types provided a context when reviewing courthouse design guides, databases and documented projects, and is discussed further in the following sections.

3.3. Prototype Building Design Principles

3.3.1. Grossing and Efficiency Factors

Courthouses have relatively less space efficiency compared to office buildings due to special volume, circulation and security needs. According to Reference [23], courthouses are typically designed to achieve a net square footage (NSF) of 57–65% and a departmental gross square footage (DGSF), or usable square feet (USF), of 75–85% of building gross square footage (BGSF or GSF), compared to 60–70% NSF in office buildings. To further clarify these terms, NSF includes space required for a particular function, exclusive of interior walls or circulation space around the functional area. DGSF equals NSF plus a circulation factor to account for internal walls and partitions, internal corridors and circulation among functional components. BGSF equals DGSF plus corridors, stairs, elevators and lobbies linking various departments, vertical shafts, common areas, public toilet facilities and exterior walls. The state-specific court design guides[2] show slight variations in these factors. In federal courts, the USF typically accounts for 67% of GSF of court facilities indicating more circulation and public areas [24].

We examined the efficiency factor in representative low-rise (4-story, 5 courtrooms), mid-rise (6-story, 10 courtrooms) and high-rise (22-story, 20 courtrooms) federal courthouses used for the GSA Unit Cost Study [34]. In all three examples, the courthouse includes court-related spaces, offices for other agencies and a secured covered parking. Table 1 outlines the building description and key area programming metrics for these courthouses and shows a 'USF of courts and other agencies' as 63–66% of BGSF, which aligns with USCDG [24].

Table 1. Example area programming metrics for low-rise, mid-rise and high-rise federal courthouses [34].

Categories	Low-Rise		Mid-Rise		High-Rise	
Building Description						
Number of floors below grade	1		1		2	
Number of floors above grade	3		5		20	
Penthouse	1		–		1	
Footprint area	38,584 ft^2	(3585 m^2)	43,296 ft^2	(4022 m^2)	24,000 ft^2	(2230 m^2)
Building gross square feet (BGSF)	136,600 ft^2	(12,691 m^2)	262,000 ft^2	(24,341 m^2)	436,700 ft^2	(40,571 m^2)
Characteristic Spaces						
Number of courtrooms [1]	3 trial + 1 bankruptcy		8 trial + 2 bankruptcy		16 trial + 4 bankruptcy	
Number of judges' chambers	4		10		20+ [2]	
Number of jury deliberation rooms	3		8		16	
Usable Square Feet (USF)						
Court	73,793 ft^2	(6856 m^2)	138,831 ft^2	(12,898 m^2)	251,137 ft^2	(23,331 m^2)
Other agencies	12,826 ft^2	(1192 m^2)	35,199 ft^2	(3270 m^2)	25,169 ft^2	(2338 m^2)
Subtotal	**86,620** ft^2	**(8047 m^2)**	**174,030** ft^2	**(16,168 m^2)**	**276,306** ft^2	**(25,670 m^2)**
Secured covered parking	11,000 ft^2	(1,022 m^2)	15,000 ft^2	(1394 m^2)	20,000 ft^2	(1858 m^2)
Total	**97,620** ft^2	**(9069 m^2)**	**189,030** ft^2	**(17,561 m^2)**	**296,306** ft^2	**(27,528 m^2)**
Area Programming Metrics						
USF of court and other agencies /BGSF	63.4%		66.4%		63.3%	
Court USF/number of courtrooms	14,759 ft^2	(1371 m^2)	13,883 ft^2	(1290 m^2)	12,557 ft^2	(1167 m^2)
BGSF/number of courtrooms	27,320 ft^2	(2538 m^2)	26,200 ft^2	(2434 m^2)	21,835 ft^2	(2029 m^2)

[1] Federal courthouse may include bankruptcy courtrooms, which are non-jury courtrooms and do not require jury deliberation rooms. Bankruptcy cases can only be filed in a federal court, not in a state court. [2] The high-rise courthouse presented here included 6 typical floors with courtrooms and judge's chambers on the same floor, 4 typical floors dedicated to courtrooms and 2 typical floors dedicated to judge's chambers. The exact number of judge's chambers could not be estimated from the aggregated area for judicial chambers provided in Reference [34].

We also examined the efficiency factor in courthouses documented in the Courthouse Retrospective book series [36–38]. These courthouses range from 3000 to 1.3 million BGSF (279–120,774 m^2), with up to 74 courtrooms. Figure 4 shows the percent frequency of building efficiency ratio (i.e., ratio of NSF

to BGSF) in federal and state courthouses and indicates 71–75% as the most common range in both federal and state courthouses. BGSF in federal courts, in most cases, includes area of court-related spaces as well as other agencies; since these projects were competitively selected and not sampled, the derived statistics may not be representative of federal and state courthouse populations.

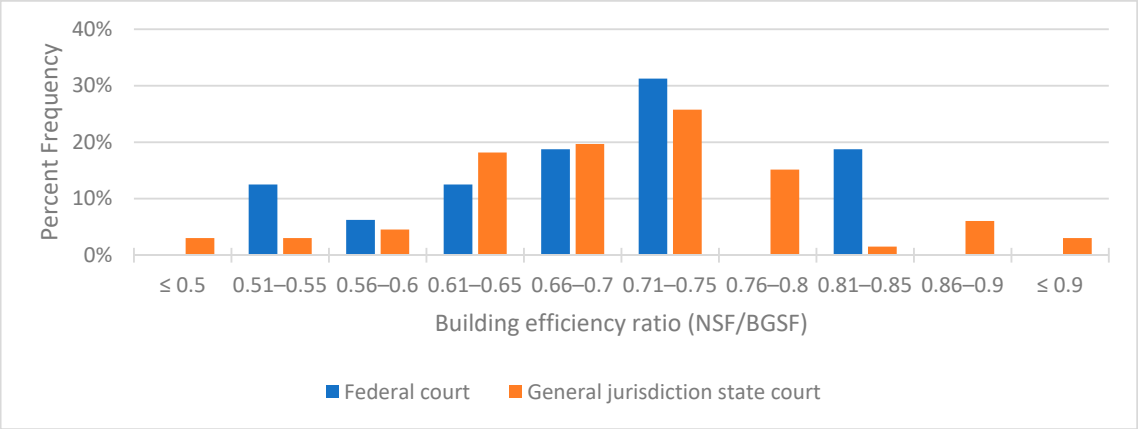


Figure 4. Building efficiency ratio in federal and state courthouses [36–38].

3.3.2. Scale and Size of Building

The number of courtrooms is the main determinant of the size of a courthouse [32]. USCDG [32] categorizes a courthouse as small for up to 5 courtrooms, medium for 6–12 courtrooms and large for more than 12 courtrooms. Virginia Courthouse Facility Guidelines [32] reports a national average BGSF of 12,000–17,000 (1115–1579 m^2) per courtroom—higher limits for trial courthouses. California Trial Court Facilities Standards [25] recommends BGSF of 9000–14,000 (836–1300 m^2) per courtroom.

We examine the number of courtrooms and how it corresponds to the building area in the representative low-rise, mid-rise and high-rise federal courthouses used for GSA Unit Cost Study [34]. Table 1 shows a court USF of 12,557–14,760 (1167–1371 m^2) per courtroom or BGSF of 21,835–27,320 (2029–2538 m^2) per courtroom—higher range for smaller, low-rise federal courthouse.

We also examined the number of courtrooms and how it corresponds to the building area in federal and state courthouses documented in the Courthouse Retrospective book series [36–38]. Figure 5a shows that the documented projects represented federal and state courthouses of all sizes. The predominant number of courtrooms in small, medium and large courthouses were 4–5 courtrooms, 7 courtrooms and 13–15 courtrooms, respectively, in federal courthouses and 4 courtrooms, 10 courtrooms and 16–25 courtrooms, respectively, in state courthouses.

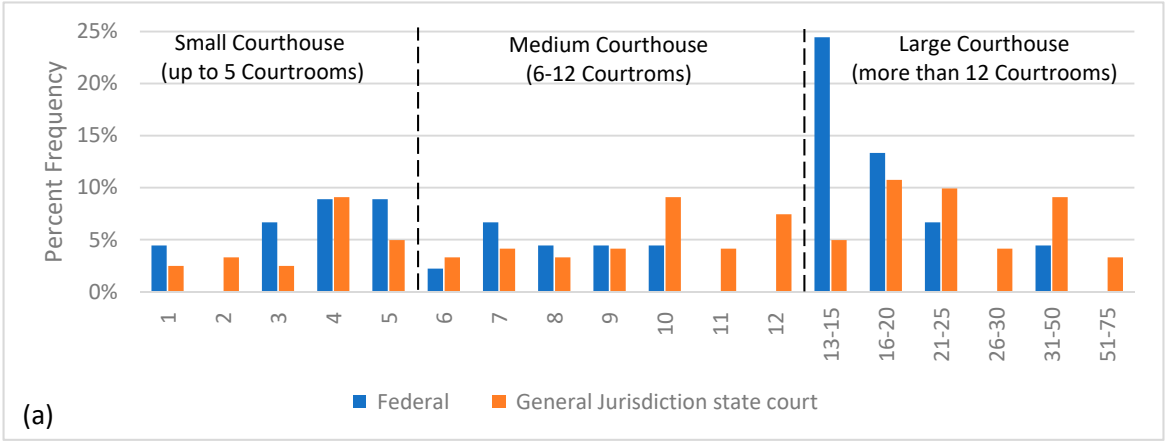


Figure 5. *Cont.*

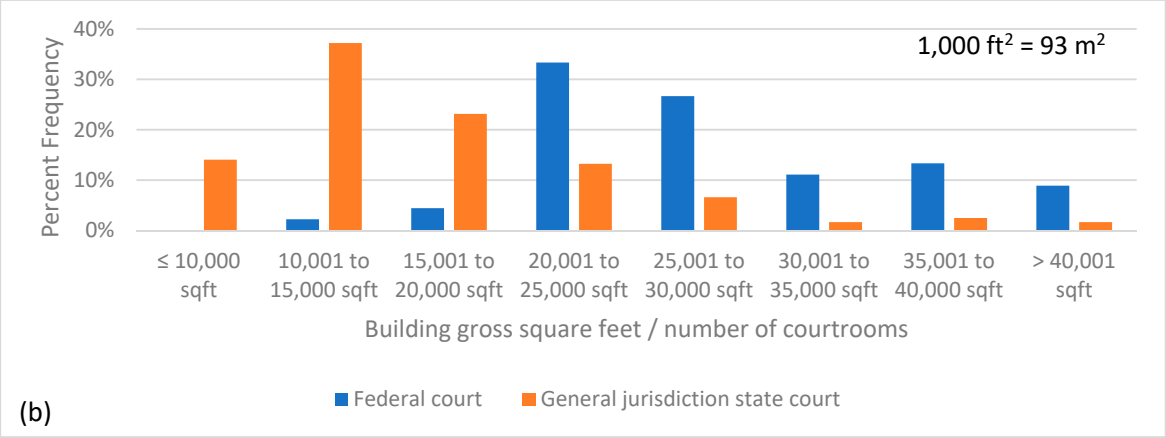


Figure 5. Percentage frequency of (**a**) number of courtrooms and (**b**) the ratio of gross square feet to number of courtrooms in federal and state courthouses [36–38].

