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Occupancy diversity factors for common university building types

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ABSTRACT

Measured occupancy diversity factors for use in building energy simulations are rare in general and practically nonexistent for university type buildings. To better understand occupancy schedules (or diversity factors) for university buildings, six types of university buildings (eleven buildings in total) were considered in this study: administrative, library, recreation, architecture, research, and classroom. Two occupancy schedules were derived for each building type; a 'similar-day' schedule and a more generic 'weekly' schedule. In addition, a simple method was developed to easily predict occupancy diversity factors for classroom-type university buildings.

1. Introduction

Typical building energy simulation models have several physical inputs (building size, building orientation, construction materials, HVAC system size/types, interior and exterior lighting, equipment, etc. . . .) and several operational inputs that vary with time, known as 'schedules' or 'profiles' (occupancy, HVAC, lighting, plug loads, etc. . . .). HVAC schedules, for example, can be more closely determined through engineering drawings and/or knowledge of the building control systems. A little more difficult to determine are occupancy schedules, which are often estimated and inherently less precise. Default values based on building type or activity have evolved over time, but with little work being done in evaluating the sensitivity of these operational schedules, specifically for occupancy in university buildings. The primary effort described in this paper was to utilize several University of Arkansas campus buildings to help characterize occupancy factors for common university building types. In addition, a simplified method to estimate occupancy profiles for common university classroom buildings is presented.

2. Background

Computer based building energy models have been around since the late 1970s [1], but have never been used more than they are today. Several standards and certifications include energy simulation modeling of the building, including ASHRAE 90.1 [2], LEED [3], and Green Globes [4]. With energy models being used more frequently and with financial implications, improving the accuracy of the model results through better inputs (including schedules) is becoming more and more important.

For most types of buildings the non-weather dependent default diversity factors have been defined through research for inputs such as lighting and plug loads. These default diversity factors are widely accepted and are commonly used when the actual schedule is unknown [5]. ASHRAE 90.1 [2] provides several of these diversity factors. While diversity factors of several building types have been defined, university building diversity factors have been neglected when compared to office type buildings, commercial buildings or K-12 school buildings. Occupancy has also been a neglected area in building energy models [1].

ASHRAE Research Project 1093 (RP-1093) [6] defined several diversity factors pertaining to office buildings, but none were directly defined for occupancy. However, RP-1093 did briefly discuss occupancy in which an occupancy diversity factor was derived, from the works of Bronson et al. [7] and Abushakra and Claridge [1], for a university engineering building. Measured occupancy, by way of a one-time walkthrough assessment, was used to create a correlation between the electric load factor and the occupancy load factor [7]. Later, this information was used to derive an equation for hourly occupancy density based on the maximum hourly occupancy density, hourly lighting and equipment load density, minimum hourly lighting and equipment load density, and maximum hourly lighting and equipment load density [1]. Similar to Bronson et al. [7], Haberl and Komor [8] compared the electric load factor and the occupancy load factor of a shopping center in New

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Jersey with one of their conclusions being that lights and equipment were left on during unoccupied periods. Keith and Krarti [9] developed average and peak occupancy load shapes from data recorded from occupancy sensors every fifteen minutes for a twelve-month period. The amount of time and/or effort that is required to collect data to this degree is not feasible for every energy building simulation that is run [1], thus the importance of creating 'typical' diversity factors. Sellers and Williams [10] modeled a simple office building comparing the outdoor air required, space cooling load, design cooling flow and outdoor air fraction if the model is run at designed full occupancy versus average occupancy. For more discussion on diversity factors, Abushakra et al. [11] provide an extensive literature review.

3. Data collection

This section contains the description and discussion of: (1) each building, (2) methods used to collect each building's hourly occupancy, (3) the determination of each building's maximum capacity, and (4) the computed occupancy factors for each building type.

3.1. Building types considered

The University of Arkansas is a land grant institution established in 1871 that is located in the south central United States (36°03′N, 94°10′W). During the fall of 2008, there were 19,194 students, 987 faculty, and 2864 staff for the university that has about 150 buildings that cover 6.9 million square feet. Eleven buildings were considered in the study, at least one from each college, including: classroom and office buildings; a purely administrative building; a recreational facility; a primary research facility; an architecture building; and a library. Table 1 provides a summary and statistics for the buildings considered in this study.

Each building had up to six general usage areas: classroom area, office area, common area, laboratory area, service area, and other. Classrooms are in all but two buildings. Offices are predominantly used for academic and administrative personnel. Every building has common areas such as a circulation area and rest rooms. Laboratory areas, used for classes as well as research, were mainly in RSCH, CLASS3, and ARCH buildings. Service areas are mostly mechanical and electrical rooms containing building equipment. Other areas include locations that are reserved for studying, special and general use facilities (e.g. clinics, animal quarters, day care, meeting rooms, or green houses), support facilities (e.g. hazardous materials storage, physical plant manufacturing and repair shops or central computer server rooms) and unclassified space.

3.2. Data collection methods

The hourly occupancy profile data were compiled from a variety of sources: building security cameras, doorway electronic counting sensors, semester classroom scheduling data, and manually collected through personal observations. Security cameras were used in four buildings. Doorway counting sensors were used in two buildings. Classroom scheduling data was primarily used in three buildings. Manual counting through personal observations was used as the main source of data collection in two buildings. Data collection occurred for each method between January 5 and May 8, 2009 (i.e., spring semester). Care was taken to select sample weeks that would be considered as typical occupancy periods. For example, an ice storm occurred during the first week of February and no data was collected during that week and the week following to ensure only representative occupancies were used. Also, the week prior to the beginning of classes was used to characterize the period when students were generally not present (i.e., faculty and staff only times). Each of the above mentioned methods is described below.

