Carbon Footprint in the Design Studio, a Paradigm Shift

Abby Brandvold, Khaled Mansy, John Phillips, Tom Spector, and Jerry Stivers,
School of Architecture, Oklahoma State University

Purpose

Holistic approach to building performance

Points of Discussion

Integrative/comprehensive design
Climate action & carbon footprint
Performance optimization
Life cycle analysis

Comprehensive Design Studio @ OSU

ARCH. DESIGN STUDIO SEQUENCE ISSUES AND CONCEPTS

BACHELOR OF ARCHITECTURE

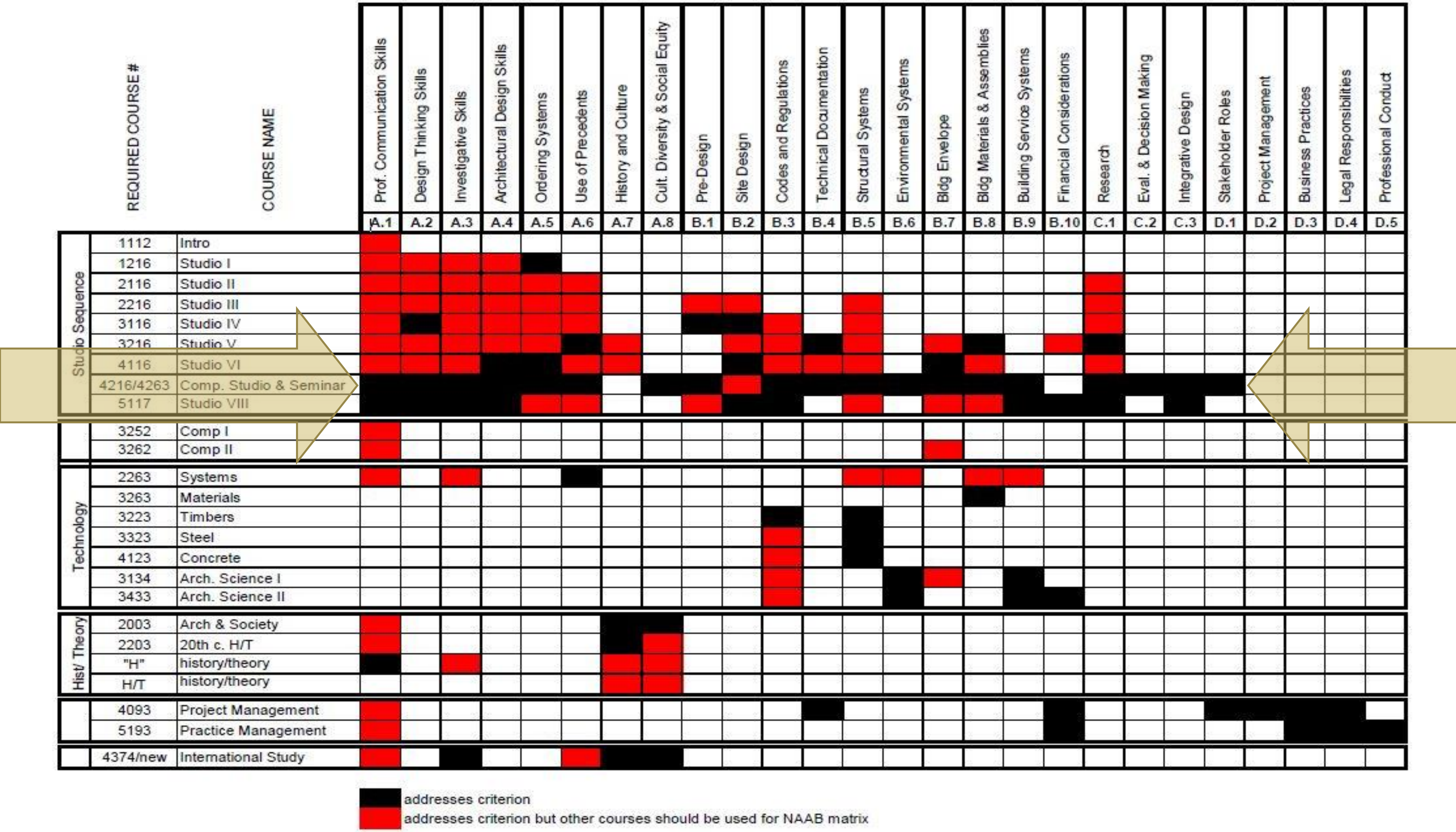
FIVE YEAR
154 hours

PRE-PROFESSIONAL PROGRAM → PROFESSIONAL PROGRAM

	ARCH 1112	ARCH 1216	ARCH 2116	ARCH 2216	ARCH 3116	ARCH 3216	ARCH 4116	ARCH 4216	ARCH 5117	ARCH 5217
STUDIO CONCEPT	Introduces students to the professions of architecture and architectural engineering.	Introduces students to the fundamental principles of design, visual perception, orthographic drawing, and visual communication.	Continues emphasis of fundamental design principles, introduces students to beginning architectural problem solving, teaches them the fundamentals of perspective and shades and shadows, introduces the role of precedent in design, and helps them develop abilities in formal analysis.	Focus on architectural problem solving with small to medium sized projects. Students are introduced to principles of site planning, building systems, parking, landscape design, vertical circulation, and the relationship of building orientation and sun-control to sustainable principles. Visual communication skills are emphasized through various techniques of hand drawing and model making.	Continues emphasis on basic architectural problem solving with increasingly larger and more complex projects. A building's relationship to context is emphasized throughout the semester. An architectural program is developed by students to help them gain an understanding of problem-seeking and computers are introduced as design and presentation tools.	Continues emphasis on basic architectural problem-solving with increasingly larger and more complex projects. At least one of the projects is a multi-story building in an urban context. Material use and integration is emphasized, as are principles of sustainability. Students utilize the DML lab for a hands-on design-build experience.	Continues emphasis on architectural problem-solving but also introduces students to issues of design development. Integration of structural systems is emphasized and at least one project helps students broaden their cultural awareness by being sited outside of the United States. Sustainability principles continue to be a focus.	Utilizes a semester-long project to introduce students to the design process from schematic design through construction documents. Emphasis is placed on technology and systems integration, low-energy design, and tectonics. Codes, life-safety issues, and ADA are addressed. Students gain a basic understanding of the concept of integrated practice and the course strongly parallels practice management issues through a co-requisite course.	Focuses on architecture in urban areas and introduces students to urban theory and city planning issues. At least one of the projects is a team project. A multi-day field trip to a major national city helps students understand urban issues through first-hand experience.	This elective studio focuses on advanced architectural problem solving and the integration of design theory. A written component is required. This studio allows students to focus and hone their design philosophy, or to experiment in alternative creative methodologies. Competition projects are utilized when appropriate.
PRIMARY ISSUES	Observation and Analysis of Architecture Basic Design Principles	Basic Design Principles Ordering Systems Color Theory	Basic Design Principles Precedent Study Analysis Concept Generation	Arch. Problem Solving Systems Intro. Site Planning, Parking, Landscape Integration Bldg. Orientation & Sustainability	Arch. Problem Solving Increasing Scale and Complexity Context	Arch. Problem Solving Multi-story building in urban context Materials Integration Sustainability	Advanced Arch. Problem Solving Structural Systems Design Development	Comprehensive Design Tech. Integration Materials Integration Systems Integration Codes, Life Safety, ADA	Architecture in Urban Areas Urban Theory/ Integration of City Planning Issues	Advanced Architectural Problem Solving Design Theory
COMMUNICATION	Introduction to Drawing Types	Sketching, Orthographic Projection	Perspective Drawing/ Shades and Shadows Jury Review	Graphic Techniques Jury Review	Computer Applications/ Integration Program Preparation	Jury Review	Jury Review	Jury with Practicing Professionals Introduction of Integrated Practice	Team Project Jury Review	Written Component
ENRICHMENT	Interview an Architect or AE	Creative Journaling	Regional Field Trip - daytrip		Regional Field Trip - overnight	DML Experience	Cultural Awareness - International project	Integration of Practice Man.Issues	National Field Trip to a Major City	Competition Projects when appropriate
	INTRO	BEGINNING DESIGN		ARCHITECTURE/ BUILDING DESIGN			TECHNOLOGY INTEGRATION/ DESIGN DEVELOPMENT		ADVANCED ARCHITECTURAL DESIGN	

