

Additions and Corrections

The following presents additional information and technical errors found between June 15, 2019, and June 16, 2022, in the I-P editions of the 2019, 2020, and 2021 *ASHRAE Handbook* volumes. Occasional typographical errors and nonstandard symbol labels will be corrected in future volumes. The most current list of Handbook additions and corrections is on the ASHRAE web site (www.ashrae.org).

The authors and editor encourage you to notify them if you find other technical errors. Please send corrections to: Handbook Editor, ASHRAE, 180 Technology Parkway, Peachtree Corners, GA, 30092, or e-mail hkennedy@ashrae.org.

2019 HVAC Applications

First page of Contributors. Charles Gullede's employer should be listed as Environmental Air Systems, LLC.

p. 11.14, Figure 13. Source year should be 2000, rather than 2007.

p. 19.2, Table 1. Source note should be "©ISO. This material is reproduced from ISO 14644-1:2015, with permission of the American National Standards Institute (ANSI) on behalf of the International Organization for Standardization. All rights reserved."

p. 35.11, Fig. 10. SI version of Figure 10 was included in both the I-P and SI versions of the chapter. Correct I-P graphic is as seen at the top of page A.2.

Chapter 37, Tables 2 to 5. The data in these tables have been updated for greater accuracy. Replacement tables are provided on pages A.3 to A.5.

Chapters 46 and 47. These were erroneously published in SI format; replacement chapters are available on www.ashrae.org/technical-resources/ashrae-handbook.

p. 59.15, Fig. 25. Figure caption should read "Velocity Vectors and Contours at Central Cross Section with 675k Grid."

p. 61.3, Fig. 2. Bottom line of figure cut off. The figure in its entirety is at right.

End papers. Title for Chapter 59 should be listed as "Indoor Air-flow Modeling," and Chapter 60 should be "Integrated Project Delivery and Building Design."

Consultant(s)

- None
- In-house security management
- Outside security consultant
- Government security (at time of design; confidential)
- Government security (at time of construction; highly confidential)

Risk Evaluation Status (see risk evaluation document for more detail)

- Baseline: No specialized operations, tenants may be relocated, long-term nonoccupancy presents minimal challenge
- Enhanced: Specialized or unique operations, larger facilities with high populations, long-term nonoccupancy undesirable
- Critical: Highly specialized or unique operations, high importance or visibility, long-term nonoccupancy unacceptable

Design Features: HVAC Security

- List Features

Design Features: Environmental Health and Safety

- List systems with enhanced air filtration and MERV rating
- List systems with enhanced safeties and alarms and types of devices used
- List zoning application
- List air intake minimum height above grade requirements
- List equipment to be located above exterior historical flood level data
- List systems to be on emergency power

Commissioning, Operation, Maintenance, and Recommissioning

- Commission beginning in design phase through construction phase
- Continuous commissioning in warranty phase
- Operation training and documentation beginning in design phase
- Preventive maintenance work order ready to implement in construction/commissioning phase
- Predictive maintenance features
- Mode of operation: evacuation, shelter-in-place, uninterrupted operation (list systems by one of these three categories)
- Recommissioning every (X) years by _____

Fig. 2 HVAC Security and Environmental Health and Safety Basis of Design Segment

(from 2019 Applications, p. 61.3)

2021 Fundamentals

Chapter Updates. Please go to technologyportal.ashrae.org and log in to download updates to Chapters 1, 2, 5, 6, 13, 14, 16, 17, 18, 19, 20, 23, 24, 31, 34, 35, and 38. ASHRAE members should use their member login; nonmembers should contact ASHRAE customer service at cservice@ashrae.org if they do not have a login.