Security cameras from four buildings were used to collect data: ADMIN, CLASS3, CLASS2, and CLASS5. For each entrance/exit of the building, a week's worth of video was recorded (Sunday through Saturday). Two days of video were also recorded for days when the university was open, but classes were not held (e.g. spring break, the week before Christmas, or the week before the spring semester starts). In total, 4968 h of time compressed video were evaluated during this study. For each hour, the number of people that entered and exited the building was counted. The occupancy for the hour was calculated by taking the occupancy of the previous hour, adding the number of people that entered, and subtracting the number that left during the hour. Counting started at midnight and concluded the following midnight. If there were people in the building when counting started, adjustments were made so there was never a negative occupancy in the early morning hours caused by people leaving before anyone entered the building.

The occupancy for two of the buildings being considered in the study came from doorway counting sensors: LIBR and PHYSED. LIBR building entrances and exits were controlled; two entrances and two exits, one of each located on the east and west sides of the building. Each hour a library staff member recorded the number of people that had entered or exited each door. These numbers were entered into a spreadsheet and stored. The PHYSED building had counting sensors installed at the entrance/exit of three major areas of the building. Recorded hourly entrance and exiting data from the counting sensors were stored on a server. In both cases, a minimum of four weeks of occupancy data were used for the analysis. Classroom scheduling data from the university's electronic enrollment information system was used in every building with the exceptions of ARCH, RSCH, and ADMIN, and was used as the primary source of occupancy data collection for CLASS6, CLASS4, and CLASS1. The semester's electronic classroom scheduling data provided a list of every class that was held in the building, along with the room the class was held, the number of students in the class, the duration of the class and which days the class met.

Finally, there were two buildings that did not have security cameras, counting sensors, or classroom scheduling data. For the RSCH and ARCH buildings, it was concluded that personal observations were the best way to collect data. For seven days, a count of the building occupants was made every hour between 6:00 AM and 10:00 PM. It took 30 min to walkthrough both buildings, and there were a total of 105 walkthrough occurrences.

3.3. Establishing each building's maximum occupancy

Diversity factors have been defined as "numbers between zero and one that are used to multiply the peak [value] that has been entered" [11]. For occupancy, the 'peak value' could be either the actual peak occupancy or the maximum building capacity. The maximum building capacity or maximum occupancy is often available through drawings or an existing building walkthrough; however, the actual annual peak number of people within a given building is not a value that is easily determined. Therefore, the maximum building capacity was selected as the peak value in this study. For eight buildings in this study (CLASS1, PHYSED, CLASS2, CLASS3, CLASS4, CLASS5, ARCH, CLASS6), the maximum building occupancy was determined by summing the "office" occupants of the building and the maximum occupancy of each room (or laboratory) in the building where classes are held. An assumption of one occupant per office was made. For the three remaining buildings (RSCH, ADMIN, and LIBR), occupant densities from ASHRAE Standard 62.1 [12] were used to calculate maximum occupancy. RSCHs maximum occupancy was considered a "laboratory space" having a density of twenty-five people per 1000 square feet. The "office" occupants of

Table 1
Summary of building information for buildings considered in the occupancy study.

Description	Code	Academic function	Year built	Year of addition	Total area ft^2/m^2	Maximum occupancy	Area use						Letter code[a]
							Classroom (%)	Office (%)	Common (%)	Laboratory (%)	Service (%)	Other (%)	
Classroom building	CLASS1	Agriculture	1927	– –	46,145 4287	279	7.4	39	25	24	2.1	2.8	C
Science	RSCH	Research	1995	– –	37,420 3476	524	0.0	0.25	25	56	19	0.0	P
Health, physical education, and recreation	PHYSED	Récréation	1984	– –	189,869 17,639	2394	4.2	5.8	19	1.9	8.3	61	E,C
Administration building	ADMIN	Administration	1965	– –	28,042 2605	146	0.0	45	26	0.0	13	16	S
Classroom building	CLASS2	Arts and Science	1875	– –	108,877 10,115	777	9.0	32	26	3.6	6.7	22	S,C
Classroom building	CLASS3	Engineering	1964	– –	30,243 2810	237	13	21	14	32	3.1	16	S,C
Library building	LIBR	Library	1968	1996 –	212,452 19,737	2,125	0.69	6.1	9.6	0.45	5.0	78	E
Classroom building	CLASS4	Arts and Science	1977	– –	29,336 2725	328	15	29	25	1.6	21	8.1	C
Classroom building	CLASS5	Education	1913	– –	29,778 2766	294	16	29	21	2.4	7.9	23	S
Architecture building	ARCH	Architecture	1934	2006 –	58,749 5458	720	10	6.0	13	22	3.3	44	P
Classroom building	CLASS6	Business	1976	– –	98,103 9114	1486	19	30	26	7.4	11	6.8	C

[a] S-security cameras, E-electronic counting sensors, C-classroom scheduling data, P-personal observations.

ADMIN were added to the occupants from the lobby area at ten people per 1000 square feet. Similarly, the maximum occupancy for LIBR was calculated as ten people per 1000 square feet.

3.4. Building occupancy factors

Universities have a wide variety of building types with each one having unique purposes and operating characteristics. Therefore, uniquely different hourly occupancy factors were developed for each of the six types of university buildings in this study: administrative (ADMIN), library (LIBR), physical education/recreation (PHYSED), architecture (ARCH), research (RSCH), and classroom (CLASS2, CLASS3). For each building, two sets of hourly factors were derived from the collected hourly occupancy data and corresponding daily factors—a general weekly profile and a more specific similar-day profile. A common method for deriving diversity factors is averaging data points that have been collected for the same period [13]. For this study, the single weekly profile, Monday through Friday hourly data were averaged together to form the weekday profile, and Saturday and Sunday were averaged together to form the single weekend profile. For the similar-day profile, when two or more days have very similar trends and hourly characteristics, they were averaged together. Recall that the university is a medium-sized, land grant university located in the south central United States. This being the case, the occupancy factors that were developed in this study are likely applicable to many other similar university buildings. Each of the six university building types and their unique occupancy characteristics are described further below.