Figure 5b shows that the predominant ratio of gross square feet to number of courtrooms is 20,000–30,000 ft^2 (1858–2787 m^2) per courtroom with an average of 28,387 ft^2 (2637 m^2) per courtroom in federal courthouses and 10,000–15,000 ft^2 (929–1394 m^2) per courtroom with an average of 16,886.5 ft^2 (1569 m^2) per courtroom in state courthouses, which are close to the higher limits of the ranges recommended by courthouse design guides and standards discussed above.

3.3.3. Characteristic Spaces

Courthouses are used by a variety of people including judges, attorneys, jury, witnesses, victims, in-custody defendants, clerks, other employees, outside social agencies, the press and the general public. The characteristic spaces in a courthouse include courtrooms, judges' suites, offices, lobby, waiting areas and secured parking for judges, court officers and others with high security clearance. Trial courts may involve a jury requiring larger courtrooms and additional spaces for jury operation (i.e., a jury assembly area and jury deliberation rooms), attorney-client/witness waiting rooms and holding areas and secured circulation for in-custody defendants. The appellate courts do not take trial cases and therefore do not require these spaces. Many courthouses include a law library. The courthouse building management and support areas typically include a mail room, maintenance, storage and supply and mechanical/electrical room.

The number of courtrooms is the major factor determining the number and size of the judicial, clerk, public, technical and other spaces throughout the building [32]. National Centers for State Courts [23] provides a few typical courthouse design parameters summarized as ratios of major room types.

Ratio of courtrooms to judges' chambers: Typically, in a courthouse with 10 or fewer courtrooms, each judge is assigned a courtroom. In larger courthouses, courtrooms can be shared, requiring three courtrooms for every four judges. In less populated areas, one courtroom may be shared by several divisions of the same court or by different courts. For courtroom sharing to work, all courtrooms should be identical in their capabilities, such as for holding a criminal jury trial. It is to be noted that not every hearing or proceeding has to take place in a courtroom; many can be held in chambers or in a smaller hearing or conference room.

Ratio of jury deliberation rooms to courtrooms: Typically, in a courthouse with up to four or five courtrooms, one jury deliberation room per courtroom in provided. In larger courthouses, a ratio of six or seven deliberation rooms per ten jury courtrooms is used, as long as deliberation rooms are accessible to all courtrooms. Criminal courts may require a higher ratio of deliberation rooms per courtroom than civil, municipal and traffic courts.

Ratio of jury to non-jury courtrooms: The ratio of jury to non-jury courtrooms depends upon several factors. The most flexible situation is for each courtroom to have a jury box or space for a jury box. As a general rule, unless jury trials are extremely rare, the court should plan to make most courtrooms jury-capable.

Table 1 shows that for the representative low-rise, mid-rise and high-rise federal courthouses in GSA Unit Cost Study [34], the number of jury deliberation rooms correspond to the number of trial courtrooms and the number of judges' chambers correspond to the total number of courtrooms (including trial and bankruptcy courtrooms) and thus, are consistent with these design parameters.

3.3.4. Circulation

The courthouse circulation related guidance is similar for federal and state courts [23,24]. The courthouse circulation system consists of three separate and distinct paths of movement for the public, court professionals and in-custody defendants (Figure 6). Public circulation provides access from main building entrances to the various functional areas of the building. Private circulation provides controlled access to particular courthouse users, specifically, movement of judges and trial-related court personnel between chambers and courtrooms and movement of sequestered jurors between courtrooms and jury deliberation rooms. Secure circulation is physically separate from all nonsecure spaces and circulation systems in the courthouse and provides for the movement of in-custody defendants—access to the building through a secure vehicular or pedestrian sally port, a secure central holding and staging area, small holding units directly adjacent to the courtrooms and secure elevators for circulation from the central holding area to the court-floor holding units. The only quasi-public interface that might occur would involve meetings with defense attorneys in holding areas. In addition, there are interfaces between public and private circulation through screening or security and in large courthouses, secondary circulation for service staff to provide movement in building support areas with controlled access from public circulation.

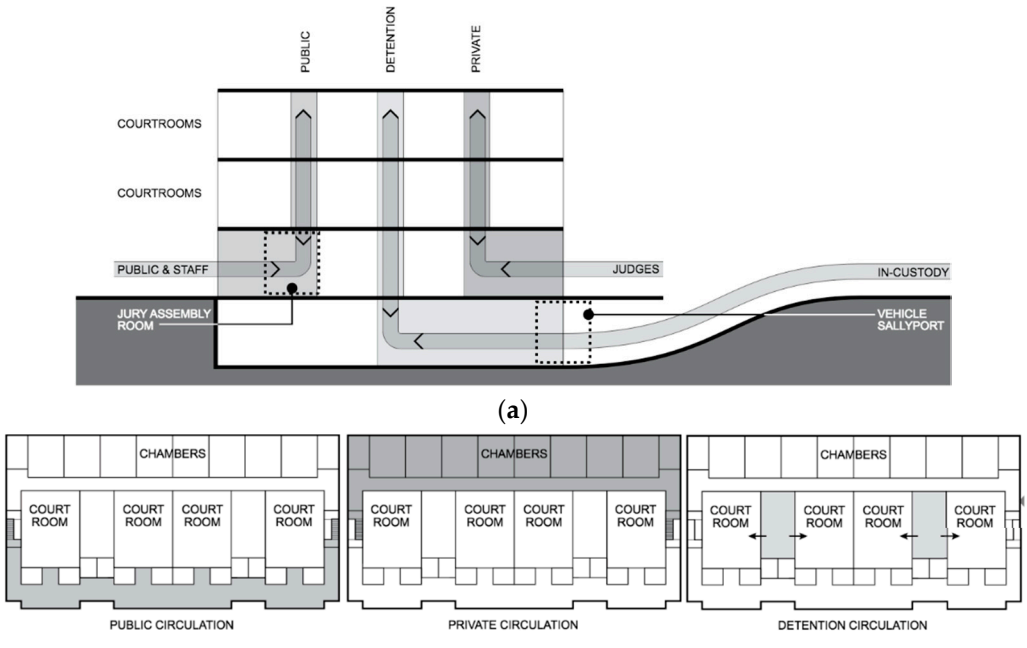
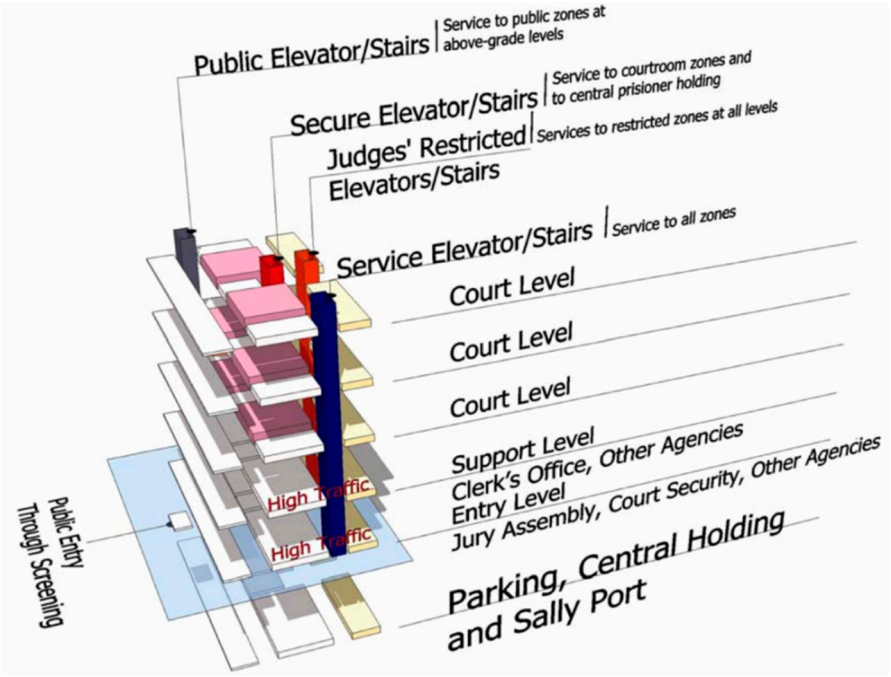


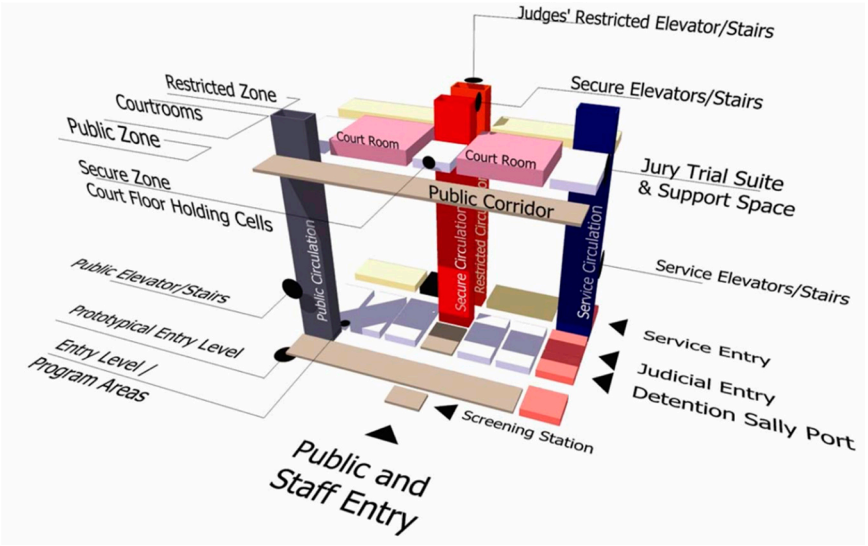
Figure 6. Three-part circulation system in a courthouse shown in section (**a**) and court-floor plan (**b**) [25].