Table 2 2012 Commercial Sector Floor Area and EUI Percentiles

Building Use	Calculated, Weighted			Calculated, Weighted Energy Use Index (EUI) Values					
	Number of Buildings, Thousand	Floor Area, 10 ⁹ ft ²	Actual Number of Buildings, N	Site Energy, kBtu/yr per gross square foot					
				Percentiles					
				10th	25th	50th	75th	90th	Mean
Administrative/professional office	558	9.00	766	19	32	52	73	122	64
Bank/other financial	91	0.90	79	45	59	88	114	152	93
Bar/pub/lounge	71	0.35	60	43	68	126	231	334	168
Clinic/other health	87	1.27	135	25	44	63	92	152	79
College/university*	27	1.88	104	26	58	88	128	160	108
Convenience store	79	0.28	47	62	114	219	357	454	244
Convenience store with gas station	52	0.19	32	124	218	247	351	466	287
Courthouse/probation office	6	0.43	26	53	74	93	105	129	92
Distribution/shipping center	151	5.74	307	7	16	29	45	71	35
Dormitory/fraternity/sorority*	25	0.80	48	10	24	58	85	121	60
Elementary/middle school	189	6.12	397	21	30	47	71	109	57
Enclosed mall	1	0.87	34	27	43	62	71	92	59
Entertainment/culture*	51	1.27	89	5	23	45	73	120	60
Fast food	92	0.30	94	96	195	412	691	844	452
Fire station/police station	69	0.57	53	21	32	57	85	140	66
Government office	113	2.66	205	21	40	58	82	131	69
Grocery store/food market	45	0.76	48	104	134	199	234	301	195
High school	43	3.05	142	23	42	63	92	126	73
Hospital/inpatient health*	10	2.35	409	95	161	207	274	319	214
Hotel	30	2.61	159	43	57	66	106	165	90
Laboratory*	16	0.47	41	45	74	156	258	627	214
Library*	24	0.76	37	28	45	70	86	99	69
Medical office (diagnostic)	60	0.51	62	18	34	57	75	103	61
Medical office (non-diagnostic)	50	0.30	42	23	30	51	64	90	53
Mixed-use office	125	2.67	212	14	25	46	69	115	56
Motel or inn	61	0.60	61	44	49	60	116	137	79
Non-refrigerated warehouse	427	5.38	350	2	6	17	40	75	27
Nursing home/assisted living	30	1.28	94	50	78	111	159	193	128
Other	109	1.54	87	1	16	40	120	233	99
Other classroom education	62	0.75	62	14	24	39	88	116	57
Other food sales	1	0.02	2	183	218	218	218	218	210
Other food service	37	0.13	27	5	42	102	227	321	141
Other lodging	13	0.43	27	38	56	71	127	159	86
Other office	74	0.48	52	12	24	43	79	131	60
Other public assembly	41	0.64	63	19	38	56	78	183	75
Other public safety	9	0.43	22	75	106	118	143	143	116
Other retail	59	0.37	41	23	40	71	127	168	84
Other service	114	0.69	83	14	24	48	112	342	133
Post office/postal	30	0.40	26	30	45	63	77	89	62
Preschool/daycare	68	0.43	50	28	39	65	90	122	74
Recreation	100	1.90	127	18	25	51	98	160	70
Refrigerated warehouse	8	0.44	21	25	35	84	231	304	128
Religious worship	412	4.56	352	9	17	28	51	82	43
Repair shop	84	0.53	53	8	14	35	86	116	51
Restaurant/cafeteria	179	1.04	180	66	126	290	479	651	326
Retail store	336	4.50	294	13	23	51	83	126	61
Self-storage	209	1.57	81	2	4	13	34	70	29
Social/meeting	135	0.97	98	12	22	47	88	123	59
Strip shopping mall	163	5.09	296	39	59	104	177	265	141
Vacant	296	3.26	247	1	4	11	32	53	21
Vehicle dealership/showroom	43	0.56	34	22	35	61	101	142	77
Vehicle service/repair	214	1.65	149	14	25	45	93	161	73
Vehicle storage/maintenance	176	1.31	113	6	17	33	74	133	62
SUM or Mean for sector	5557	87.09	6720	10	24	51	95	195	88

Source: Oak Ridge National Laboratory, T. R. Sharp, calculated from U.S. DOE/EIA 2012 CBECS microdata.

* District chilled water use and cost are not reflected in building EUIs and cost metrics because they were not reported in the CBECS public database. Analysis showed there was potential this could significantly impact some EUIs for these building use types: college/university, dormitory/fraternity/sorority, entertainment/culture, library, hospital/inpatient health, and laboratory. Commentary in this chapter will explain the impact of chilled water systems on these categories.

NOTE: Metrics will not exactly match those in CBECS Table PBA3 as shown on the CBECS website due to including propane and wood as energy sources and because EIA uses a database to generate Table PBA3 that is slightly different from the database they make available to the public.