3.4.1. Administrative (ADMIN building)

ADMIN is a two-storey building containing three general entrances and exits and five private/employee entrances and exits. Occupancy for an administrative building is more predictable than other university buildings because it is fairly constant throughout the core hours of the day. During the building's hours of operation, at least half of the occupancy of ADMIN was made up of staff employees. The remainder of the occupancy was made up of students and/or perspective students who briefly visit the building. Current students primarily use ADMIN for financial aid, pay student bills, and transcript information. ADMIN is also used as a "home base" for perspective students where groups will meet for a tour of the campus. Fig. 1 provides a graph of all weekday and weekend data and their averages. Also note that due to technical difficulties, data was not obtained for Tuesday and Wednesday. Between the hours of 9:00 AM and 3:00 PM the density remains fairly constant around 0.65 ± 0.1 despite having a high rate of students coming and going. On average, the number of people that entered and exited in a one-hour period was equal to the maximum occupancy of the building (about 100 people). During the 4:00 PM hour, staff start to leave for the day dropping the density to about 0.4. In the 5:00 PM hour the number of occupants entering and exiting the building was reduced and the density dropped to around 0.3. It was observed on Monday and Thursday (and it is reasonable to assume for Tuesday and Wednesday) nights between the hours of 6:00 PM and 8:00 PM to have a density of 0.1 before zeroing shortly thereafter. Due to the day-to-day consistency, this type of building is best modeled as weekday and weekend schedule.

3.4.2. Library (LIBR building)

The operating hours for LIBR is 7:00 AM to 1:00AM Monday through Thursday, 7:00 AM to 6:00 PM Friday, 9:00 AM to 6:00 PM Saturday, and 12:00 PM to 12:00 AM Sunday. LIBR is a four-storey building with a basement that has two entrances and exits. The primary occupants in LIBR were working staff, students, and faculty. Faculty and students primarily use LIBR for studying and research. Fig. 2 shows the occupancy for each weekday with an average of Monday through Thursday and the weekend's occupancy. During the weekdays, the maximum occupancy occurred around 10:00 AM at an occupancy factor of about 0.2. After reaching its maximum occupancy, Friday's profile steadily drops each hour until closing. The remaining weekdays reached their maximum and stayed fairly steady for the next four hours before dropping off to 0.15 at 5:00 PM, where it stays for the next four hours before finally reducing each hour to zero at the buildings close. During the weekend, the maximum occupancy reached about three fourths of the weekday's maximum occupancy. Because of Friday's early closing, occupancy for this type of building is best modeled as Monday through Thursday, Friday, and weekend schedules.

3.4.3. Recreation/physical education (PHYSED building)

PHYSED contains four basketball courts, an Olympic sized natatorium, several racquetball courts, a climbing wall, a bouldering wall, an indoor track, two dance studios, a large gym, fifteen classrooms, and several offices. Occupancy in PHYSED is driven by different factors throughout the day. Initially the occupancy is driven by early morning workouts. Then during the core hours of the day (8:00 AM to 4:00 PM), the occupancy is strongly influenced by classes. Finally the evening occupancy is mostly affected by evening workouts and other extracurricular activities. Fig. 3 shows the hourly occupancy for each weekday with an average of Monday through Thursday's occupancy and also the weekend's occupancy. Hourly change in occupancy for PHYSED was gradual with a maximum of 0.15 occurring around noon during the weekdays. Friday can be modeled the same as Monday through Thursday until noon, but then the occupancy dropped off at a much quicker rate than the rest of the week. The occupancy profile was a similar shape as the weekday during the weekend, with a maximum of 0.06 occurring at 5:00 PM. This type of building is best modeled as a Monday, Tuesday, and Thursday schedule, a Wednesday and Friday schedule, and a weekend schedule.

3.4.4. Architecture (ARCH building)

ARCH initially was the university's library before being converted to the architecture building. In 1996 ARCH was expanded by 3000 square feet and the addition of a fourth floor. ARCH is a unique building in that there was a significant occupant load throughout the night time hours, on the weekend, and Friday. The occupancy is not reduced during these times like in other university building types. This is not thought to be distinctive to the University of Arkansas in this study, but to architecture disciplines at most universities. ARCH has large studios that contain a workspace for each student. During data collection, it was observed that the majority of the early morning occupants were in the building during the previous night's walkthrough. Fig. 4 shows the data for Monday through Friday with averages for the two weekday schedules and the weekend schedule. There is a strong correlation between Monday, Wednesday, and Friday profiles and with Tuesday and Thursday profiles. Monday, Wednesday, and Friday have significantly more people than on Tuesday and Thursday, reaching a maximum of about 0.22 as compared to 0.13. The occupancy for Tuesday and Thursday was fairly constant from 10:00 AM to midnight, having an average of about 0.09 ± 0.04. For Monday, Wednesday, and Friday, the maximum was set at noon, followed by two hours of a relative minimum (0.10), and then increased to 0.15 for the next three hours. This type of building is best modeled as Monday–Wednesday–Friday (MWF) and Tuesday–Thursday (TTh), and weekend schedules (Saturday–Sunday, SS).