- Communication and Analytical Thinking
- Graphic Thinking, Drawing, and Modeling Skills/ Creativity/ Application of Design Theory
- Form, Function, and Space Development/ Venustas in Architecture
- Contemporary Issues in Architecture/ Site Planning and Response to Context/ Sustainability Issues/ Systems Integration
- Materials Integration/ Computer Integration/ Architecture in the Global Context
- Technology Integration/ Design Development
- Integration of All Issues

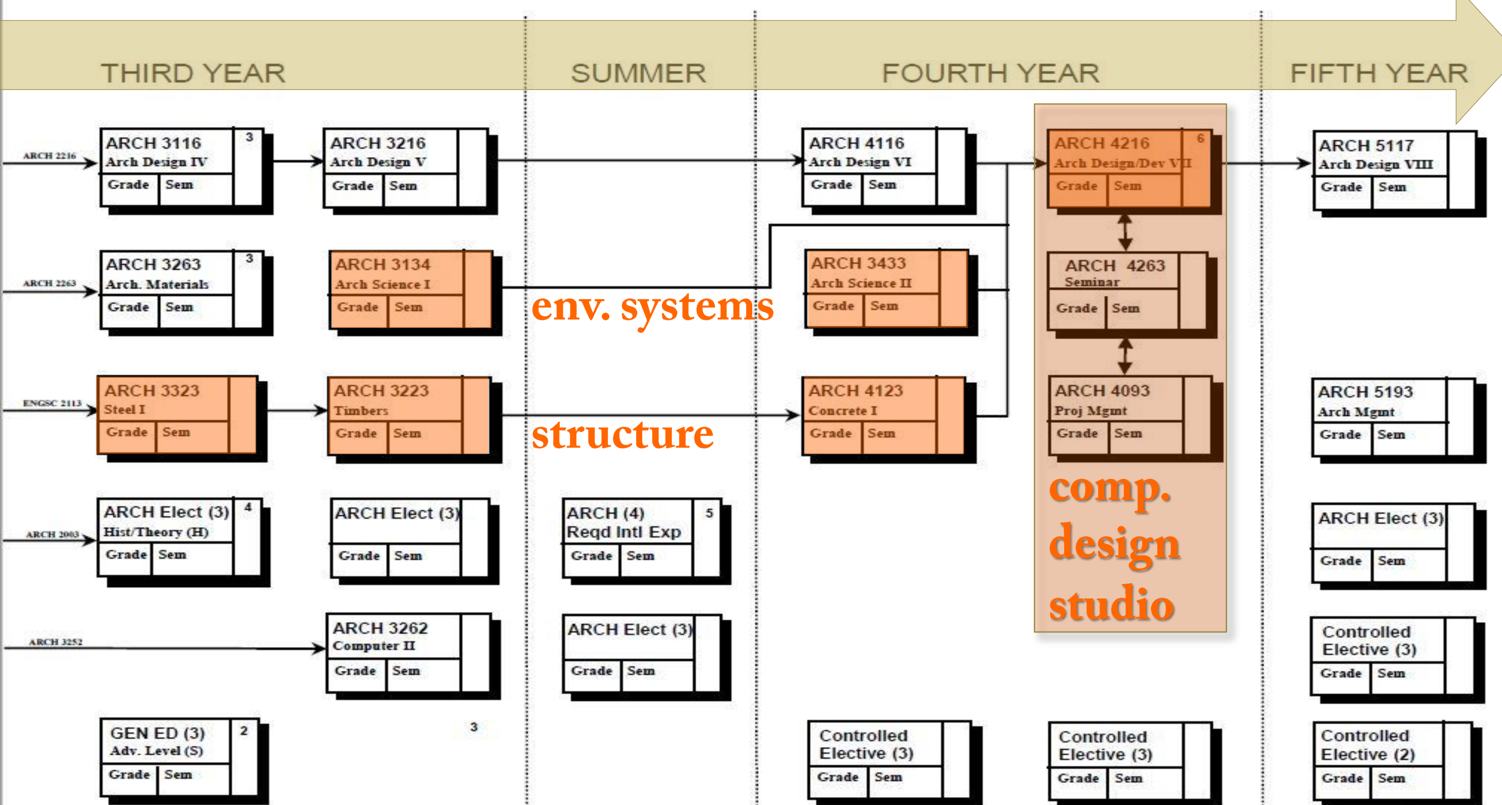
Comprehensive Design Studio @ OSU



Comprehensive Design Studio @ OSU

BACHELOR OF ARCHITECTURE
PROFESSIONAL SCHOOL OF ARCHITECTURE

Oklahoma State University
College of Engineering, Architecture & Technology



FLOW CHART NOTES (con't):
2. Selected from list of approved courses.
3. Formal admission to upper division required.
4. At least one of the ARCH elective History/Theory courses must have an "H" designation.
5. International Program approved by the School.
6. Senior Capstone course with corequisite enrollment of 4263 and 4093.

GENERAL EDUCATION
Students are required to take at least 40 credit hours of General Education courses met by required courses and electives. These must include:

(A), 7 hours: MATH 2144, ENSC 2113.

(H), 6 hours: ARCH 2003 and ARCH___3 H/T course.

(S), 3 hours lower division "S" and 3 hours upper division "S": see list of Approved upper "S" courses with focus on Urban Issues.

(I), 3 hours: ARCH 2003.
(D), 3 hours: Diversity component.

(N), 7 hours: PHYS 1114 and one course from
ASTR 1014, 1024;
BIOL 1114; BOT 1404;
CHEM 1314, 1414; DHM 2573;
GEOG 1114, 3023, 3033;
GEOL 1014, 1114; HORT 1013;
NSCI 2114.

ARCHITECTURE ELECTIVES
Students are required to take 9 credit hours of ARCH electives and 3 Hours of ARCH History and Theory, for a total of 9 hours of ARCH H/T.

CONTROLLED ELECTIVES
Students are required to take 11 credit hours of CONTROLLED electives, selected in consultation with the head of the School of Architecture and/or the Academic Advisor.