Table 3 2012 Commercial Sector Floor Area and Source EUI Percentiles

Building Use	Calculated, Weighted			Calculated, Weighted Energy Use Index (EUI) Values Source Energy, kBtu/yr per gross square foot					
	Number of Buildings, Thousand	Floor Area, 10 ⁹ ft ²	Actual Number of Buildings, N	Percentiles					
				10th	25th	50th	75th	90th	Mean
Administrative/professional office	558	9.00	766	49	78	123	182	310	158
Bank/other financial	91	0.90	79	113	147	234	300	369	239
Bar/pub/lounge	71	0.35	60	108	169	304	535	696	376
Clinic/other health	87	1.27	135	65	106	157	231	414	197
College/university	27	1.88	104	78	139	215	263	383	249
Convenience store	79	0.28	47	187	346	658	1123	1392	717
Convenience store with gas station	52	0.19	32	335	652	766	1065	1421	825
Courthouse/probation office	6	0.43	26	131	160	223	243	319	215
Distribution/shipping center	151	5.74	307	18	38	70	116	160	82
Dormitory/fraternity/sorority	25	0.80	48	32	71	118	193	209	135
Elementary/middle school	189	6.12	397	54	80	111	155	236	133
Enclosed mall	1	0.87	34	36	130	187	215	267	166
Entertainment/culture	51	1.27	89	15	48	79	173	317	145
Fast food	92	0.30	94	241	553	1009	1527	1905	1064
Fire station/police station	69	0.57	53	45	64	111	197	252	143
Government office	113	2.66	205	58	102	155	232	294	174
Grocery store/food market	45	0.76	48	272	418	496	659	774	529
High school	43	3.05	142	67	97	150	206	287	167
Hospital/inpatient health	10	2.35	409	225	350	487	592	686	472
Hotel	30	2.61	159	106	130	181	231	384	216
Laboratory	16	0.47	41	131	180	358	516	1149	517
Library	24	0.76	37	89	141	164	215	226	172
Medical office (diagnostic)	60	0.51	62	38	80	136	202	253	158
Medical office (non-diagnostic)	50	0.30	42	63	87	134	161	199	135
Mixed-use office	125	2.67	212	34	65	116	174	252	136
Motel or inn	61	0.60	61	89	135	162	260	380	203
Non-refrigerated warehouse	427	5.38	350	6	19	47	97	153	65
Nursing home/assisted living	30	1.28	94	98	168	235	381	483	274
Other	109	1.54	87	4	48	90	237	615	217
Other classroom education	62	0.75	62	39	59	91	164	205	116
Other food sales	1	0.02	2	451	526	526	526	526	510
Other food service	37	0.13	27	16	126	274	619	1013	396
Other lodging	13	0.43	27	81	87	158	269	348	177
Other office	74	0.48	52	38	67	102	188	255	135
Other public assembly	41	0.64	63	61	80	106	159	335	162
Other public safety	9	0.43	22	166	244	305	369	422	310
Other retail	59	0.37	41	38	92	180	302	468	218
Other service	114	0.69	83	34	62	112	210	735	242
Post office/postal	30	0.40	26	64	113	145	162	197	140
Preschool/daycare	68	0.43	50	71	98	142	207	288	183
Recreation	100	1.90	127	40	58	120	221	363	166
Refrigerated warehouse	8	0.44	21	48	111	265	493	956	387
Religious worship	412	4.56	352	20	38	59	95	163	83
Repair shop	84	0.53	53	26	39	82	158	236	103
Restaurant/cafeteria	179	1.04	180	165	280	590	977	1279	678
Retail store	336	4.50	294	34	58	130	216	330	155
Self-storage	209	1.57	81	6	12	40	91	219	86
Social/meeting	135	0.97	98	28	51	105	171	330	133
Strip shopping mall	163	5.09	296	103	170	260	416	533	324
Vacant	296	3.26	247	2	10	24	63	110	48
Vehicle dealership/showroom	43	0.56	34	45	89	134	261	352	183
Vehicle service/repair	214	1.65	149	31	59	110	182	296	142
Vehicle storage/maintenance	176	1.31	113	16	42	76	125	289	131
SUM or Mean for sector	5557	87.09	6720	26	59	119	223	460	206

Source: Oak Ridge National Laboratory, T. R. Sharp, calculated from U.S. DOE/EIA 2012 CBECS microdata.

* District chilled water use and cost are not reflected in building EUIs and cost metrics because they were not reported in the CBECS public database. Analysis showed there was potential this could significantly impact some EUIs for these building use types: college/university, dormitory/fraternity/sorority, entertainment/culture, library, hospital/inpatient health, and laboratory. Commentary in this chapter will explain the impact of chilled water systems on these categories.