3.4.5. Research (RSCH building)

RSCH is a four-storey building that has four ground floor entrances, and two walkways that connect it to two different buildings. Each floor of the building, in general, has six research rooms

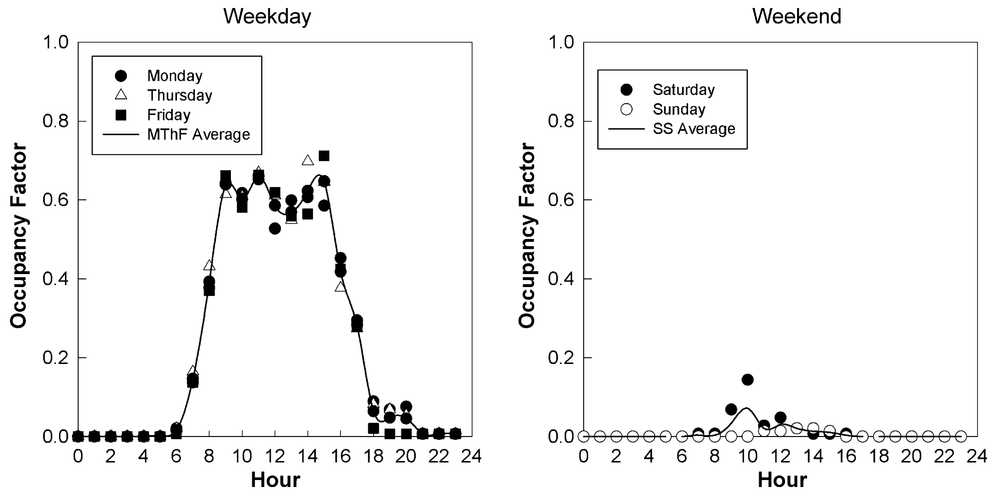

Fig. 1. Weekday and weekend observed occupancy factor for ADMIN. Average inserted as a simple spline curve.

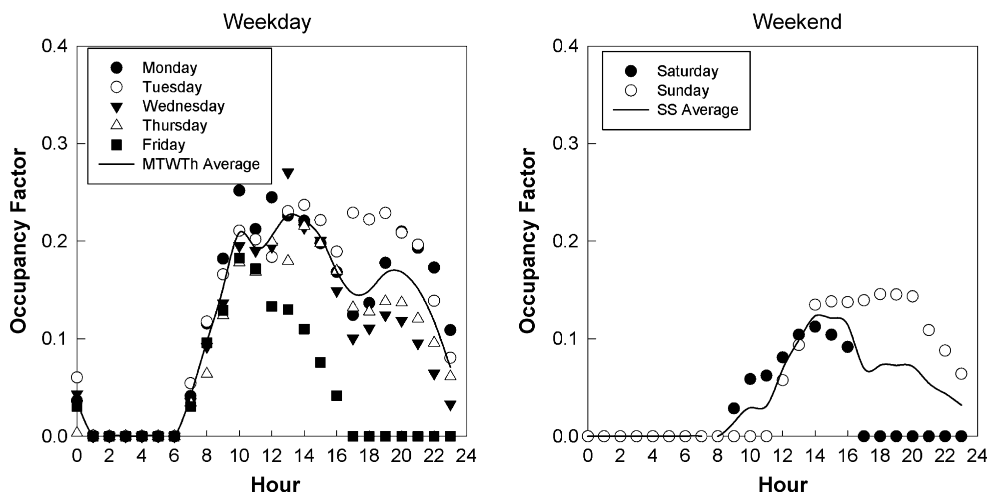

Fig. 2. Weekday and weekend observed occupancy factor for LIBR. Average inserted as a simple spline curve.

and one room used for chemical storage. The shape of the occupancy profile for a research facility has the potential to vary greatly from university to university. For this building, the occupants were primarily graduate and undergraduate research assistants and advising professors, all of whom have varied work schedules. Unlike a typical office building, the research-based occupants did not have specific hours that they were required to be in the laboratory. In this study, the occupants began to arrive at 6:00 AM and left around midnight. Fig. 5 shows the weekday and weekend profiles for RSCH. Note that the scale for occupancy factor is different than

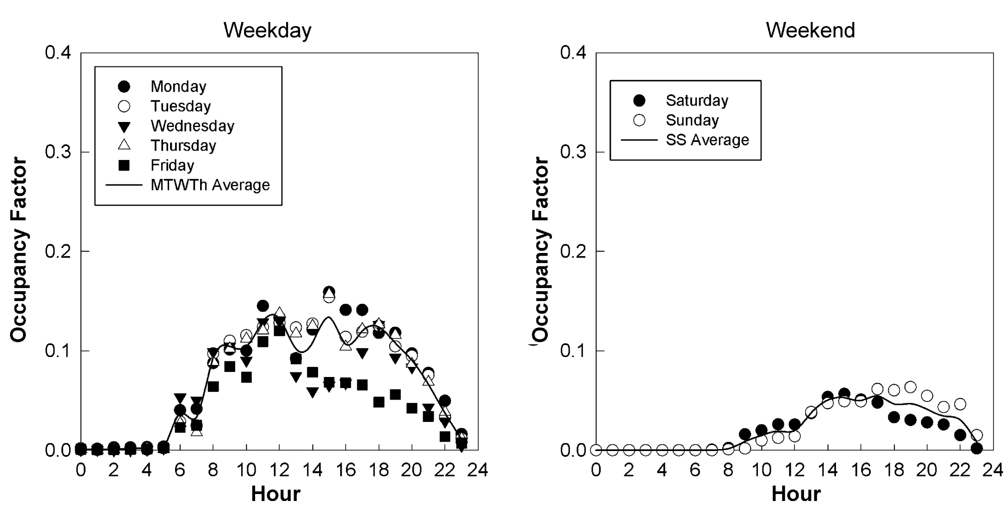

Fig. 3. Weekday and weekend observed occupancy factor for PHYSED. Average inserted as a simple spline curve.