For further information, go to www.architecture.ceat.okstate.edu

Performance as a design goal:

Energy Performance

- *Code compliance (IECC), daylighting design (average illuminance & distribution), electric lighting design (illuminance in fc & light load in W/sf), cooling load (Energy Use Intensity in kBtu/sf.yr & peak load in CFM/sf).*

Structural Performance

- *Comparison between possible structural systems, i.e., timber, steel, and concrete. Then, complete design of the structural system (AE students).*

Cost Performance

- *Project management and cost estimating (no set construction budget).*

Performance as a design goal:

Energy Performance

1. ***Code compliance*** *(IECC), based on the code prescriptive values or based on performance (min. of 15% energy cost saving).*

2. ***Daylighting design*** *(average illuminance & distribution). Students test daylight models under an artificial sky dome.*

3. ***Electric lighting design*** *(illuminance in fc & light load in W/sf). Students use hand calculations, online calculators, or an illumination design software.*

4. ***Cooling load*** *(Energy Use Intensity in kBtu/sf.yr & peak load in CFM/sf). Students use a verified energy simulation software.*

Comprehensive Design Studio @ OSU

Lighting & Daylighting

2020-Apr-15
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Results

40 fc | 36 luminaires | 0.49 W/ft²

Luminaire

76-4-L115-840-DIM-UNV_.ies

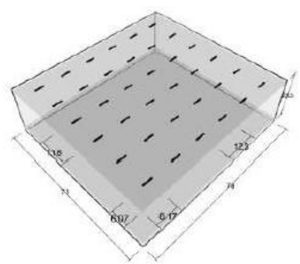
76-4-L115-840-DRV-UNV

4' STRIP LUMINAIRE LED ARRAYS ON WHITE REFLECTOR

Luminaire Watts	76	W
Ballast/Driver Factor	1.00	
Light Loss Factor	0.650	
Total Proration Factor	1.00	
Luminaire Lumens	11514	lms

Room

Length	78	ft
Width	71	ft
Height	23.5	ft
Workplane Height	2.50	ft
Suspension Length	1.00	ft



Reflectance

Ceiling	80	%
Walls	50	%
Floor	20	%

Layout

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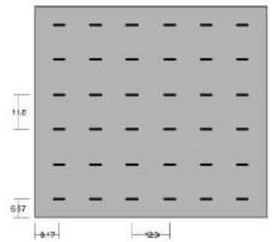
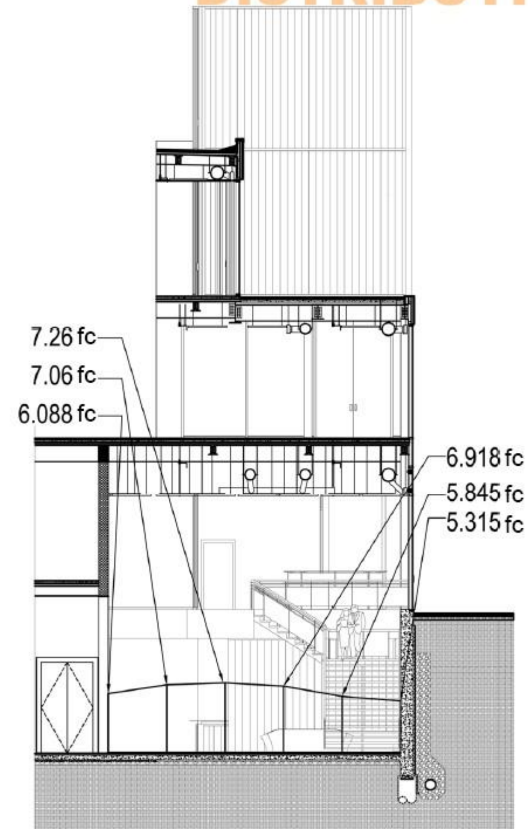
Layout	6	6	
Spacing	12.3	11.8	ft
Offset	8.17	6.07	ft
Spacing Criteria	1.26	1.26	



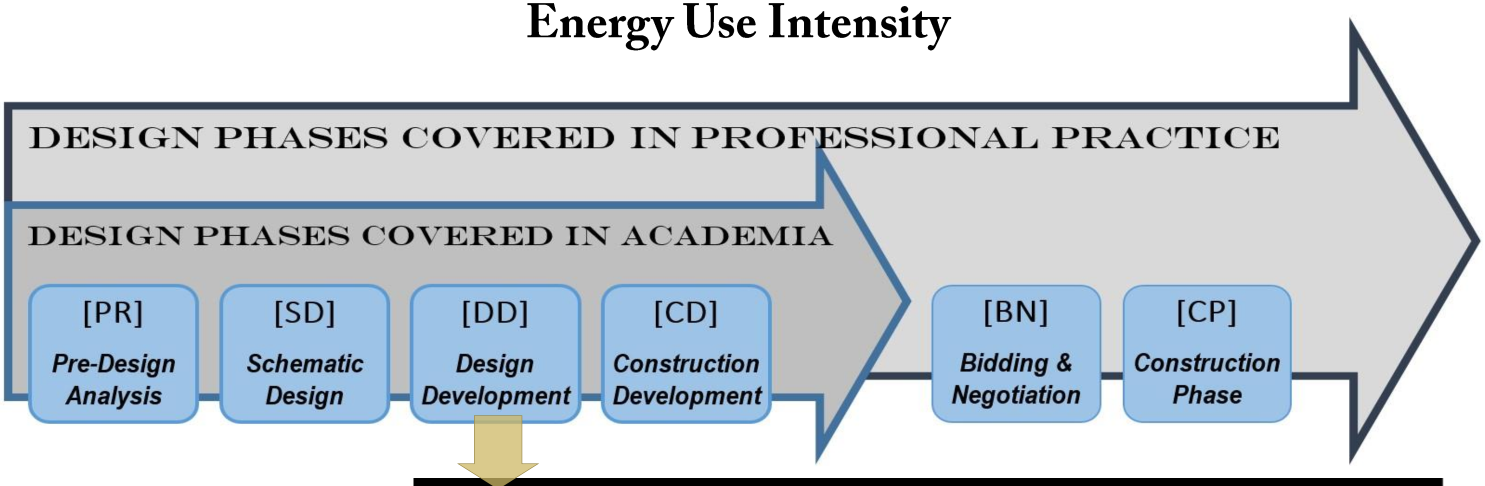
Current design uses 34 luminaires. Values of the light load and illumination levels were interpolated from a 36 count luminaire layout and a 30 count luminaire layout.

DAYLIGHT
DISTRIBUTION

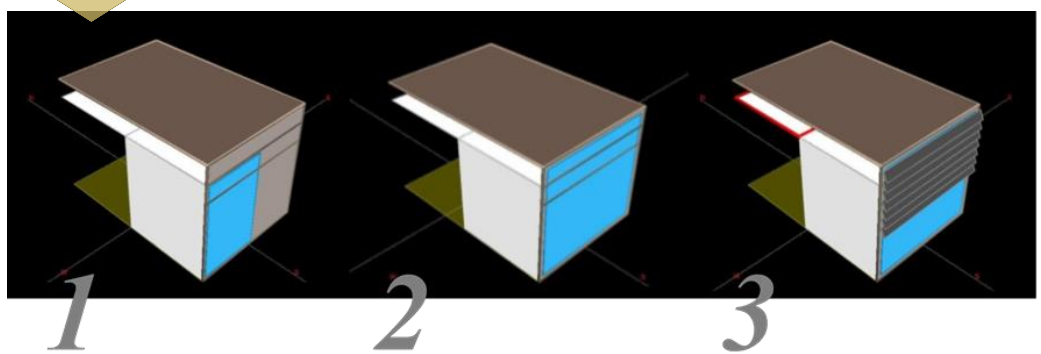


Performance Optimization

Energy Use Intensity



Performance Optimization:



Energy Use Intensity (EUI):		
133.7 kBtu/sf.yr	111.6 kBtu/sf.yr	108.6 kBtu/sf.yr
Design improvement		
Baseline (40% glass)	90% glass	90% glass + external shading

Env. Performance : EUI & IECC Code Compliance

ARCH 4216/5226/4263 - Spring 2020

DD - most current | DD - Standard Refeence Design Building | DD Final Submission. Last updated on 05/01/2020

End of DD Environmental Analysis

DD - environmental performance | Performance of the Standard Reference Design (30% glass for code compliance) | Zero Code

DD - most current design (using your own HVAC system)