Table 4 Electricity Index Percentiles from 2012 Commercial Survey

Building Use	Weighted Electricity Use Index Values, kWh/yr per gross square foot					
	Percentiles					
	10th	25th	50th	75th	90th	Mean
Administrative/professional office	3.2	5.5	9.7	15.3	24.5	12.5
Bank/other financial	8.7	11.0	19.0	24.2	33.2	19.4
Bar/pub/lounge	9.0	11.4	25.3	38.3	45.9	27.3
Clinic/other health	4.8	7.2	13.1	18.7	30.6	15.7
College/university	6.1	9.3	14.7	19.9	27.9	17.5
Convenience store	16.5	29.5	49.3	104.0	120.9	64.2
Convenience store with gas station	28.1	56.8	68.3	94.9	114.6	72.8
Courthouse/probation office	7.9	13.2	17.2	18.3	24.0	16.0
Distribution/shipping center	1.0	2.3	5.0	8.4	12.6	6.1
Dormitory/fraternity/sorority	3.0	5.1	8.4	12.9	17.2	9.5
Elementary/middle school	4.3	5.7	8.1	11.8	18.5	10.1
Enclosed mall	0.9	11.2	16.2	20.0	22.9	14.4
Entertainment/culture	0.9	1.8	6.7	13.2	25.4	11.2
Fast food	16.9	43.0	73.8	119.8	152.1	81.4
Fire station/police station	1.9	3.9	7.8	14.6	22.6	10.0
Government office	4.7	7.8	11.9	16.9	25.3	14.1
Grocery store/food market	22.7	34.8	43.2	54.7	64.5	44.9
High school	4.0	6.3	10.5	15.6	24.2	12.3
Hospital/inpatient health	16.6	20.3	32.2	44.1	45.4	33.1
Hotel	7.4	9.5	13.7	18.1	29.1	16.8
Laboratory	11.7	14.1	33.0	40.3	66.3	40.3
Library	8.3	10.5	14.5	15.6	18.1	13.5
Medical office (diagnostic)	3.1	4.8	11.4	16.7	23.0	13.0
Medical office (non-diagnostic)	4.0	6.6	9.0	14.4	15.6	11.0
Mixed-use office	2.2	4.4	8.6	13.3	19.0	10.7
Motel or inn	5.6	12.1	14.8	21.2	33.8	16.6
Non-refrigerated warehouse	0.5	1.4	3.5	6.7	11.7	5.1
Nursing home/assisted living	5.1	10.7	17.4	27.5	35.5	19.1
Other	0.3	2.1	4.9	16.7	50.9	15.1
Other classroom education	1.3	2.6	6.9	10.8	14.8	7.6
Other food sales	35.9	41.2	41.2	41.2	41.2	40.0
Other food service	1.5	8.9	21.7	56.9	94.2	34.4
Other lodging	2.8	3.1	8.8	15.0	24.8	11.8
Other office	3.2	4.0	7.4	9.8	16.9	9.9
Other public assembly	3.7	4.7	7.1	12.5	29.6	11.3
Other public safety	10.4	16.0	26.9	34.1	37.8	25.8
Other retail	2.7	6.4	14.2	22.4	43.6	18.0
Other service	2.2	4.3	7.3	15.3	29.2	13.7
Post office/postal	4.5	7.4	10.3	13.3	14.2	10.3
Preschool/daycare	2.8	7.8	11.4	16.6	23.8	14.4
Recreation	1.5	3.8	7.4	18.0	33.2	12.7
Refrigerated warehouse	2.9	10.4	24.7	45.9	89.0	35.2
Religious worship	1.2	2.2	3.5	5.8	11.1	5.0
Repair shop	1.8	3.1	5.3	10.1	13.1	6.7
Restaurant/cafeteria	10.7	19.4	38.5	67.8	86.3	45.8
Retail store	2.4	4.4	9.2	17.8	27.0	12.5
Self-storage	0.6	1.1	3.2	8.5	20.4	7.8
Social/meeting	1.5	2.9	6.3	11.0	28.5	9.8
Strip shopping mall	9.5	13.9	20.0	27.9	40.2	24.3
Vacant	0.1	0.8	1.6	3.8	9.4	3.5
Vehicle dealership/showroom	1.6	5.3	8.8	21.5	30.1	14.1
Vehicle service/repair	2.0	4.6	7.5	11.6	16.9	8.9
Vehicle storage/maintenance	0.5	2.1	4.9	9.1	19.9	8.9
Mean for sector	1.7	3.9	8.7	17.1	35.8	15.6

Source: Oak Ridge National Laboratory, T. R. Sharp, calculated from U.S. DOE/EIA 2012 CBECs microdata.