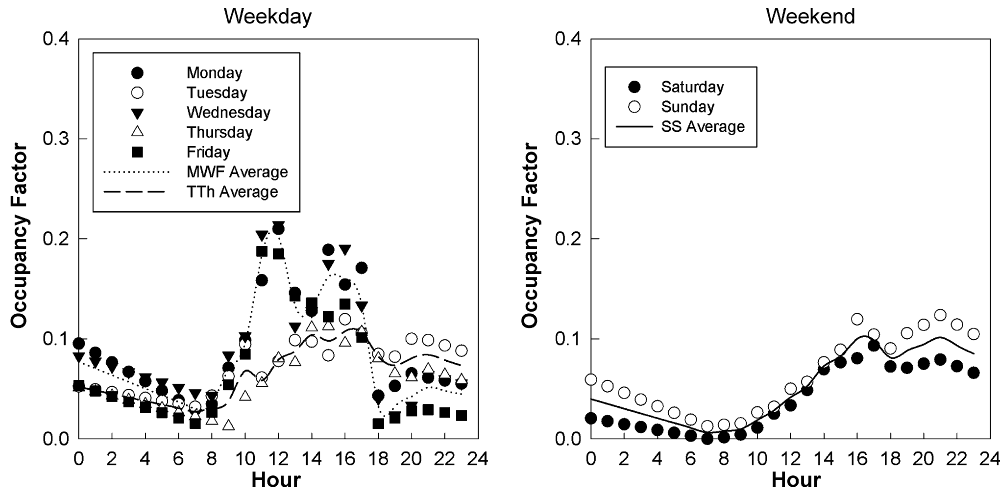

Fig. 4. Weekday and weekend observed occupancy factor for ARCH. Averages inserted as a simple spline curve.

Figs. 1–4 to better show the shape of the RSCH profile. It appears that there are more occupants on Tuesday and Thursday afternoons than on Monday, Wednesday, and Friday afternoons, but in reality there are only a few more people occupying the building. Between the hours of 10:00 AM and 5:00 PM, RSCH had a constant occupancy of 0.05 ± 0.02. After 5:00 PM, the occupancy dropped to 0.02 and steadily decreased the remainder of the night. The weekend occupancy is very low, having a maximum of 0.02. For our study, RSCH had a similar profile Monday–Friday. This type of building is best modeled as Monday through Friday and weekend schedules.

3.4.6. Classroom (CLASS2 and CLASS3 buildings)

The most common type of nonresidential building on most university campuses is one that contains several classrooms and academic faculty and staff offices. At the University of Arkansas there are approximately 35 classroom-type buildings. CLASS2 and CLASS3 buildings were chosen to represent the typical "classroom" building. With only a few exceptions, typical class scheduling were those classes held on Monday, Wednesday and Friday for an hour (actually 50 min with 10 min break between classes), while the classes held on Tuesday and Thursday were an hour and a half (actually 80 min and a 10 min break between classes). There are substantially fewer classes on Friday afternoon than on Monday or Wednesday afternoons. These are typical classroom-type university buildings and profiles that should easy apply to other universities. As one would expect, for classroom-type buildings, class scheduling was the driving factor for occupancy. Considering both CLASS2 and CLASS3 as typical, there was a strong similarity between Monday and Wednesday profiles, thus a 'similar-day' profile was developed. While not as strong as Monday and Wednesday, there is a similarity between Tuesday and Thursdays profiles as well; again creating a separate 'similar-day' profile. One possible explanation for Thursday not matching up with Tuesday as well as Monday and Wednesday is that less people attend class on Thursday (e.g., as the week progresses). Fig. 6 contains two pairs of graphs for CLASS2 and CLASS3's occupancy Monday through Friday. Monday through Friday had a maximum occupancy density of 0.7 that occurred at 10:00 AM. Between 10:00 PM and 6:00 AM there was low to no occupancy in the buildings. Monday and Wednesday had three humps in the profile, each becoming progressively smaller (peaking at values of 0.7, 0.4, and 0.2). Tuesday and Thursday had four humps, each getting progressively smaller (peaking at values of 0.65, 0.55, 0.4, and 0.2). For our study, classroom-type buildings are best modeled as Monday and Wednesday, Tuesday and Thursday, Friday, and Weekend Schedules; however, modeling with the similar-day profiles (MWF and TTh) may be adequate as well. A third non-traditional classroom was evaluated in the study, the CLASS5 building. It was not deemed a typical classroom building because, as will be discussed below, no classes were scheduled on Friday.

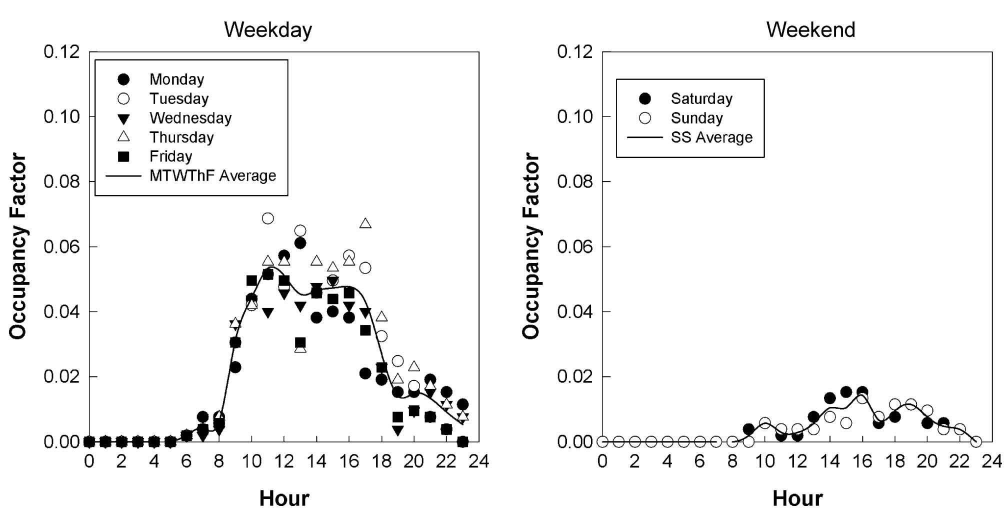

Fig. 5. Weekday and weekend observed occupancy factor for RSCH. Average inserted as a simple spline curve.