3.3.5. Adjacency, Stacking and Blocking

The courthouse zoning related guidance is similar for federal and state courts [23,24]. Due to the adjacency requirements of different spaces, courthouses have a characteristic stacking scheme of different floors and a characteristic blocking scheme on the court floor, as shown in Figure 7.



(**a**)



(**b**)

Figure 7. Typical stacking scheme (**a**) and court-floor blocking scheme (**b**) in a courthouse [24].

Stacking scheme: The high-volume functions of the courthouse (such as central office areas, including clerks and jury assembly) and functions that require after-hours access are located on the lower floors and near the lobby. Courtrooms are clustered on the higher floor(s), with shared support spaces. In trial courthouses, a central detention area for in-custody defendants is located on the lower floor and accessed through a sally port.

Blocking scheme on the courtroom floor: Courtrooms are clustered in groups of two, four, six or eight, with shared support spaces. Court-related functions such as witness rooms, audio-visual room, evidence room and detention area are placed near courtrooms. Jury deliberation rooms are located near trial courtrooms and accessed from private circulation. Judges' suites including judges' chambers and offices of judiciary staff are located on the courtroom floor behind the courts or clustered on dedicated floor(s).

The Courthouse Retrospective book series [36–38] shows the possible variations in the floor layout, while adhering to these organizational concepts, such as (a) single-loaded versus double-loaded public corridor/waiting areas on the court floor, (b) judges' suites on the courtroom floors versus all on a dedicated floor in large courthouses, (c) courtroom sharing in larger courthouses versus one courtroom per judge and (d) location of courtrooms in the center versus on the perimeter.

In Figure 8, the court floor plan of the three representative courthouses in GSA [34] shows double-loaded corridor on the court floor for the low-rise and single-loaded for mid-rise and high-rise courthouses; judges' suites on the courtroom floors for the low-rise and mid-rise courthouses and non-jury courtroom floors in the high-rise courthouse; and off-the-perimeter location of courtrooms in all courthouses.

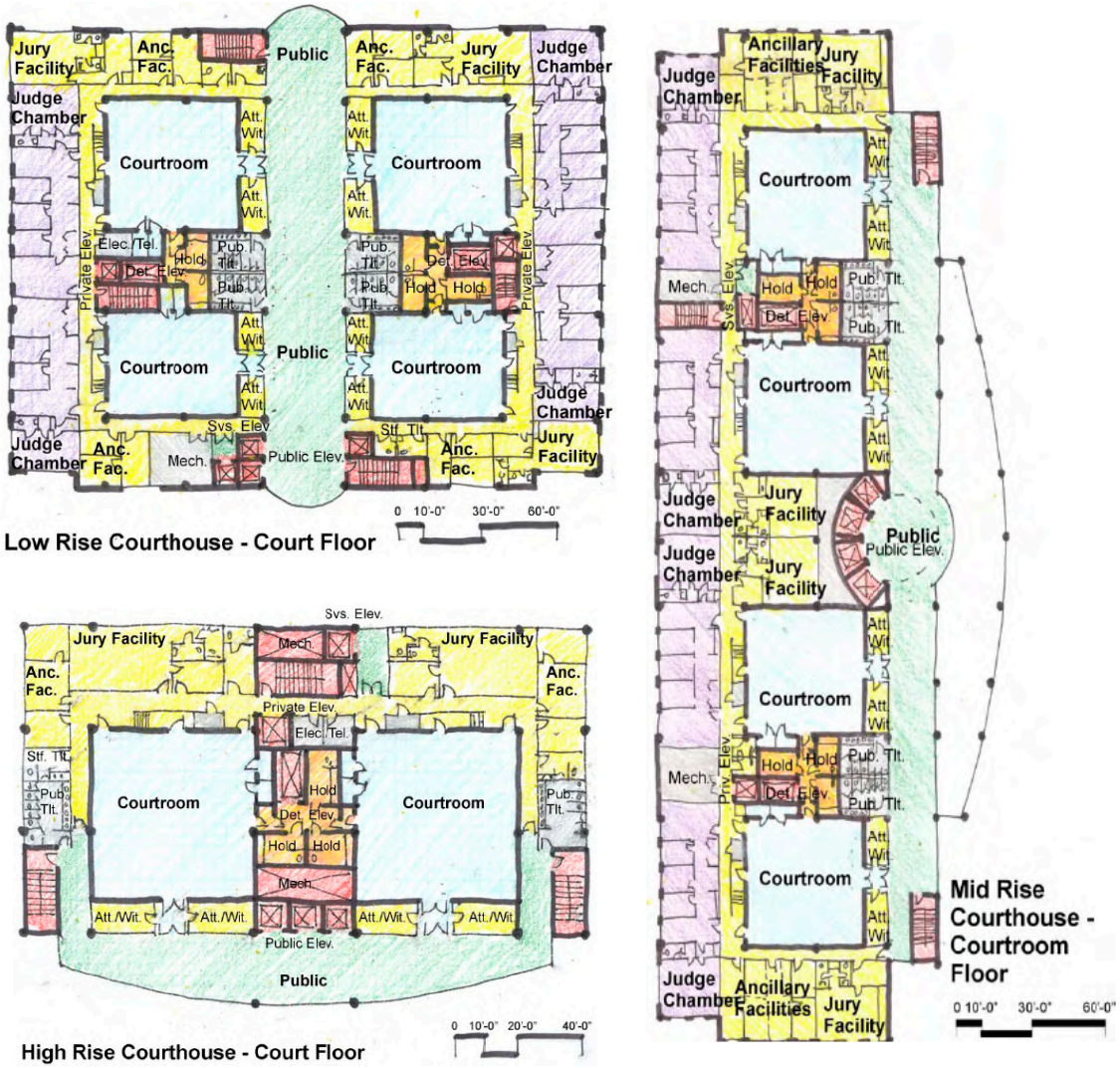
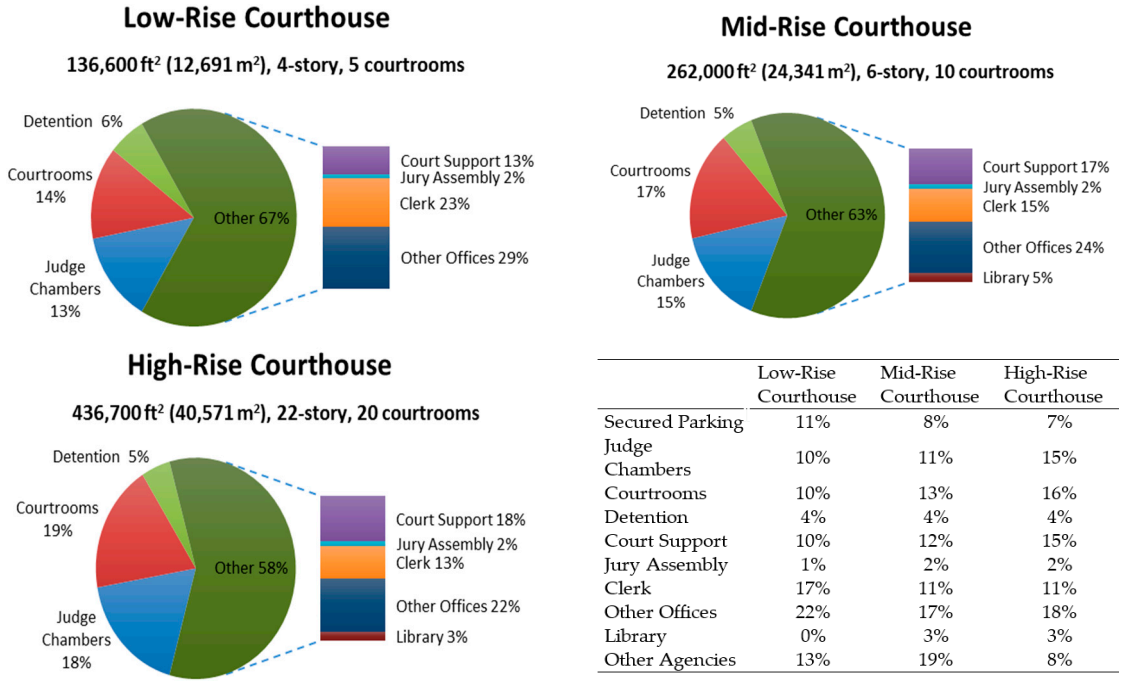


Figure 8. Example floor plan for courtroom floors of low-rise, mid-rise and high-rise federal courthouses [34].

These variations demonstrate how multiple blocks of courtroom functional sets, comprised of two courtrooms and associated spaces, can be arranged in linear or concentric pattern of recursion [45] and stacked on different floors (and supplemented by proportional change in the area of support level(s) which houses clerk's office, jury assembly, security, etc.) to develop smaller or larger courthouses.

3.3.6. Space area Distribution

To examine the space area distribution in courthouses, we reviewed the area program of representative low-rise, mid-rise and high-rise federal courthouses in GSA [34]. Figure 9 compares the space area distribution in these courthouses. It shows courtrooms occupying 14–19% of court USF; judges' chambers, 13–18%; detention areas, 5–6%; and offices, 63–67% (including 13–23% for clerk, 13–18% for court support, 2% for jury assembly, up to 5% for library and 22–29% for other offices).