Design Teams		% Energy Saving [15% min.]	% Glass Ratio - whole building [30% max.]	Building EUI (kBtu/sf.yr)	CO_2 Reduction %	2030 Benchmark EUI	2030 Target EUI	Cooling EUI	Heating EUI	Lighting EUI	HVAC system: Brief Description of your HVAC system	Daylighting performance: sDA* (higher is better)	Daylighting performance: ASE** (lower is better)	Total enclosed area of the building (sf)
1	Curtsinger	4.8%	32.0%	30.78	53%	65.73	13.15	4.96	2.51	8.16	VAV + GSHP (COP 4.5 & 6.0)	24%	21%	21,704
	Severson	34.1%	42.0%	22.87	66%	69.03	13.81	2.20	1.45	5.81	VAV + GSHP (COP 4.5 & 6.0)	25%	23%	16,600
	Roeming	38.1%	60.0%	28.54	58%	69.43	13.89	3.16	2.35	5.78	VAV + GSHP (COP 0.9 & 6.0)	45%	44%	12,667
2	Ramirez		30.0%											19,483
	Strom	16.1%	28.0%	24.95	62%	66.00	13.20	1.95	1.28	5.33	VAV + GSHP (COP 4.5 & 6.0)	28%	26%	18,511
	Gee	10.5%	30.0%	25.65	60%	64.84	12.97	2.26	0.96	6.02	VAV + GSHP (COP 4.5 & 6.0)	21%	19%	16,250
3	Bailey	15.2%	43.0%	25.54	62%	67.84	13.57	2.19	1.93	5.89	VAV + All Elect (COP 4.5 & 6.0)	7%	6%	26,760
	Cornelius	20.5%	37.4%	27.11	59%	67.73	13.95	2.69	2.26	4.88	VAV + GSHP (COP 4.5 & 6.0)	37%	35%	20,220
	Pick	17.2%	28.0%	25.90	57%	61.57	12.31	3.60	0.62	4.97	VAV + GSHP (COP 3.2 & 4.0)	32%	27%	15,653
4	Reese	14.3%	13.3%	27.95	56%	63.69	12.74	2.06	1.71	7.33	VAV + GSHP (COP 4.5 & 6.0)	14%	16%	16,262
	Snyder	41.9%	16.5%	26.06	59%	64.05	12.81	2.38	1.28	5.16	VAV + GSHP (COP 4.5 & 6.0)	25%	22%	17,510
	Garrison	22.6%	13.0%	25.63	60%	64.16	12.83	3.20	0.50	5.73	VAV + GSHP (COP 4.5 & 6.0)	14%	12%	11,436
5	Bullard	10.8%	21.0%	27.57	58%	65.98	13.20	2.08	2.25	6.70	VAV + GSHP (COP 4.5 & 6.0)	9%	8%	21,500
														22,613
	Stephens	22.5%	40.0%	23.77	63%	65.94	13.19	2.59	2.38	5.50	VAV + GSHP (COP 4.5 & 6.0)	20%	17%	21,719
6	Berndt	1.6%	26.0%	25.97	60%	66.34	13.07	2.39	1.90	5.08	VAV + GSHP (COP 4.5 & 6.0)	45%	43%	19,536
	King	0.3%	26.0%	25.28	61%	65.34	13.07	2.40	1.36	5.08	VAV + GSHP (COP 4.5 & 6.0)	45%	43%	20,614
	Reddout	16.6%	19.1%	28.94	55%	64.92	12.98	2.16	5.81	5.42	VAV + GSHP (COP 4.5 & 6.0)	22%	19%	19,000
7	Loomis	29.5%	27.0%	19.87	76%	66.84	13.37	3.77	1.89	6.51	VRF-WS (COP 3.2 & 4.0)	51%	48%	23,473
	Russell	43.4%	54.0%	15.49	78%	70.65	14.13	4.10	0.03	5.87	VRF-WS (COP 4.5 & 6.0)	25%	22%	22,848
	Soto	56.6%	30.0%	15.80	76%	65.94	13.19	3.73	3.69	5.69	VRF-WS (COP 2.9 & 4.8)	29%	26%	14,772
8	Siddall	4.7%	30.0%	26.98	58%	65.03	13.01	2.40	2.93	4.75	VAV + GSHP (COP 4.5 & 6.0)	28%	23%	16,000
	Wiese	27.0%	32.0%	27.22	57%	63.92	12.78	3.06	4.04	4.46	Rad + GSHP (COP 4.5 & 6.0)	20%	17%	18,249
	Harbert	20.4%	35.0%	31.26	50%	63.14	12.63	3.52	3.84	5.83	VAV + GSHP (COP 4.5 & 6.0)	32%	29%	17,939
9	Costin	19.5%	30.0%	24.42	62%	65.03	13.01	2.18	1.92	3.83	VAV + GSHP (COP 4.5 & 6.0)	14%	12%	18,956
	Crawford	0.0%	26.0%	23.78	63%	65.06	13.01	1.67	0.84	5.71	VAV + GSHP (COP 4.5 & 6.0)	15%	12%	20,125
	Carnes	25.2%	31.0%	21.09	67%	65.40	13.08	1.87	1.21	5.60	VAV + GSHP (COP 0.9 & 6.0)	19%	16%	20,514
10	Finch													
	Hummingbird		40.0%											
	Jeffers	0.7%	24.4%	31.97	52%	66.96	13.39	4.08	3.41	6.37	VAV + All Elect (COP 4.5 & 6.0)	16%	15%	20,601
11	Slavin	18.7%	42.5%	26.44	59%	65.33	13.07	1.86	3.11	4.47	VAV + GSHP (COP 4.5 & 6.0)	43%	37%	20,603
	Yen	25.8%	32.0%	25.49	61%	66.26	13.25	1.93	1.95	5.01	VAV + GSHP (COP 4.5 & 6.0)	43%	39%	20,360
	Fernandez	10.8%	28.0%	24.36	64%	69.41	13.88	2.76	0.15	4.83	VAV + GSHP (COP 4.5 & 6.0)	28%	24%	19,490
12	Hutton	15.9%	52.0%	27.90	56%	63.75	12.75	2.39	2.56	6.66	VAV + GSHP (COP 3.2 & 4.0)	14%	12%	16,891
	Klempa	23.1%	58.0%	25.08	59%	62.16	12.43	3.06	2.90	5.22	VAV + All Elect (COP 3.2 & 4.0)	42%	38%	13,502
	Nemec	15.9%	50.0%	25.09	59%	62.16	12.43	2.81	2.33	4.11	VAV+Ch+GF Boiler (COP3.2&4.0)	53%	15%	14,816
13	Ryan	15.1%	29.0%	23.71	63%	65.75	13.15	3.09	0.27	3.58	VAV + GSHP (COP 4.5 & 6.0)	18%	16%	19,894
	Thompson	19.7%	22.0%	25.64	61%	67.13	13.43	2.47	1.04	5.58	VAV + GSHP (COP 4.5 & 6.0)	18%	17%	19,134
	Mayorga	4.5%	33.0%	28.29	55%	65.48	13.10	3.49	1.76	5.86	VAV + GSHP (COP 4.5 & 6.0)	27%	23%	20,265
14	Coppick [mob]	8.3%	26.9%	27.75	65%	81.20	16.24	2.31	2.40	5.96	VAV + All Elect (COP 4.0 & 4.0)	27%	23%	67,800
	Minimum	0.0%	13.0%	15.49	50%	61.57	12.31	1.67	0.03	3.58		7%	6%	11,436
	Average	19.0%	32.7%	25.50	61%	65.66	13.14	2.76	2.01	5.51	All Electric	27%	23%	18,824
	Maximum	56.6%	60.0%	31.97	78%	70.65	14.13	4.96	5.81	8.16		53%	48%	26,760