Table 2
Summary of the recommended occupancy diversity factors for various university building types.

	Administrative			Library					Récréation				
	MTWThF	stdev	SS	MTWThF	stdev	SS	MTWTh	F	MTWThF	stdev	SS	MTTh	WF
12:00 AM	0.00	0.00	0.00	0.02	0.02	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.00
1:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6:00 AM	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.03	0.04
7:00 AM	0.15	0.02	0.00	0.04	0.01	0.00	0.04	0.03	0.03	0.01	0.00	0.03	0.04
8:00 AM	0.39	0.03	0.00	0.09	0.02	0.00	0.10	0.10	0.09	0.01	0.00	0.09	0.08
9:00 AM	0.64	0.02	0.03	0.14	0.03	0.01	0.15	0.13	0.10	0.01	0.01	0.10	0.09
10:00 AM	0.60	0.02	0.07	0.20	0.03	0.03	0.21	0.18	0.10	0.02	0.01	0.11	0.08
11:00 AM	0.66	0.01	0.02	0.18	0.02	0.03	0.19	0.17	0.13	0.01	0.02	0.13	0.12
12:00 PM	0.59	0.05	0.03	0.19	0.04	0.07	0.21	0.13	0.13	0.01	0.02	0.13	0.12
1:00 PM	0.57	0.03	0.02	0.18	0.05	0.10	0.23	0.13	0.10	0.02	0.04	0.11	0.08
2:00 PM	0.62	0.07	0.01	0.18	0.05	0.12	0.22	0.11	0.10	0.03	0.05	0.12	0.07
3:00 PM	0.65	0.06	0.01	0.16	0.06	0.12	0.20	0.08	0.12	0.05	0.05	0.16	0.07
4:00 P M	0.42	0.04	0.00	0.13	0.06	0.11	0.17	0.04	0.10	0.03	0.05	0.12	0.07
5:00 PM	0.28	0.01	0.00	0.09	0.08	0.07	0.15	0.00	0.11	0.03	0.05	0.13	0.08
6:00 P M	0.06	0.04	0.00	0.09	0.08	0.07	0.15	0.00	0.11	0.03	0.05	0.12	0.09
7:00 P M	0.05	0.04	0.00	0.11	0.09	0.07	0.17	0.00	0.10	0.03	0.05	0.11	0.07
8:00 P M	0.05	0.04	0.00	0.12	0.09	0.07	0.17	0.00	0.08	0.02	0.04	0.09	0.06
9:00 PM	0.01	0.00	0.00	0.10	0.08	0.05	0.15	0.00	0.06	0.02	0.03	0.07	0.04
10:00 P M	0.01	0.00	0.00	0.09	0.07	0.04	0.12	0.00	0.03	0.01	0.03	0.04	0.02
11:00 PM	0.01	0.00	0.00	0.06	0.04	0.03	0.07	0.00	0.01	0.00	0.01	0.01	0.01

	Architecture					Research			Classroom					
	MTWThF	stdev	SS	MWF	TTh	MTWThF	stdev	SS	MTWThF	stdev	SS	MWF	TTh	F
12:00 AM	0.07	0.02	0.04	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
1:00 AM	0.06	0.02	0.04	0.07	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:00 AM	0.05	0.02	0.03	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3:00 AM	0.05	0.02	0.03	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4:00 AM	0.04	0.01	0.02	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5:00 AM	0.03	0.01	0.02	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6:00 AM	0.03	0.01	0.01	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7:00 AM	0.02	0.01	0.01	0.03	0.03	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.02	0.02
8:00 AM	0.03	0.01	0.01	0.03	0.03	0.01	0.00	0.00	0.29	0.08	0.01	0.35	0.20	0.33
9:00 AM	0.05	0.03	0.01	0.07	0.04	0.03	0.01	0.00	0.58	0.06	0.01	0.58	0.62	0.50
10:00 AM	0.08	0.02	0.02	0.10	0.07	0.05	0.00	0.01	0.55	0.10	0.02	0.62	0.44	0.63
11:00 AM	0.13	0.07	0.03	0.18	0.06	0.05	0.01	0.00	0.46	0.06	0.01	0.51	0.43	0.44
12:00 PM	0.16	0.07	0.04	0.20	0.08	0.05	0.00	0.00	0.37	0.17	0.01	0.25	0.56	0.24
1:00 PM	0.12	0.03	0.05	0.13	0.09	0.04	0.02	0.01	0.34	0.02	0.01	0.34	0.35	0.31
2:00 PM	0.13	0.02	0.07	0.13	0.10	0.05	0.01	0.01	0.33	0.08	0.01	0.38	0.34	0.21
3:00 PM	0.14	0.04	0.08	0.16	0.10	0.05	0.01	0.01	0.29	0.10	0.01	0.29	0.36	0.13
4:00 P M	0.13	0.04	0.10	0.16	0.11	0.05	0.01	0.01	0.14	0.05	0.01	0.15	0.14	0.09
5:00 PM	0.13	0.03	0.10	0.14	0.11	0.04	0.02	0.01	0.12	0.07	0.01	0.17	0.11	0.03
6:00 P M	0.05	0.03	0.08	0.03	0.08	0.03	0.01	0.01	0.13	0.07	0.00	0.17	0.15	0.01
7:00 P M	0.05	0.03	0.09	0.03	0.07	0.01	0.01	0.01	0.12	0.06	0.01	0.14	0.15	0.01
8:00 P M	0.05	0.03	0.09	0.04	0.08	0.02	0.01	0.01	0.04	0.01	0.01	0.04	0.04	0.02
9:00 PM	0.05	0.02	0.10	0.05	0.08	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.02
10:00 P M	0.05	0.02	0.09	0.05	0.08	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.01
11:00 PM	0.05	0.02	0.09	0.04	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01

4. Summary of occupancy factors

A summary of each building type's occupancy factor is given in Table 2. It contains weekday and weekend averaged factors, as well as some similar-day average values. Similar-day averages can be seen in Figs. 1–6. Depending on the level of desired detail, the weekday and weekend profiles can be used in building energy models. The similar-day profiles can be used to group occupancy factors and still adequately capture the shape and magnitude of the hourly occupancy.