	Low-Rise Courthouse	Mid-Rise Courthouse	High-Rise Courthouse
Secured Parking	11%	8%	7%
Judge Chambers	10%	11%	15%
Courtrooms	10%	13%	16%
Detention	4%	4%	4%
Court Support	10%	12%	15%
Jury Assembly	1%	2%	2%
Clerk	17%	11%	11%
Other Offices	22%	17%	18%
Library	0%	3%	3%
Other Agencies	13%	19%	8%

Figure 9. Example space area distribution in low-rise, mid-rise and high-rise federal courthouses [34].

3.3.7. Space Standards and Heights

Courthouse design guides provide space planning standards as the min–max range for many characteristic spaces (such as courtroom, court support areas, judges' chambers, jury deliberation room, detention cell, security control room), as well as detailed guidance on determining the area requirements for occupancy-dependent spaces (such as courtroom waiting, jury assembly, clerk). In general, the courtrooms, public spaces and judges' chambers are larger in federal courthouses. However, large variations in the area requirements for these spaces are found in the state-specific design guides[2]. Further, the area for the courtroom depends on the type of courtroom (such as jury trial courtroom, non-jury trial courtroom, appellate courtroom) as well as the size of the jury and number of spectators [23,24].

Courthouses have explicit requirements for high ceiling heights in courtrooms depending on the type and area of courtroom [23,24]. For efficient planning, dedicating the entire floor(s) for courtrooms is recommended [23]. The floor-to-floor height should be determined to include the height of the accessible floor system (or ceiling plenum) [46].

3.3.8. Construction

GSA [46] specifies baseline construction standards for federal courthouses, which includes a precast concrete exterior envelope with stone, brick or other durable finishing materials; ballistic-resistance glazing at various levels of the facility; interior wall partitions composed of gypsum board on metal studs; and concrete masonry for detention spaces, elevators and service shafts. The GSA Unit Cost Study [33] and GSA LEED Cost Study [35] used slight variants of the GSA baseline construction. Additional construction details in these studies include—poured-in-place concrete for basement walls; composite concrete on steel deck for floor and roof construction; flat roof with built-up roofing and closed cell polystyrene rigid insulation; and aluminum frame punched window system.

On the other hand, the 2012 CBECS data [41] shows 'brick, stone or stucco' on stud-walls (representing 84% of courthouses and 43% of courthouse floorspace) as the predominant wall construction and 'plastic, rubber or synthetic sheeting' (representing 43% of courthouses) and 'built-up roofing' (representing 45% of courthouse floorspace) as the common roof construction (Figure 10).

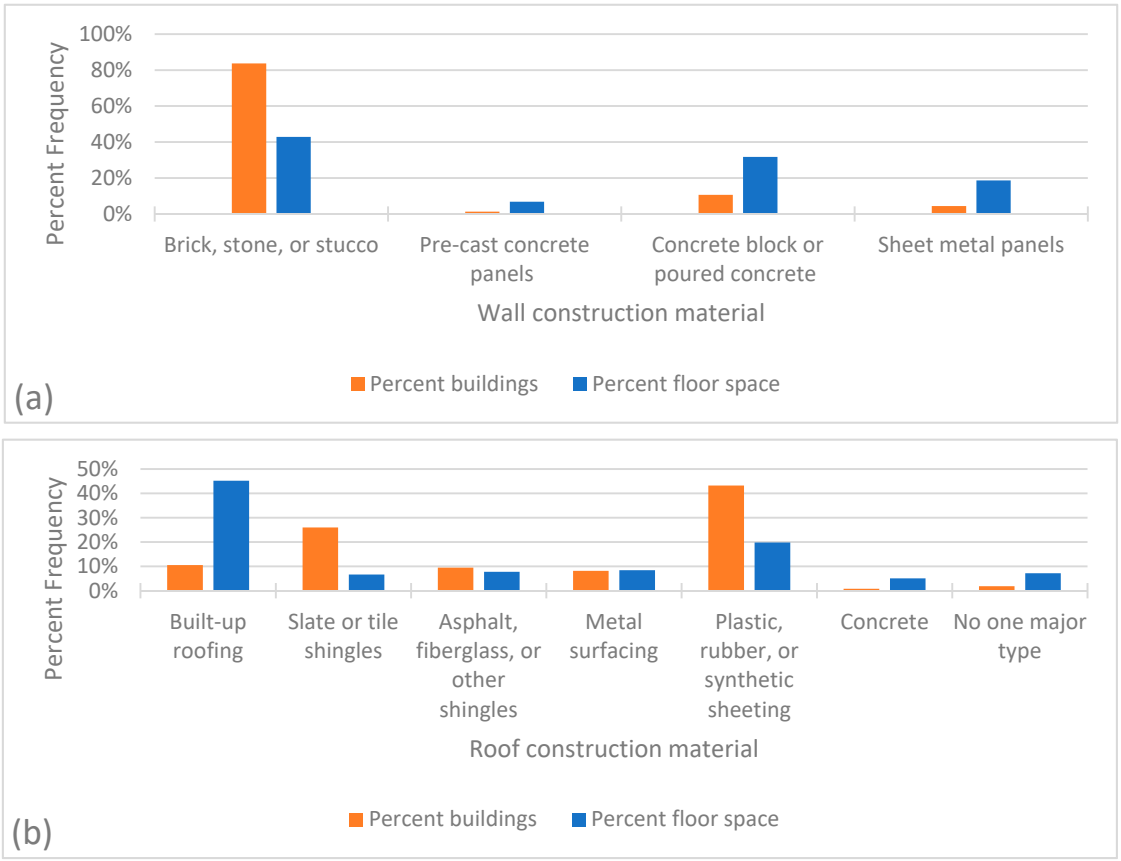


Figure 10. Courthouse construction characteristics [41]. 'Brick, stone or stucco' on stud-walls is the predominant wall construction (**a**) and 'plastic, rubber or synthetic sheeting' and 'built-up roofing' are the common roof construction (**b**).

3.3.9. Schedule of Building Use

According to USCDG [24], courtrooms may be used during extended hours. Judges' chambers are routinely in use during evenings and weekends. Clerks' offices operate on flextime. Probation offices can have early morning and late evening hours. Other areas that routinely require off-hours operation are the trial jury suite and grand jury suite. There is often a need for after-hours access to some parts of the building [32].

To examine the implementation of this guidance, we reviewed the space-specific schedules modelled for the GSA LEED Cost Study [35] and noted space occupancy from 7 a.m. to 6 p.m. in

general office areas and judge's chambers, 8 a.m. to Noon in jury assembly area, 9 a.m. to 7 p.m. in courtrooms, 9 a.m. to 4 p.m. in jury deliberation rooms and 9 a.m. to 5 p.m. in holding cells. We also noted the diversity of use among courtrooms throughout the year modelled through multiple daily, weekly and annual schedules.

We also examined the hours of operation for 31 federal courthouses [40] (Figure 11a) and found that most federal courthouse operate from 7 a.m. through 6 p.m., with 11 hours per day as the average duration of operation. In the 26 sample courthouses in the 2012 CBECS data [41] (Figure 11b), most of them open only during weekdays, the total hours open per week ranged between 40 and 60 (excluding two outliers open 168 h per week or 24 h per day). Accounting for the sample weights, the average duration of courthouse operation is 53.2 h per week (i.e., 10.6 hours per day), which aligns with the finding in Figure 11a.

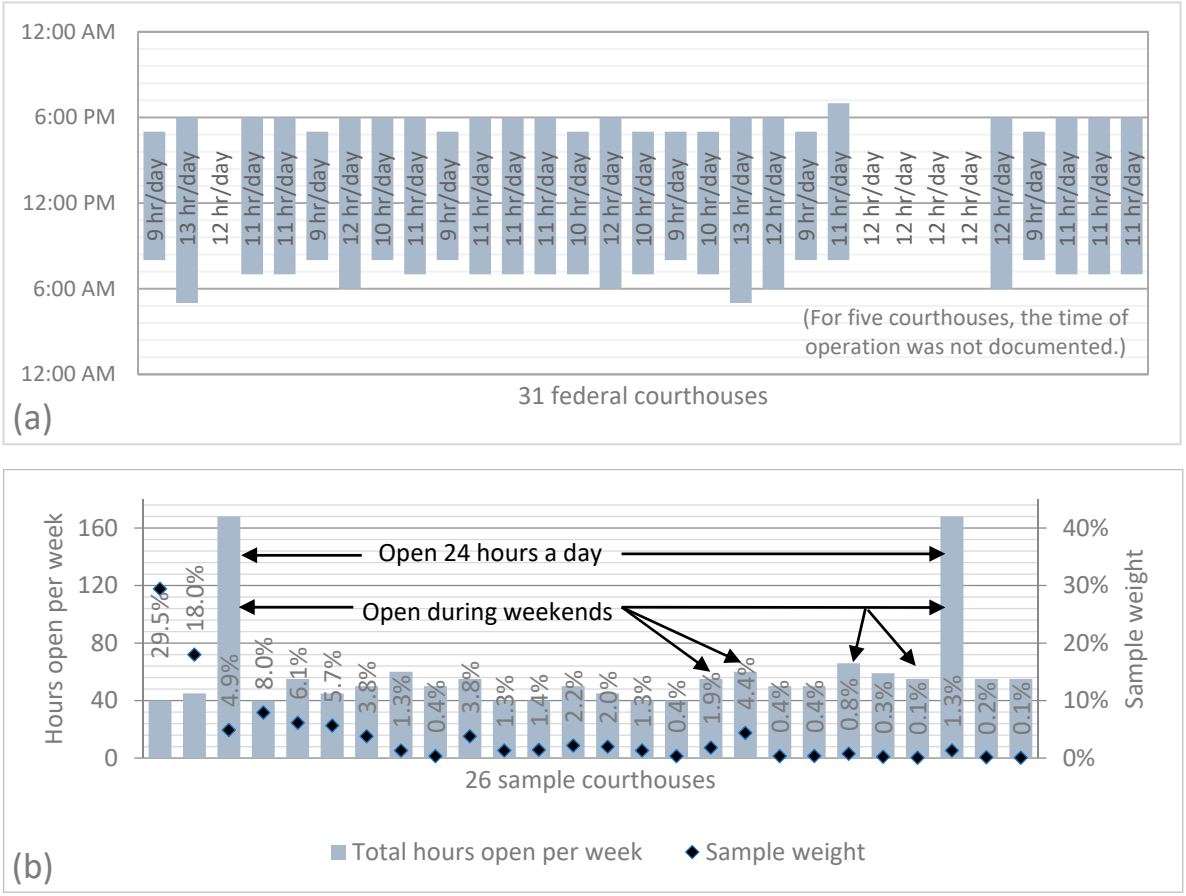


Figure 11. Hours of operation in (**a**) federal courthouses [40] and (**b**) sample courthouses in the 2012 Commercial Building Energy Consumption Survey (CBECS) data [41].