Table 5 Energy Cost Percentiles from 2012 Commercial Survey

Building Use	Weighted Energy Cost Values, \$/yr per gross square foot					
	Percentiles					
	10th	25th	50th	75th	90th	Mean
Administrative/professional office	0.53	0.86	1.31	1.98	3.11	1.66
Bank/other financial	0.99	1.29	2.13	3.02	3.75	2.2
Bar/pub/lounge	1.2	1.63	2.57	4.49	8.13	3.54
Clinic/other health	0.52	0.95	1.77	2.2	3.24	1.86
College/university	0.83	1.2	1.91	2.47	4.22	2.14
Convenience store	1.58	2.82	4.85	8.23	15.86	6.87
Convenience store with gas station	3.23	4.11	6.26	9.16	10.01	7.07
Courthouse/probation office	1.04	1.28	2.43	3.53	4.75	2.66
Distribution/shipping center	0.21	0.34	0.65	1.09	1.76	0.82
Dormitory/fraternity/sorority	0.49	0.59	1.11	1.73	2.36	1.21
Elementary/middle school	0.56	0.8	1.13	1.58	2.31	1.33
Enclosed mall	0.3	0.94	1.57	1.95	2.43	1.43
Entertainment/culture	0.19	0.52	1.08	1.66	2.73	1.44
Fast food	2.96	5.83	9.14	12.97	16.29	9.51
Fire station/police station	0.39	0.52	0.96	1.62	2.69	1.3
Government office	0.53	0.82	1.35	2.06	2.88	1.66
Grocery store/food market	2.17	3.72	4.67	6.46	7.02	4.91
High school	0.61	0.89	1.32	1.79	2.61	1.63
Hospital/inpatient health	1.96	2.77	3.65	4.78	6.28	3.94
Hotel	0.86	1.11	1.41	2.14	3.26	1.87
Laboratory	1.67	2.31	3.36	5.24	11.02	4.85
Library	0.81	1.41	1.67	2.26	3.12	1.81
Medical office (diagnostic)	0.63	0.94	1.53	2.07	3.29	1.69
Medical office (non-diagnostic)	0.56	0.84	1.27	1.6	2.82	1.39
Mixed-use office	0.35	0.69	1.25	1.94	2.81	1.45
Motel or inn	0.65	1.14	1.75	2.14	3.07	1.77
Non-refrigerated warehouse	0.07	0.23	0.54	0.91	1.51	0.69
Nursing home/assisted living	0.99	1.33	2.05	3.48	5.81	2.57
Other	0.09	0.45	0.73	2.16	5.62	2.36
Other classroom education	0.22	0.51	1	1.61	2.3	1.09
Other food sales	3.55	3.55	3.55	3.55	4.07	3.66
Other food service	0.12	0.93	2.96	7.68	8.64	4.28
Other lodging	0.79	0.81	1.31	1.89	2.28	1.49
Other office	0.33	0.65	1.15	1.57	2.42	1.45
Other public assembly	0.56	0.77	0.99	1.34	2.95	1.45
Other public safety	1.36	1.75	2.04	2.93	2.93	2.14
Other retail	0.51	0.94	1.57	3.29	5.04	2.26
Other service	0.32	0.57	1.04	2.3	5.5	2.14
Post office/postal	0.71	0.94	1.25	1.61	2.02	1.31
Preschool/daycare	0.84	1.12	1.46	2.01	3.37	1.73
Recreation	0.38	0.69	1.11	2.51	4.35	1.78
Refrigerated warehouse	0.76	0.9	2.35	3.81	8.86	3.48
Religious worship	0.2	0.36	0.59	0.94	1.42	0.78
Repair shop	0.22	0.44	0.9	1.33	2.48	1.06
Restaurant/cafeteria	1.41	2.67	5	7.81	11.04	5.74
Retail store	0.39	0.68	1.16	2	3.17	1.56
Self-storage	0.06	0.13	0.31	0.8	2.55	0.9
Social/meeting	0.26	0.47	0.85	1.49	2.98	1.2
Strip shopping mall	0.89	1.45	2.24	3.5	4.85	2.79
Vacant	0.06	0.13	0.3	0.68	1.24	0.5
Vehicle dealership/showroom	0.4	0.87	1.26	2.45	3.92	1.87
Vehicle service/repair	0.32	0.71	1.16	1.58	3.3	1.48
Vehicle storage/maintenance	0.17	0.42	0.87	1.59	2.48	1.35
Mean for sector	0.29	0.61	1.18	2.13	4.33	1.96

Source: Oak Ridge National Laboratory, T. R. Sharp, calculated from U.S. DOE/EIA 2012 CBECS microdata.

* District chilled water use and cost are not reflected in building EUIs and cost metrics because they were not reported in the CBECS public database. Analysis showed there was potential this could significantly impact some EUIs for these building use types: college/university, dormitory/fraternity/sorority, entertainment/culture, library, hospital/inpatient health, and laboratory. Commentary in this chapter will explain the impact of chilled water systems on these categories.