5. Utilizing student information system's data to predict occupancy

As stated before, classroom-type buildings are the most common nonresidential buildings on university campuses and their driving force for occupancy within these buildings are educational classes. With the prevalence of software automation and electronic storage of class scheduling information, entire semester blocks of this information should be relatively simple to obtain for most universities. Using this available dataset to create occupancy factors for classroom buildings would provide profiles easier than previous means. For this method, classroom scheduling data included the number of students enrolled in the class, the name of the class, days the class meets, time the class meets, what building and room the class meets in, and the maximum number of occupants for the classroom. The data were sorted by building, room number, and then by course number. A daily schedule, in thirty-minute intervals, was made for each classroom. From this, a classroom building schedule was created. While classroom occupancy dominates the building occupancy and the profile, the inclusion of faculty and staff was still needed. Using the assumption of one occupant per office, the total number of office occupants was determined for each classroom-type building. Between the hours of

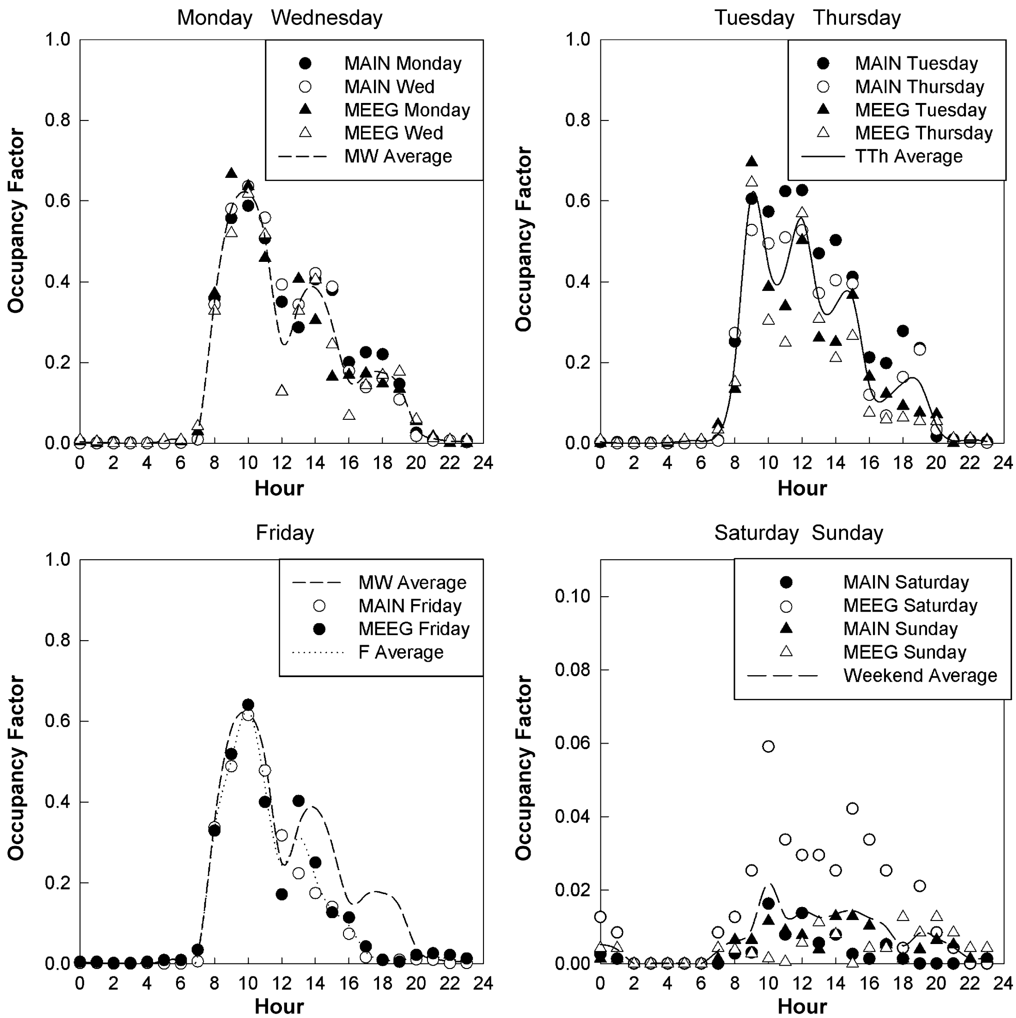

Fig. 6. Weekday and weekend observed occupancy factor for CLASS2 an CLASS3. Averages inserted as a simple spline curve.

8:00 AM and 5:00 PM the office occupants were added to the classroom building schedule to create the classroom-office building schedule or predicted occupancy. To validate this approach, the schedule was transformed into occupancy factors and then compared to the measured factor for three buildings (CLASS5, CLASS3, and CLASS2). The buildings' occupancy factors were well known since they were previously determined from security camera videos.