3.3.10. Control of HVAC System

Courthouse design guides provide guidelines for the control of HVAC systems in different spaces. California Trial Court Facilities Standards [25] specifies that each courtroom, judge's suite, jury deliberation room, corner office, entrance lobby, staff lounge, conference room, mailroom and equipment room should be an independent zone. USCDG [24] specifies that each 'court set,' which comprises of a courtroom and supporting spaces, a judge's suite (when located adjacent to a courtroom) and a jury deliberation room, must be served from the same HVAC system (i.e., separate zones having related thermostats) and the design must account for variation in occupancy load.

Further, inside the courtroom, three HVAC zones must be provided for air distribution–the judge and attorney area, the jury area and the spectator area [24]. Architectural features in courtrooms

are generally above the standard conventional design, often with custom millwork including wood and ornate ceilings, which require both temperature and humidity control [47].

Court functions also require flexibility in the time of operation and control of HVAC systems. Therefore, the HVAC system must be designed to operate after standard building operation hours.

3.4. Additional Findings from Prototype-Specific Datasets

3.4.1. Building Area

In the 2012 CBECS data [41], the area of courthouses is between 1300 and 800,000 ft^2 (121–74,322 m^2) with an average of 69,400 ft^2 (6447 m^2). Figure 12a plots this data as percent buildings and percent floorspace by square footage categories. It shows that most courthouses (30%) are small buildings (i.e., 1000–5000 ft^2 or 93–465 m^2) but they comprise less than 1% of the total floorspace occupied by courthouses. In the GSA Portfolio Data [39], the court USF in federal courthouses is between 4200 and 788,000 (390–73,208 m^2) with an average of 109,000 (10,126 m^2) and a median of 55,000 (5110 m^2). This court USF excludes non-court functions, such as other federal offices, covered parking, common spaces (e.g., lobbies, corridors, service areas, toilets, etc.) and vertical penetrations. Figure 12b plots this data as percent buildings and percent floorspace by court USF categories. It aligns with Figure 12a except that federal courthouses are rarely small buildings.

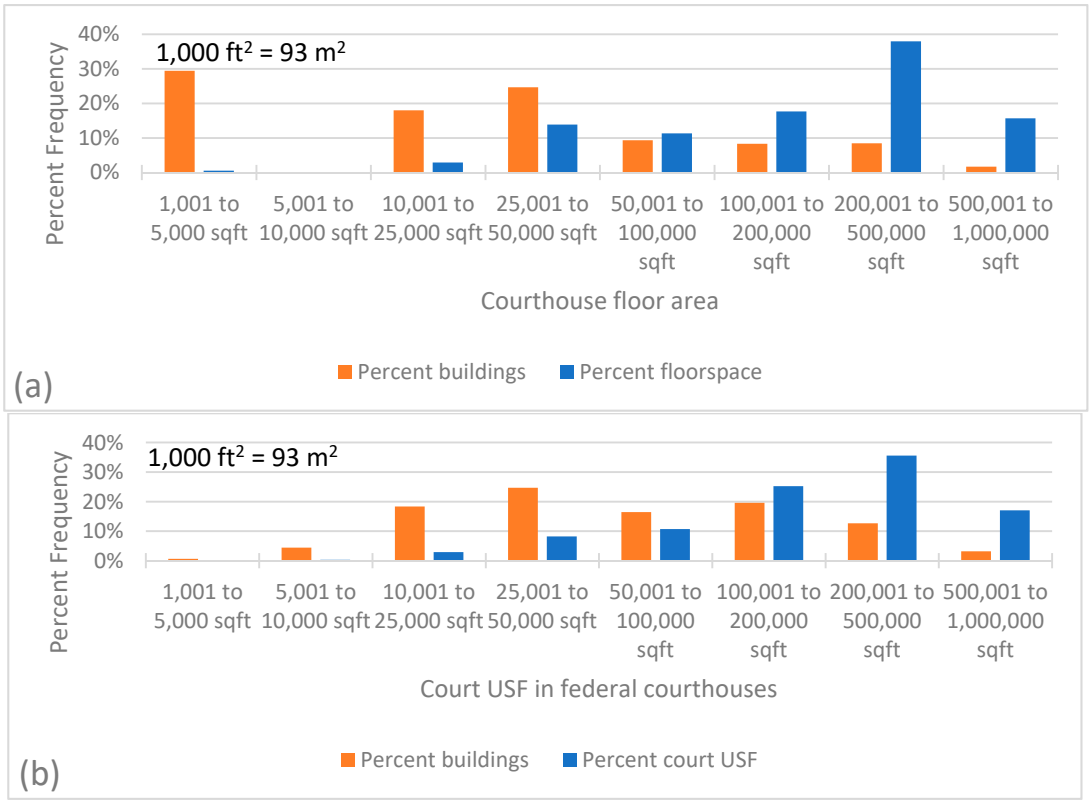


Figure 12. Courthouse floor area in (**a**) the 2012 CBECS data [41] and (**b**) the General Services Administration (GSA) Portfolio Data [39].

3.4.2. Building Shape

According to the 2012 CBECS data [41], wide rectangle is the predominant building shape for courthouses. They represent 66% of courthouses and 59% of total courthouse floorspace in the United States (Figure 13a). To determine the building aspect ratio, we used the 1992 CBECS data [48], since the newer CBECS datasets no longer include this data. In the 1992 CBECS dataset [48], buildings are categorized only by the principal building activity (e.g., Public Order and Safety) and not

by subcategory (e.g., courthouse). For the 'public order and safety' building category, the average aspect ratio of rectangular buildings, percent buildings and percent floorspace are plotted in Figure 13b by building square footage categories. It shows that for the categories between 5000 and 1 million ft^2 (465–93,000 m^2), which comprise 65% of buildings and 70% of courthouse floorspace, the average aspect ratio ranges between 2:1–2.4:1. Buildings less than 5000 ft^2 (465 m^2) and more than 1 million ft^2 (93,000 m^2) have a smaller aspect ratio.

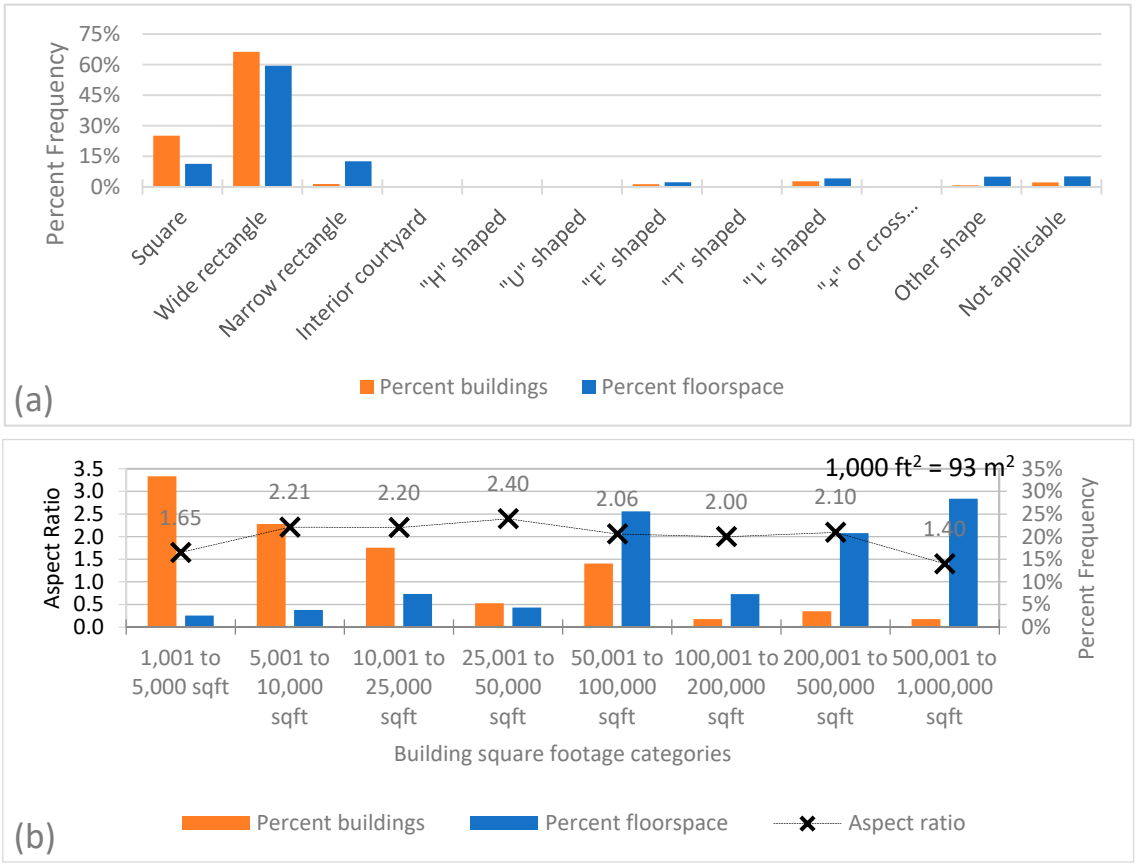


Figure 13. Building shape statistics for (**a**) courthouses in the 2012 CBECS data [41] and (**b**) 'Public Order and Safety' buildings in the 1992 CBECS data [48].