Standard Reference Design (minimum IECC code requirements)

Design Teams		Building EUI (kBtu/sf.yr)	CO_2 Reduction %	2030 Benchmark EUI	2030 Target EUI	Cooling EUI	Heating EUI	Lighting EUI	HVAC system: Brief Description of your HVAC system	Daylighting performance: sDA* (higher is better)	Daylighting performance: ASE** (lower is better)	Zero Code Benchmark EUI
1	Curtsinger	32.33	50%	65.73	13.15	6.62	3.01	7.97	VAV + All Elect (COP 3.2 & 4.0)	33%	30%	28.5
	Severson	34.72	49%	69.03	13.81	4.67	11.36	4.42	VAV + All Elect (COP 0.9 & 4.3)	18%	30%	
	Roeming	46.07	29%	65.19	13.04	4.30	20.27	6.40	VAV + All Elect (COP 0.9 & 6.0)	18%	17%	
2	Ramirez											28.5
	Strom	29.73	54%	66.00	13.20	3.83	2.66	5.83	VAV + All Elect (COP 3.2 & 4.5)	28%	26%	
	Gee	28.65	55%	64.84	12.97	5.00	2.40	6.76	VAV + All Elect (COP 3.2 & 4.0)	21%	19%	
3	Bailey	30.11	55%	67.84	13.57	4.20	1.52	6.89	VAV+All Elect (COP 4.5 & 6.0)	7%	6%	28.5
	Cornelius	34.11	49%	67.73	13.55	2.61	9.40	4.58	Chiller+GF Boiler (COP4.0&4.0)	27%	26%	
	Pick	31.29	49%	61.78	12.36	6.63	1.29	4.92	PK unit+GF Boiler (COP4.0&3.2)	29%	28%	
4	Reese	32.61	48%	63.69	12.74	4.49	3.77	7.30	VAV + All Elect (COP 3.2 & 4.0)	19%	16%	28.5
	Snyder	44.84	29%	64.05	12.81	6.19	17.75	5.13	VAV+Ch+GF Boiler (COP0.9&4.3)	26%	23%	
	Garrison	33.13	48%	64.16	12.83	4.84	2.92	7.37	VAV+Ch+GF Boiler (COP3.2&4.0)	14%	12%	
5	Bullard	30.91	53%	65.98	13.20	4.44	2.99	6.39	VAV + All Elect (COP 3.2 & 4.0)	15%	13%	28.5
	Stephens	30.66	53%	65.94	13.19	6.60	1.72	8.34	VAV + All Elect (COP 3.2 & 4.0)	25%	21%	
6	Berndt	26.39	59%	66.34	13.07	2.55	2.03	5.08	VAV + GSHP (COP 4.5 & 6.0)	45%	43%	28.5
	King	25.36	61%	65.34	13.07	2.53	1.28	5.08	VAV + GSHP (COP 4.5 & 6.0)	45%	43%	
	Reddout	34.71	46%	64.92	12.98	5.33	3.12	8.34	PK unit+GF Boiler (COP4.0&3.2)	48%	45%	
7	Loomis	28.17	57%	66.84	13.37	4.33	2.23	4.71	VAV + All Elect (COP 4.5 & 4.3)	30%	27%	28.5
	Russell	27.36	61%	70.65	14.13	3.41	1.85	5.85	VAV + All Elect (COP 4.5 & 6.0)	41%	38%	
	Soto	36.41	44%	65.94	13.19	7.12	5.04	5.60	VAV + All Elect (COP 3.2 & 4.0)	32%	28%	
8	Siddall	28.32	56%	65.03	13.01	2.48	2.99	5.85	VAV + GSHP (COP 4.5 & 6.0)	28%	23%	28.5
	Wiese	37.31	41%	63.92	12.78	5.52	5.26	5.94	Rad + GSHP (COP 3.2 & 4.0)	28%	25%	
	Harbert	39.25	37%	63.14	12.63	6.13	3.84	7.10	VAV + GSHP (COP 3.2 & 4.0)	41%	37%	
9	Costin	30.34	53%	65.03	13.01	4.09	3.06	6.28	VAV + GSHP (COP 3.2 & 4.0)	18%	15%	28.5
	Crawford	23.78	63%	65.06	13.01	1.67	0.84	5.71	VAV + GSHP (COP 4.5 & 6.0)	15%	12%	
	Carnes	28.21	56%	65.40	13.08	3.33	2.03	5.54	VAV + GSHP (COP 3.2 & 4.0)	19%	16%	
10	Finch											28.5
	Hummingbird											
	Jeffers	32.20	54%	71.20	14.24	6.43	3.18	4.82	no data	16%	14%	
11	Slavin	32.51	50%	65.33	13.07	5.89	2.82	6.27	VAV + All Elect (COP 4.0 & 4.0)	43%	37%	28.5
	Yen	34.35	48%	66.26	13.25	4.87	3.23	7.19	VAV + All Elect (COP 3.2 & 4.0)	43%	39%	
	Fernandez	27.30	60%	69.41	13.88	3.13	1.04	5.69	VAV + All Elect (COP 3.2 & 4.0)	31%	28%	
12	Hutton	33.17	47%	63.75	12.75	2.92	4.01	8.19	PK unit+GF Boiler (COP3.2&4.0)	13%	12%	28.5
	Klempa	32.61	47%	62.16	12.43	5.06	5.66	6.06	VAV + All Elect (COP 3.2 & 4.0)	54%	51%	
	Nemec	29.83	52%	62.51	12.50	3.28	4.87	3.02	VAV+Ch+GF Boiler (COP3.2&4.0)	70%	31%	
13	Ryan	27.92	57%	65.68	13.14	2.98	2.10	5.40	VAV + GSHP (COP 4.5 & 6.0)	37%	35%	28.5
	Thompson	31.92	52%	67.13	13.43	5.13	3.30	5.65	VAV + GSHP (COP 3.2 & 4.0)	16%	14%	
	Mayorga	29.61	54%	65.48	13.10	3.51	3.52	5.64	VAV + All Elect (COP 3.2 & 4.0)	32%	29%	
14	Coppick [mob]	30.27	62%	81.20	16.24	4.95	2.20	5.83	VAV + GSHP (COP 4.5 & 6.0)	26%	24%	28.5
	Minimum	23.78	29%	61.78	12.36	1.67	0.84	3.02		7%	6%	
	Average	31.89	51%	65.67	13.13	4.46	4.24	6.04	All Electric	29%	26%	
	Maximum	46.07	63%	71.20	14.24	7.12	20.27	8.34		70%	51%	

NOTES:

* sDA is the Spatial Daylight Autonomy, which is the percentage of floor area that receives at least 30 fc illuminance for at least 50% of the occupied hours per year. For the PIVOT Community Center, annual occupied hours = 9 hours x 5 days x 52 weeks = 2,340 hours.

** ASE is the Annual Solar Exposure, which is the percentage of floor area that receives too much direct sunlight, i.e., 100 fc illuminance or more for at least 250 occupied hours per year, which may cause glare and/or increased cooling load.

- All Energy Use Index (EUI) values are site EUI (not source EUI), based on equipment loads (not space loads).