On Fridays in the CLASS5 building, no classes were held; therefore the bulk of the occupancy was faculty and staff only. The classes in CLASS5 are primarily education classes which often require student off-campus observation hours, thus no on-campus classes are held on Friday. This can be seen in Fig. 7 as the actual occupancy was at the projected level (consisting of only faculty and staff) or below for the whole day. This comparison helps validate the assumptions made for determining the peak office occupant levels. Next, the occupancy profiles were predicted using this method. Fig. 8 is an example of how well the predicted occupancy tracked actual, with only fourteen combined hours that fell outside of the 20% band and five of these hours occurred in the evening. When greater differences occurred, the predicted occupancy tended to be slightly higher than actual occupancy (see Fig. 9). This was likely caused from students not attending class and to a lesser degree, classes getting out early.

The occupancy factors provided best describe common spring and fall semester class periods which make up around thirty weeks of a calendar year. The remaining twenty-two weeks can consist of final exam (two weeks), summer classes (twelve weeks), and times without classes (eight weeks from spring break, semester transition weeks, Thanksgiving holiday, and Christmas holiday). Occupancy factors for the final exam weeks should be closely characterized by the predicted method since it assumes high class attendance, which is expected during exams. Standard fall and spring occupancy factors could not be used to represent summer sessions, but electronic scheduling information could also be used to predict reduced enrollment summer occupancies. Finally, semester transition weeks should be considered as faculty and staff occupancy only and vacation periods should be modeled as zero occupancy.

6. Estimated uncertainty

Four different methods were used to determine occupancy factors: building security cameras, doorway electronic counting sensors, semester classroom scheduling data, and manually collected through personal observations. The uncertainty for both the security camera and manually collected methods is similar and related to human error via miscounting. An uncertainty for these methods was estimated at ±2%. The uncertainty for the doorway sensor method is associated with the combination of possible human error and sensor uncertainty and was estimated as ±5%. Finally, the uncertainty for the scheduling data was based on the majority of observed data that fell within the error bands, resulting in an estimated uncertainty of ±20%.

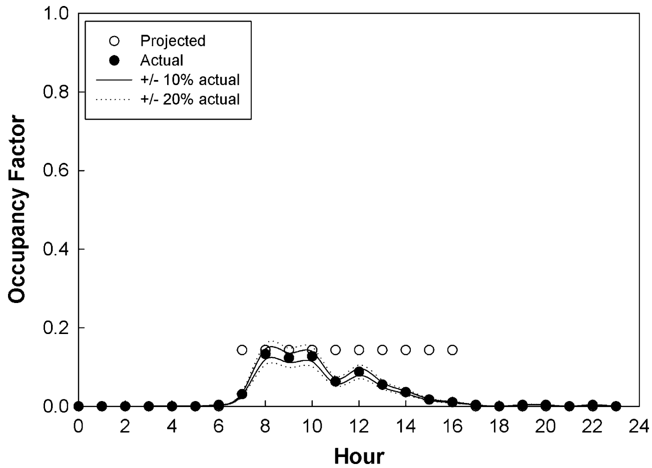

Fig. 7. Friday's projected and actual occupancy for CLASS5.

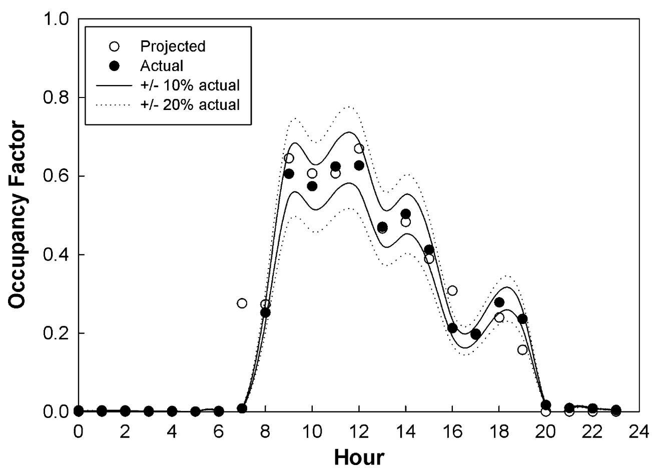

Fig. 8. Tuesday's projected and actual occupancy for CLASS2.

7. Conclusions

In an effort to gain more insight into university building occupancy, several occupancy profiles were created for six university building types that had previously not been defined: administrative, library, recreation, architecture, research, and classroom. Each university building has a distinctly different occupancy profile and a different motivation for its occupancy. A summary of the determined occupancy factors was provided. Recall that the maximum building capacity was used as the peak values in this study. Finally, a method was developed, using a combination of the class scheduling data and an estimation of office occupants, to predict occupancy for classroom-type buildings. In conclusion, this work has provided new and useful occupancy factors for six well characterized university building types and a discussion of the unique factors that influence each building's occupancy. In addition, the simplified method for classroom-type buildings provides adequate occupancy profiles and is a good alternate to traditional approaches.

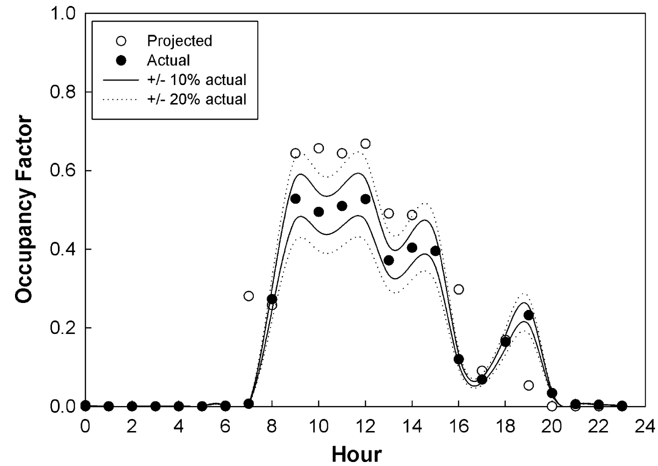

Fig. 9. Thursday's projected and actual occupancy for CLASS2.

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