3.4.3. Number of Floors

USCDG [24] designates courthouses as low-rise—up to 4 floors, mid-rise—5 to 9 floors and high-rise—10 or more floors above grade. According to the 2012 CBECS data [41], 47% of courthouses are one story but they represent only 3% of total courthouse floorspace (Figure 14a). The next most common buildings are three- and four-story courthouses; together they represent 31% of all courthouses and 22% of total courthouse floorspace.

The 2012 CBECS data [41] also provide the number of elevators in the building. Figure 14b plots the number of elevators versus number of floors for varying building area categories. Combining all area categories, the plot shows a general tendency of the number of elevators corresponding to the number of floors with a maximum of 12 elevators. However, for courthouses larger than 100,000 ft^2 (929 m^2), no such tendency is discernable. Also, the type of courthouse is not evident that determines the requirement for separate elevators for public, judges and in-custody defendants.

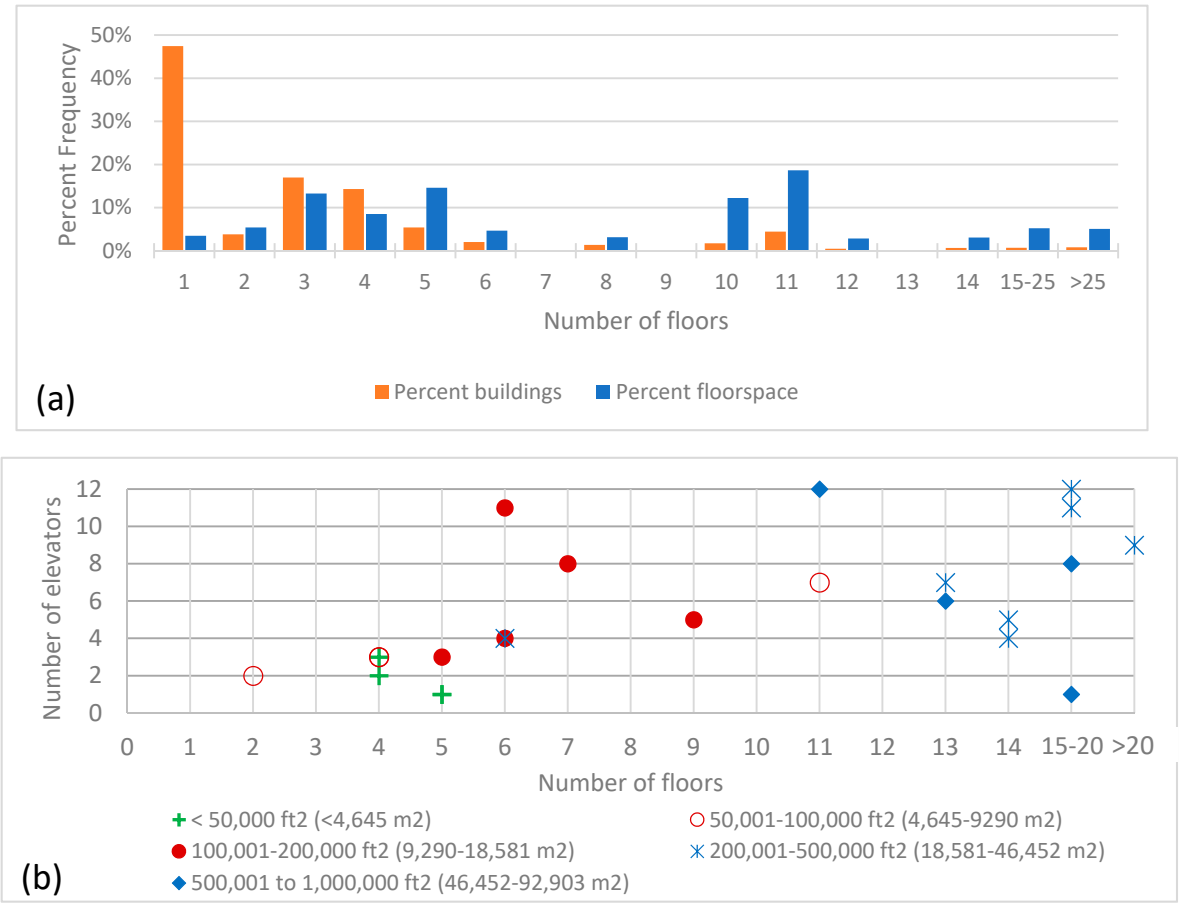


Figure 14. Number of floors in courthouses [41] (**a**), and number of elevators versus building square footage and number of floors (**b**).

3.4.4. Windows

CBECS data provides window area as percent exterior glass categories. According to the 2012 CBECS data [41], the 11–25% category for exterior glass percent is the most common (i.e., in 73% of courthouses) (Figure 15). The GSA Unit Cost Study [33] used 40% glazing for the fenestration system for federal courthouse. Courthouse Retrospective book series [36–38] indicates a recent design trend of allowing more natural light in all spaces including courtrooms, as opposed to that in older courthouses which show less window area and courtrooms with no windows.

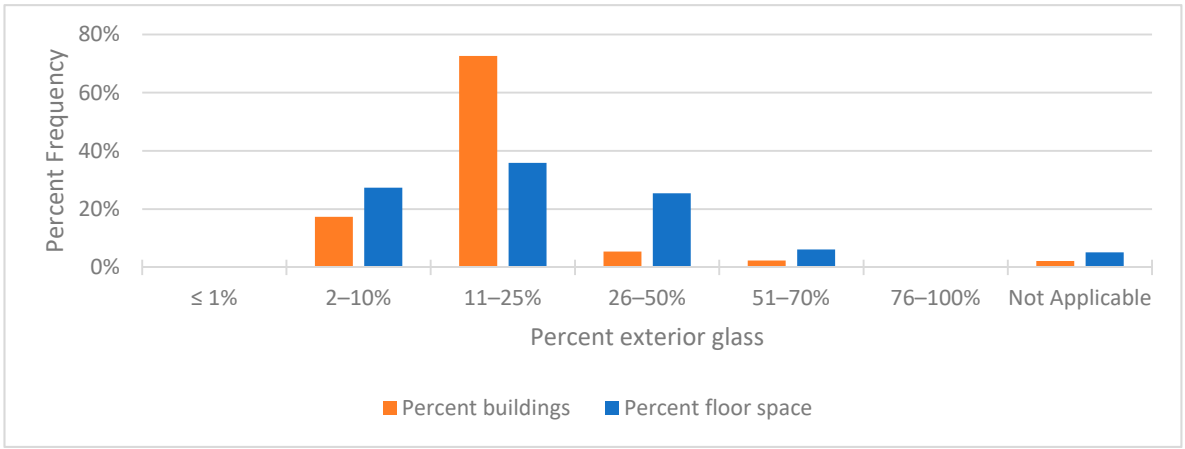


Figure 15. Percent exterior glass in courthouses [41].

For the properties of windows, CBECS data only provide descriptive window characteristics. Accounting for the sample weights, the predominant window characteristics for courthouse include–(a) single-layer glass (54.1% buildings) and multilayer glass (41.7%) versus combination of both (4.2%); (b) non-tinted glass (52.9%); (c) non-reflective glass (69.2%); (d) external overhangs or awnings (64.8%) and (e) no skylights or atriums (95.3% buildings).

For determining the placement of windows in different spaces in the courthouse (e.g., presence, size, sill height), one relevant consideration is found in USCDG [24] and California Trial Courts Facilities Standards [25], which specifies that for courtrooms, judges' chambers and jury assembly rooms, windows with direct line of sight from public areas, circulation zones and parking garages should be minimized to prevent observation of activities, threat exposure or communication with courthouse occupants.

3.4.5. HVAC System

According the 2012 CBECS data [41], natural gas is the dominant heating source, serving 81% of courthouses (Figure 16a). Boiler is the dominant main heating system (52%), followed by packaged central heating unit (30%) (Figure 16b). Central chiller is the dominant main cooling system type (39%) (Figure 16c); 95% of which are water cooled. Ventilation is provided centrally through variable air volume (34%) and constant air volume systems (32%) (Figure 16d).