COMMENTS:

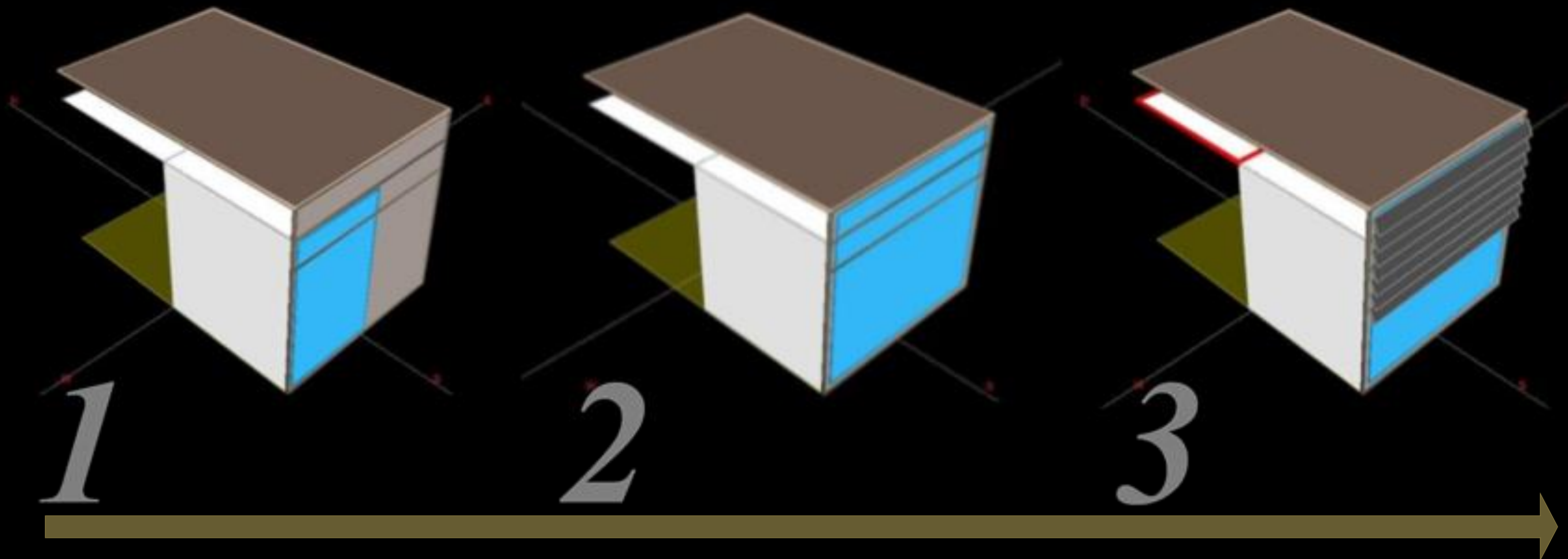
- During the design development phase (DD), unless complying with IECC 2018 code based on prescriptive values, students will need to comply with code based on energy cost: The building energy cost shall be equal to or less than 85% of the 'Standard Refernce Design' building (C401.2 Application).
  (continued) 'Standard Reference Design' is: a version of the proposed design that meets the minimum requirements of IECC 2018 code and is used to determine the maximum annual energy use requirement for compliance based on total building performance.
- Acording to IECC 2018, prescriptive values for code compliance include: minimum U-factors or maximum R-values, 30% vertical fenestration (can be increased to 40%), 3% skylight area (can be increased to 6%), glass properties, and minimum efficiencies of mechanical equipment.
- For projects 1 through 13, SD average gross area of the PIVOT Community Center is 19,992 SF