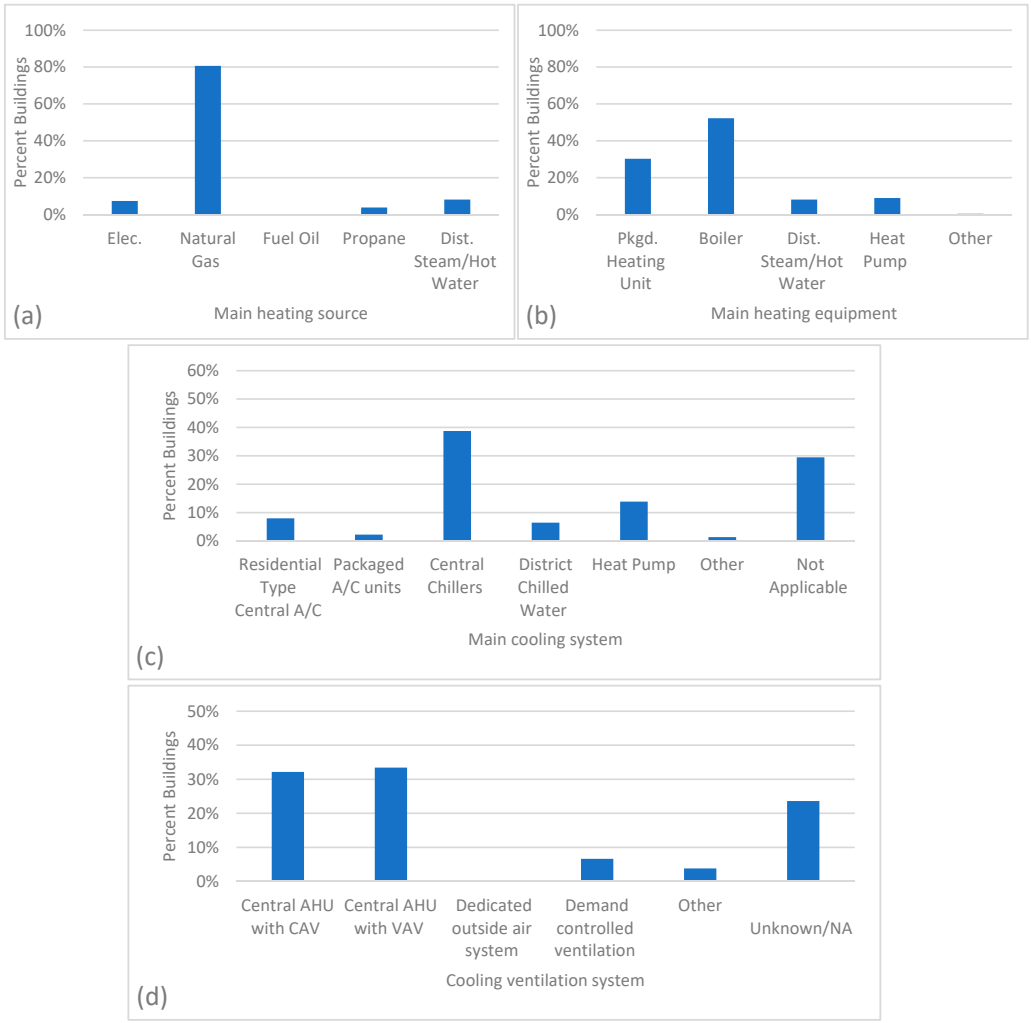


Figure 16. Heating ventilation and air conditioning (HVAC) system characteristics in courthouses [41] by heating source (**a**); type of heating equipment (**b**); type of cooling system (**c**); and type of ventilation system (**d**).

4. Prototype Decisions

With a comprehensive understanding of the building characteristics acquired from a variety of resources, the building and system characteristics required to develop the prototype building model are defined. The following sections demonstrate this step through the context of courthouse building.

Based on the statistics on US courthouses and inputs from federal and state courthouse design consultants, we propose a small, low-rise, general jurisdiction trial court (i.e., one of the state court types) for the prototype courthouse model. The functional spaces would include courtrooms and supporting areas, judges' suites, clerk's office, administration office, jury areas, detention areas, law library, other offices (for prosecuting attorney, public defender, probation and parole), circulation, secure parking and building management and support areas. The building characteristics for the prototype courthouse and the basis for their selection are described in the following sections.

4.1. Building Geometry

Based on Section 3.3.2, we propose a four-courtroom courthouse and accordingly determine the building area to be consistent with the national average BGSF per courtroom. This results in a floor area close to the 2012 CBECS average floor area of 69,400 ft^2 (6447 m^2) for courthouse building type [41]. Following the space-specific guidance in courthouse design guides and targeting three floors (Section 3.4.3), we propose one floor dedicated to the four courtrooms at the top with a floor-to-ceiling height of 16 ft (4.9 m), an entrance floor occupied by high-volume public and general office spaces with a floor-to-ceiling height of 10 ft (3.3 m) and one floor occupied by secured parking and central detention area at the bottom with a floor-to-ceiling height of 10 ft (3.3 m) and a 4 ft (1.2 m) ceiling plenum on each floor. Based on the schematic design of courthouse (Figure 6), we propose the bottom floor to be below the ground with one side exposed for separate entrances for secured parking, services and escorted in-custody defendants. Based on Section 3.4.2, we target a wide rectangle footprint with 2.06:1 aspect ratio—that is, the average aspect ratio for the 50,000–100,000 ft^2 (4645–9290 m^2) bin (Figure 13b), to which the targeted 69,400 ft^2 (6447 m^2) floor area belongs.

4.2. Floor Layout

We developed the floor layout and area programming of the prototype courthouse in consultation with courthouse facility planning and design experts, adhering to the courthouse organizational concepts and space requirements. Targeting equal areas on all three floors and 2.06:1 aspect ratio, we developed the floor layout of court floor based on the space, location and adjacency requirements for different spaces. The remaining functional spaces were then housed on other levels inside the building footprint. With these considerations, the total floor area of the building resulted in 69,324 ft^2 (6440 m^2) with a footprint of 218 ft × 106 ft (66.4 m × 32.2 m).

Figure 17 shows the layout of basement, first floor and second floor. The second floor is the courtroom floor housing courtrooms and supporting spaces, judges' suites and court-floor holding areas; the first floor has a public entrance lobby, clerk's office, court administration office, other offices, jury assembly area and law library; and 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 the courthouse design guides. Separate sets of stairs and elevators are provided for the public and general staff, judges and in-custody defendants.

Figure 18 shows the usable space area distribution for the prototype courthouse and confirms the suitability of the proposed area programming when compared to Figure 9. Excluding the secured covered parking, the building efficiency ratio is 67%; that is, circulation and building support areas comprise 33% of BGSF.

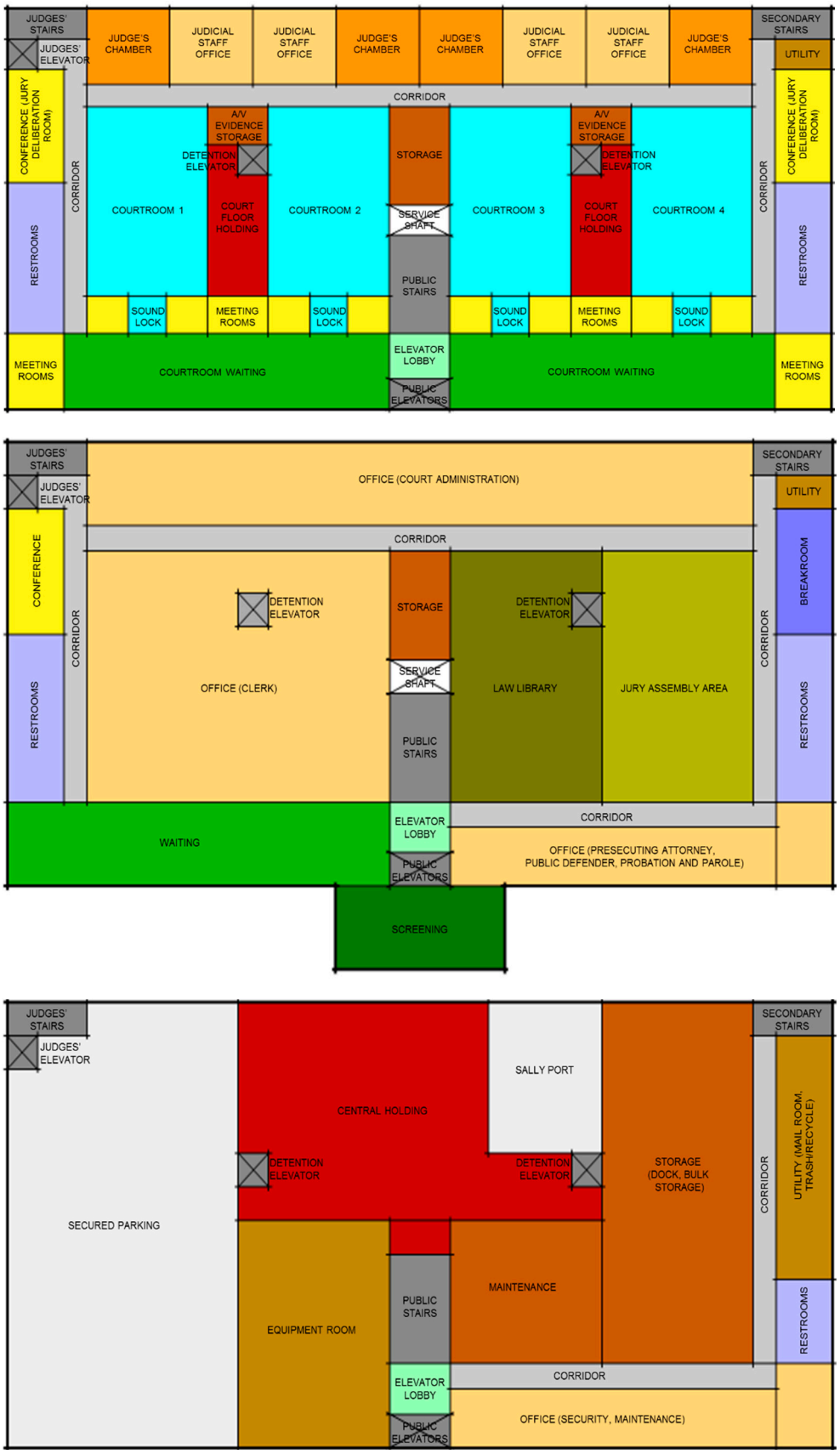


Figure 17. Prototype courthouse layout of basement (**bottom**), first floor (**middle**) and second floor (**top**).

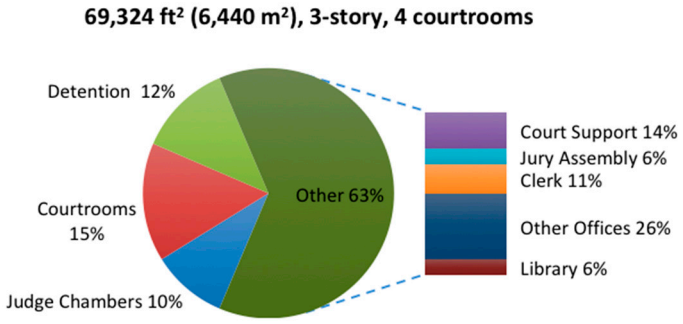


Figure 18. Prototype courthouse space area distribution.

4.3. Occupancy Schedule

Based on Section 3.3.9, we adopted the occupancy schedules used for the GSA LEED Cost Study [35]. For the courtrooms, we derived a single weekly schedule from the multiple weekly schedules, taking into accounting the frequency of their use in the annual schedules of different courtrooms of the model. Figure 19 shows the space-specific weekly occupancy schedules proposed for the prototype courthouse.

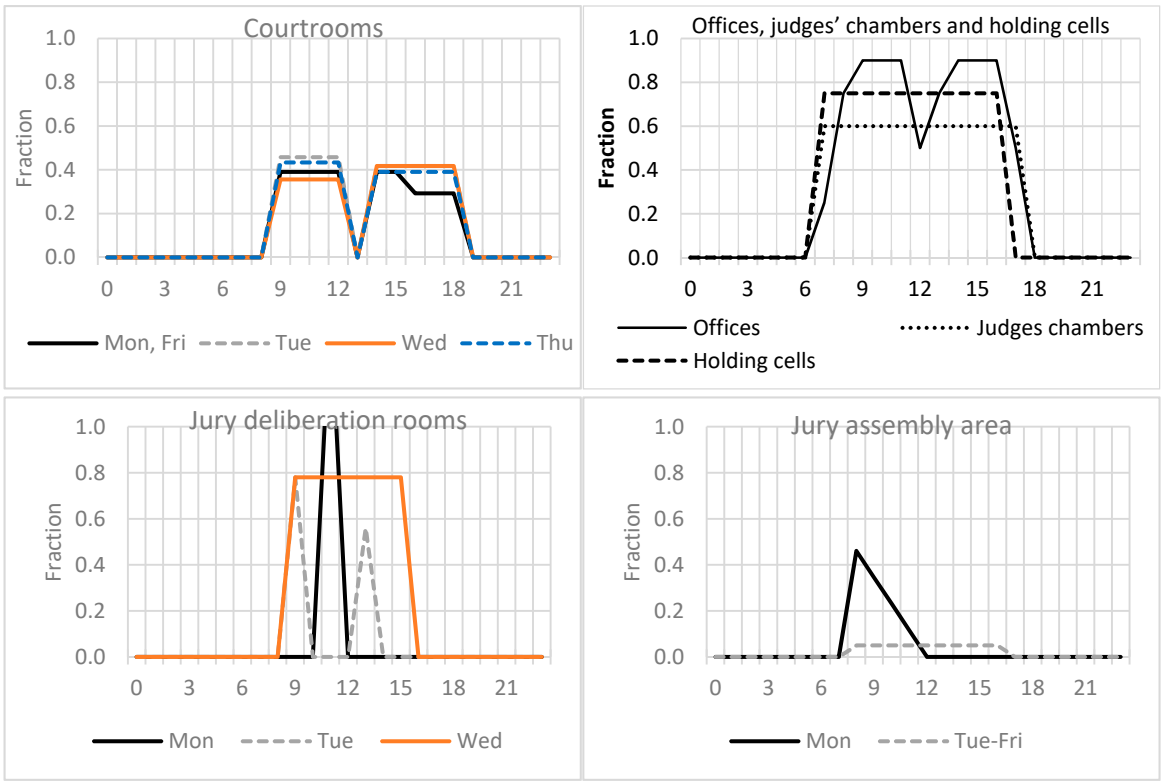


Figure 19. Prototype courthouse space-specific occupancy schedules.

4.4. Windows

Based on Section 3.4.4, we propose an 18% window-to-wall area ratio (i.e., targeting the average of the 11–25% bin range in Figure 15, which has the maximum percent frequency), punched window system with no exterior shading and a 4 ft (1.2 m) sill height to avoid direct sightline for seated occupants in certain spaces. The distribution of windows on different orientations was determined after placement of windows for different spaces, as shown in Figure 20. The thermal properties of windows including U-value and solar heat gain coefficient (SHGC) will be based on the requirements for pre-1980

and 1980–2004 construction vintages and ASHRAE Standard 90.1-2004, 2007, 2010, 2013 and 2016 for the 17 ASHRAE climate zones [5], as part of prototype model development (see Section 2, Step 3).

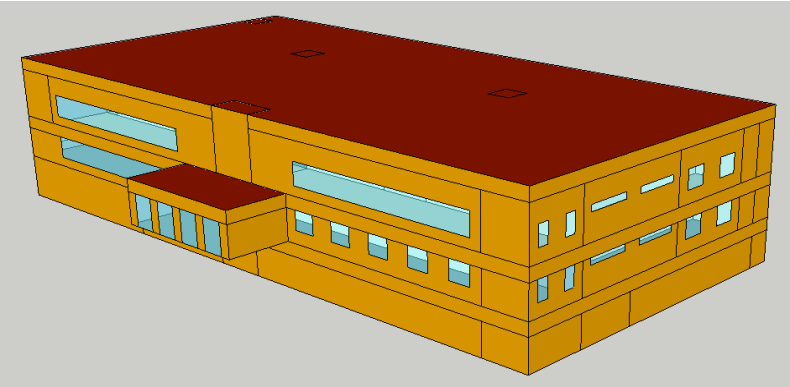


Figure 20. Prototype courthouse building massing and window placement.

4.5. Construction

Based on Section 3.3.8, we propose 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 building envelope components will be determined based on the requirements for pre-1980 and 1980–2004 construction vintages and ASHRAE Standard 90.1-2004, 2007, 2010, 2013 and 2016 for the 17 ASHRAE climate zones [5], as part of prototype model development (see Section 2, Step 3).

4.6. Systems and Equipment

Based on the data described in Section 3.4.5, we propose the HVAC system comprising of natural gas-fired boilers, water-cooled chillers and VAV terminal units with hot-water reheat and a natural gas water heater for service hot water. The system efficiency, ventilation and auxiliary equipment requirements will be determined from codes and standards. These systems will be autosized to design days through energy simulation. The space-specific lighting and plug loads, temperature and humidity setpoints and ventilation requirements will be determined from codes and standards; and the schedules will follow the hours of occupancy shown in Figure 19. From Figure 14b, considering the data points for 100,000 ft^2 (929 m^2) or less floor area, we propose three primary elevators (2 public elevators and a judges' elevator for the three-story prototype courthouse. Considering the courtrooms of the prototype courthouse to be trial courtrooms, we propose two additional elevators for in-custody defendants.

5. Summary

The US Department of Energy uses a suite of Commercial Prototype Building Models, which currently 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. In this paper we described a systematic approach for creating prototype building models, while doing so in the pragmatic context of a courthouse building.

We divided the overall workflow of prototype model development in four steps:

(1) Defining a narrative for the prototype building using databases and/or inventory of buildings and inputs from facility design experts who could advice on common building typologies, primary and secondary function in the building, space types, occupancy characteristics;
(2) Prototype building planning and design using building design guides, case studies and inputs from facility design experts to determine the building size, form and geometry, area programming,

floor plans and thermal zoning, construction type and windows, system type and schedule of use of spaces;

(3) Determining detailed modeling specifications based on the requirements in building codes and standards (including thermal properties of the building envelope and characteristics of the heating, ventilation and air conditioning (HVAC) system, water heating system, lighting and equipment), followed by a review by building energy codes and standards experts;

(4) Prototype model development according to the established protocols and model verification by comparing simulated energy use with available measured energy use and utility data from existing building datasets.

We demonstrated the first two steps of this workflow to determine the characteristics of the prototype courthouse relevant for energy model development, while providing the rationale for these determinations. We defined the prototype courthouse to be a 69,324 ft^2 (6440 m^2), three-story, four-courtroom building. The floor layout and area programming were developed in consultation with courthouse design experts, adhering to the courthouse organizational concepts and space requirements. The occupancy, construction and systems characteristics were determined based on courthouse databases and documented projects. Table 2 summarizes the building characteristics for the prototype courthouse.

Table 2. Summary of prototype courthouse building characteristics.

Category	Description
Form	
Total floor area	69,324 ft^2 (6440 m^2)
Building footprint	218 ft × 106 ft (66.4 m × 32.2 m); 2.06:1 aspect ratio; non-directional azimuth
Number of floors	3 (including partly conditioned basement)
Floor-to-ceiling height	10 ft (3.3 m) for basement and first floor; 16 ft (4.9 m) for second floor; 4 ft (1.2 m) ceiling plenum
Volume of building	1,121,179 ft^3 (31,748 m^3)
Window-to-wall ratio	18.4% (front: 24.3%, right: 10.1%, back: 13.6%, left: 12%)
Window height	6 ft (1.8 m); 4 ft (1.2 m) sill height
Construction [a]	
Exterior walls	Concrete masonry unit, stucco on the exterior, interior wall insulation
Roof	Built-up roof on metal decking and roof insulation
Fenestration system	Punched window system with hypothetical windows defined by U-factor and SHGC (i.e., glass type and window frame not explicitly defined); no exterior shading; no skylights
Foundation	Heavyweight concrete for basement walls and floor
Interior partitions	Steel-frame walls; concrete for vertical shafts and detention areas
Systems and equipment [b]	
HVAC system	Gas boiler, water-cooled chiller; variable air volume (VAV) terminal box with damper and hot water reheating coil
Service water heater	Storage type, natural gas water heater
Elevator	5 hydraulic elevators including two public elevators, one judges' elevator and two elevators for in-custody defendants

[a] The physical properties of layers will be based on the protocols followed for the prototype models included in the DOE Commercial Prototype Building Model suite. The thermal properties of building envelop materials will be based on the requirements in codes and standards for different climates and construction vintages. Infiltration rates will be based on the infiltration modelling guidelines for commercial building energy analysis and the continuous air barrier requirements in codes and standards. [b] System efficiency, controls and setpoints and auxiliary equipment details will be based on the requirements in codes and standards. Systems will be autosized to design days through energy simulation. Space-specific lighting and plug loads and ventilation requirements will be based on codes and standards.

In follow-up work, these details will be supplemented with requirements in codes and standards to develop 119 versions of the prototype courthouse model to represent pre-1980 and 1980–2004 construction vintages and ASHRAE Standard 90.1–2004, 2007, 2010, 2013 and 2016 for 17 ASHRAE

climate zones. For model verification, simulated energy consumption will be compared with available measured energy use and utility data from existing courthouse building datasets.

Though the prototype courthouse represents an average-sized courthouse in the United States, the comprehensive information presented in this paper can also guide modification of the model to more accurately capture the dynamics of smaller or larger courthouses for building or system size-specific research and allow modifications that can accommodate country-specific differences

While demonstrated in the context of real-world data sources for a U.S. courthouse, the authors encourage readers to leverage, extend or institute similar data collection processes that capture the unique operational characteristics of your built environment.

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