Env. Performance : Peak Cooling Reduction

Peak Cooling in the Focus Space - PIVOT @ OKC - 2020

								Most Current DD Design									30% Baseline						
								Perimeter Thermal Zone						Internal Thermal Zone			Perimeter Thermal Zone				Internal Thermal Zone		
	Student	% reduction of peak cooling in perimeter thermal zone	% glass ratio - whole building	Space Function	Space Exposure	Bay Height	Ext. Wall Assembly	Glass Ratio	External Shading	Better Glass	Skylight	Time (date & hour)	Peak in perimeter th zone	Skylight	Time (date & hour)	Peak in interior th zone	Glass Ratio	Skylight	Time (date & hour)	Peak in perimeter th zone	Skylight	Time (date & hour)	Peak in interior th zone
1	Curtsinger	6.15%	36%	M.Purpase	N	30	W.framed	50%	mesh	yes	--	Aug 15 @ 8:00	1.12	--	Aug 15 @ 8:00	0.77	30%	--	Aug 15 @ 8:00	1.19	--	Aug 15 @ 8:00	0.81
	Severson	-3.18%	42%	M.Purpase	NE	28	W.framed	91%	--	yes	--	Aug 12 @ 8:00	1.69	--	Aug 15 @ 8:00	1.04	30%	--	Aug 12 @ 8:00	1.63	--	Aug 12 @ 8:00	1.03
	Roeming	42.46%	60%	M.Purpase	NNW	30	W.framed	98%	mesh	yes	--	Aug 15 @ 8:00	1.97	--	Aug 12 @ 8:00	0.86	98%	--	Aug 12 @ 8:00	3.42	--	Aug 15 @ 8:00	1.11
2	Ramirez	46.39%		Lobby	S	12	W.framed	100%	--	--	--	Aug 27 @ 16:00	0.81	--	Aug 14 @ 16:00	0.54		--	Sept 23 @ 16:00	1.51	--	Aug 15 @ 8:00	0.74
	Strom	14.31%	28%	Lobby	S	14	W.framed	100%	--	yes	--	Aug 15 @ 8:00	0.74	--	Aug 15 @ 8:00	0.64		--	Aug 27 @ 16:00	0.86	--	Aug 15 @ 8:00	0.67
	Gee	16.46%	32%	M.Purpose	N	11	W.framed	29%	--	yes	--	Aug 15 @ 8:00	0.82	--	Aug 15 @ 8:00	0.69	30%	--	Aug 15 @ 8:00	0.99	--	Aug 15 @ 8:00	0.76
3	Bailey	-20.42%	43%	Lobby	SE	14	M.framed	90%	overhang	yes	--	Sept 5 @ 14:00	1.15	--	Aug 15 @ 8:00	0.73	30%	--	Aug 13 @ 14:00	0.95	--	Aug 15 @ 8:00	0.66
	Cornelius	13.16%	40%	Lobby	S	44	M.framed	28%	mesh	yes	--	Aug 26 @ 8:00	1.36	--	Aug 15 @ 8:00	0.82	30%	--	Aug 15 @ 8:00	1.57	--	Aug 15 @ 8:00	0.94
	Pick	26.83%	35%	M.Purpose	N	27	M.framed	27%	--	no	--	Aug 15 @ 8:00	0.61	--	Aug 15 @ 8:00	0.59	30%	--	Aug 15 @ 8:00	0.84	--	Aug 15 @ 8:00	0.70
4	Reese	-48.32%	13%	Lobby	S	13	M.framed	88%	screen	no	--	Sept 23 @ 16:00	2.11	--	Aug 14 @ 16:00	0.42	30%	--	Sept 23 @ 16:00	1.42	--	Aug 14 @ 16:00	0.42
	Snyder																						
	Garrison	4.23%	13%	T.Kitchen	E	13	M.framed	18%	--	no	--	Aug 14 @ 16:00	0.70	--	Aug 14 @ 16:00	1.32	18%	--	Aug 14 @ 16:00	0.73	--	Aug 14 @ 16:00	1.34
5	Bullard	-6.51%		M.Purpose	NW	24	M.framed	50%	canopy	no	--	Aug 12 @ 9:00	4.14	--	Aug 15 @ 8:00	1.15	30%	--	Aug 14 @ 8:00	3.89	--	Aug 15 @ 8:00	1.15
	Stephens	3.01%	35%	M.Purpose	NNE	24	M.framed	38%	s.overhang	yes	--	Aug 12 @ 12:00	1.10	--	Aug 15 @ 8:00	0.70	30%	--	Aug 12 @ 12:00	1.13	--	Aug 15 @ 8:00	0.68
6	Berndt	-45.85%	26%	M.Purpose	S	33	M.framed	100%	mesh	yes	--	Aug 15 @ 8:00	1.54	--	Aug 15 @ 8:00	0.93	30%	--	Aug 15 @ 8:00	1.06	--	Aug 15 @ 8:00	0.73
	King	-13.09%	26%	M.Purpose	N	36	M.framed	95%	mesh	yes	--	Aug 15 @ 8:00	1.19	--	Aug 15 @ 8:00	0.79	30%	--	Aug 15 @ 8:00	1.06	--	Aug 15 @ 8:00	0.73
	Reddout	34.36%	19%	Retail	N & W	15	M.framed	0%	--	--	--	Aug 15 @ 8:00	0.78	--	Aug 15 @ 8:00	0.62	30%	--	Aug 15 @ 8:00	1.20	--	Aug 15 @ 8:00	0.79
7	Loomis	6.77%	27%	Office	S	14	M.framed	29%	overhang	--	--	Aug 15 @ 8:00	1.10	--	Aug 15 @ 8:00	0.86	30%	--	Aug 27 @ 16:00	1.18	--	Aug 15 @ 8:00	0.74
	Russell	10.08%	54%	Office	S	14	M.framed	40%	overhang	yes	--	Aug 14 @ 16:00	1.15	--	Aug 14 @ 16:00	0.59	30%	--	Aug 27 @ 16:00	1.28	--	Aug 14 @ 16:00	0.59
	Soto	11.68%	30%	Office	S	14	M.framed	30%	overhang	yes	--	Aug 27 @ 16:00	0.91	--	Aug 15 @ 8:00	0.78	30%	--	Aug 15 @ 8:00	1.03	--	Aug 15 @ 8:00	0.88
8	Siddall	2.97%	30%	M.Purpose	E	22	M.framed	40%	overhang	no	--	Aug 14 @ 16:00	1.94	--	Aug 14 @ 16:00	0.87	30%	--	Aug 12 @ 12:00	2.00	--	Aug 12 @ 8:00	1.07
	Wiese	-4.72%	32%	M.Purpose	NE	24	M.framed	33%	--	no	--	Aug 14 @ 16:00	1.17	--	Aug 15 @ 8:00	0.90	30%	--	Aug 14 @ 16:00	1.11	--	Aug 12 @ 8:00	0.77
	Harbert	3.29%	35%	Office	N	14	M.framed	20%	--	yes	--	Aug 15 @ 8:00	0.61	--	Aug 15 @ 8:00	0.55	30%	--	Aug 14 @ 16:00	0.63	--	Aug 14 @ 16:00	0.49
9	Costin	-11.07%	30%	M.Purpose	N	24	W.framed	55%	overhang	yes	yes	Aug 14 @ 16:00	1.25	--	Aug 12 @ 8:00	0.92	30%	yes	Aug 14 @ 16:00	1.13	--	Aug 15 @ 8:00	0.79
	Crawford	0.42%	23%	Retail	S	12	W.framed	66%	oh+louvers	--	--	Aug 14 @ 16:00	0.99	--	Aug 14 @ 16:00	0.83	30%	--	Aug 14 @ 16:00	0.99	--	Aug 14 @ 16:00	0.83
	Carnes	28.20%	34%	Office	S	12	W.framed	12%	overhang	--	--	Aug 14 @ 16:00	0.51	--	Aug 14 @ 16:00	0.48	30%	--	Aug 14 @ 16:00	0.71	--	Aug 15 @ 8:00	0.56
10	Finch																						
	Hummingbird																						
	Jeffers	37.97%	24%	T.Kitchen	N	15	M.framed	24%	overhang	no	--	Aug 14 @ 16:00	0.82	--	Aug 15 @ 8:00	0.57	30%	--	Aug 15 @ 8:00	1.32	--	Aug 15 @ 8:00	1.07
11	Slavin	-94.35%	43%	M.Purpose	W	28	W.framed	78%	--	no	clerestory	Aug 12 @ 8:00	3.48	--	Aug 12 @ 8:00	1.18	30%	--	Aug 12 @ 8:00	1.79	--	Aug 15 @ 8:00	1.15
	Yen	-46.70%	33%	M.Purpose	E	21	W.framed	71%	--	yes	clerestory	Aug 12 @ 8:00	1.90	--	Aug 15 @ 8:00	1.13	30%	--	Aug 14 @ 16:00	1.30	--	Aug 15 @ 8:00	0.97
	Fernandez	-67.58%	28%	M.Purpose	E	20	M.framed	75%	overhang	yes	clerestory	Aug 12 @ 8:00	2.96	--	Aug 12 @ 14:00	1.46	30%	--	Aug 14 @ 16:00	1.77	--	Aug 15 @ 8:00	1.36
12	Hutton	-47.98%	52%	Lobby	W	16	M.framed	60%	overhang	yes	--	Aug 12 @ 8:00	1.29	--	Aug 15 @ 8:00	0.66	30%	--	Aug 15 @ 8:00	0.87	--	Aug 15 @ 8:00	0.73
	Klempa	25.07%	58%	Lobby	W	22	M.framed	58%	overhang	yes	--	Aug 12 @ 8:00	1.04	--	Aug 15 @ 8:00	0.83	30%	--	Aug 19 @ 8:00	1.39	--	Aug 12 @ 8:00	1.03
	Nemec	8.73%		Lobby	E	22.5	M.framed	56%	--	--	--	Aug 12 @ 8:00	1.94	--	Aug 15 @ 8:00	1.10	56%	--	Aug 12 @ 8:00	2.13	--	Aug 12 @ 8:00	1.10
13	Ryan	-65.99%	32%	Lobby	S	25	W.framed	100%	screen	--	--	Aug 26 @ 8:00	1.64	--	Aug 26 @ 8:00	0.93	30%	--	Sept 23 @ 16:00	0.99	--	Aug 15 @ 8:00	0.73
	Thompson	5.27%	22%	Lobby	S	30	M.framed	30%	--	--	--	Sept 23 @ 16:00	1.29	--	Aug 15 @ 8:00	0.81	30%	--	Sept 23 @ 16:00	1.36	--	Aug 15 @ 8:00	0.90
	Mayorga	-97.41%	38%	Lounge	S	30	W.framed	100%	mesh	yes	--	Aug 26 @ 8:00	2.99	--	Aug 15 @ 8:00	0.68	30%	--	Aug 15 @ 8:00	1.51	--	Aug 15 @ 9:00	1.00
14	Coppick [mob]	25.92%		Gallery	S	16'	M.framed	36%	screen	yes	--	Aug 15 @ 8:00	0.75	--	Aug 15 @ 8:00	0.67	30%	--	Aug 27 @ 16:00	1.01	--	Aug 15 @ 8:00	0.72
		%	%			ft		%					CFM/SF			CFM/SF	%			CFM/SF			CFM/SF

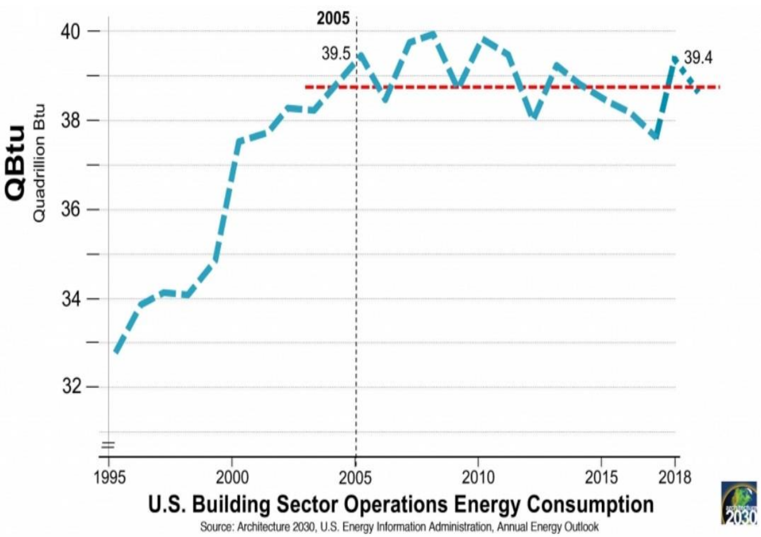
Performance Optimization



	Standard Reference Design	*+ glass + aluminum frame*	*+ external shading*
Energy Use Intensity (EUI) – source energy:			
	133.7 kBtu/sf.yr	*111.6 kBtu/sf.yr*	*108.6 kBtu/sf.yr*
	Baseline	*16.5% energy saving*	*18.8% energy saving*
Cost Comparison:		*+$164.67/sf*	*+ $239.67/sf*
Return on Investment:		*base for comparison*	*- 3.57%*
Global Warming Potential/sf:		*24.98 kg CO_2 eq*	*156.30 kg CO_2 eq*

Life Cycle Analysis
Operational Carbon + Embodied Carbon

Operational energy outlook:



Source: Architecture 2030, accessed January 2020.

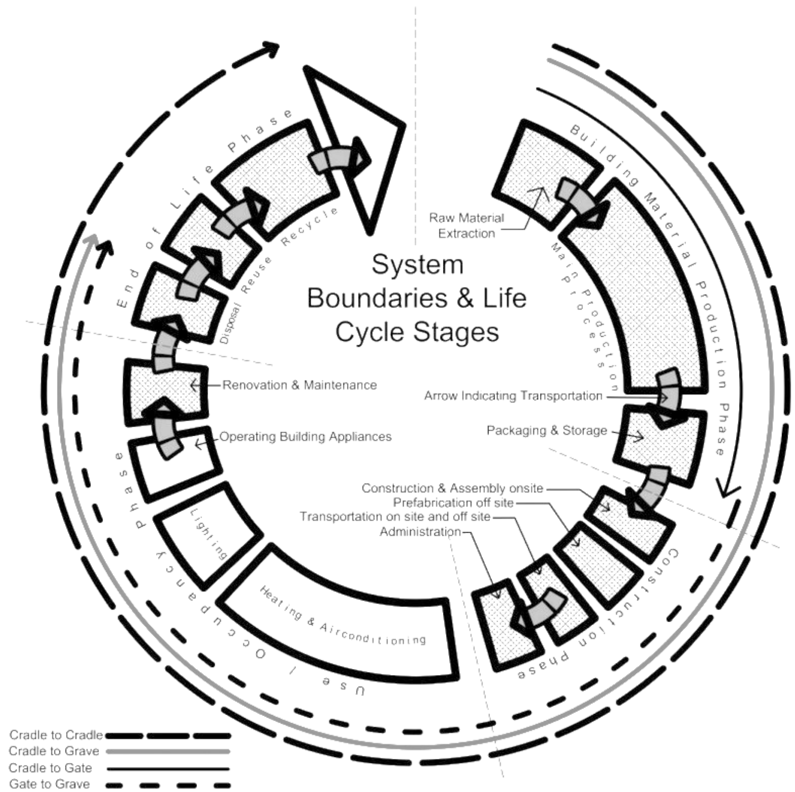


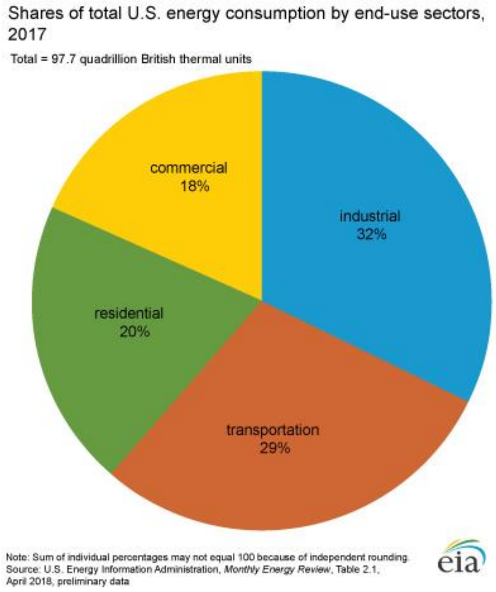
Fig. 3. System boundaries and life cycle stages of a building.

Source: Dixit, M. (2017). Life cycle embodied energy analysis of residential buildings: A review of literature to investigate energy parameters. Renewable and Sustainable Energy Reviews, 79, pp.390-413.

A New Paradigm

Performance as a design goal:

1. *Energy Performance*
2. *Structural Performance*
3. *Cost Performance*



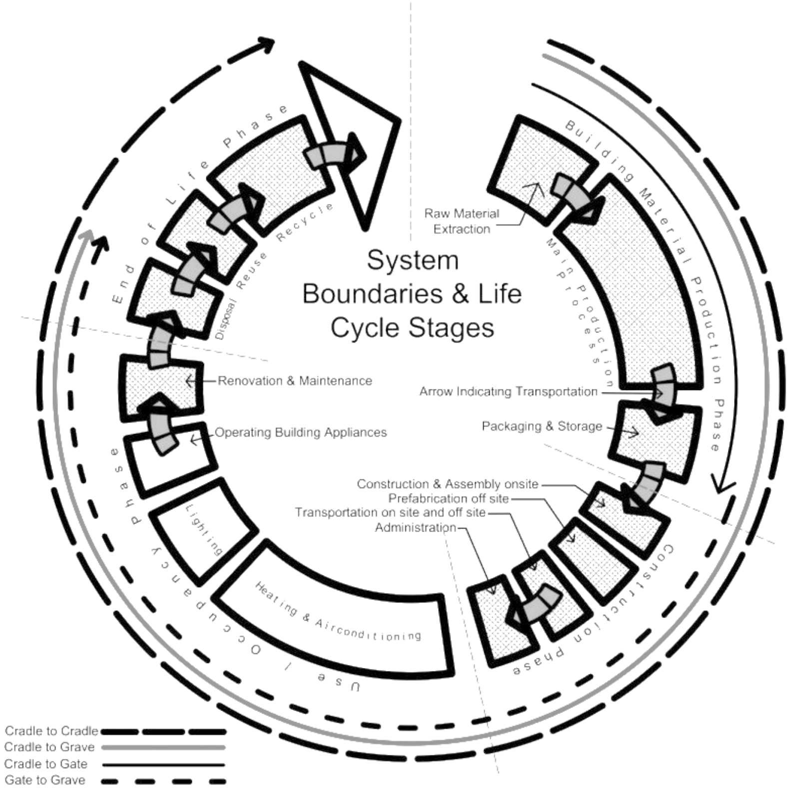


Fig. 3. System boundaries and life cycle stages of a building.

Source: Dixit, M. (2017). Life cycle embodied energy analysis of residential buildings: A review of literature to investigate energy parameters. Renewable and Sustainable Energy Reviews, 79, pp.390-413.

Thank You !!

Abby Brandvold, Khaled Mansy, John Phillips, Tom Spector, and Jerry Stivers,
School of Architecture, Oklahoma State University

Presenter: Khaled Mansy, khaled.mansy@okstate.edu