CAE 465/526 Building Energy Conservation Technologies

Fall 2023

November 09, 2023

Measure installation and lifecycle analysis

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PROJECT & EXAM

Project & Exam

- CAE 526 students:
  - ❑ Complete the group formation (thanks to those who have already added their names
  - ❑ It is fine to use Excel for the project
  - ❑ Do not forget about the first deadline 11/18
  - ❑ Do you need any new recordings?

Project & Exam

- IPRO students:
  - ❑ Weekly presentations
  - ❑ Did you submit the group formation to Kaplan?

PAYBACK PERIOD EXAMPLES

Payback Period Examples

- An example of short payback period in Dayton Ohio:

	AR No.	Description	Payback (yrs)
Lighting	1	Replace Metal Halide Lamps with T-8 Flourescent Fixtures	2.3
	2	Install Photosensor Controls to Utilize Daylight	0.6
Space Conditioning	3	Install Programable Thermostat in the Office	0.2
	4	Adjust the Year Round Thermostat Set Points in the Office	0.2
Compressed Air	5	Reduce Overall Pressure in Compressed Air System	0.2
	6	Reduce Leaks in Compressed Air System	1.1
	7	Eliminate use of Air Motors on Pipe Turners	1.0

	AR No.	Description	Cost-Benefit Analysis Results	Simple Payback (yrs)
Lighting	1	Replace 8' T-12 Bulbs with 8' T-8 Bulbs	1.085	3.6
	2	Install Photo Sensor Controls	0.525	2.0
Comp Air	3	Lower Air Compressor Discharge Pressure	0.093	0.3
Space Conditioning	4	Install Programmable Thermostats	0.128	0.4
	5	Increase Air Conditioning Thermostat Set Points	0.012	0.0
Other Rec.		Replace 4' T-12 Lamps with 4' T-8 Lamps	1.881	4.9

Economic analysis of energy retrofit of buildings, 2011

Payback Period Examples

- Building: Liberty Tower (Dayton, Ohio)
  - ❑ 85-year-old
  - ❑ 114,000 ft^2
- Three energy efficiency measures are:
  - ❑ Steam boiler replaced with vertical fire tube boilers
  - ❑ Replace interior and exterior with LEDs
  - ❑ Building control upgrade

https://www.forbes.com/sites/pikeresearch/2016/04/13/energy-efficient-building/#6fd887e748f8

Payback Period Examples

- Building: Liberty Tower (Dayton, Ohio)
  - ❑ LEDs consume 60% less energy
  - ❑ Add controls to dim or turn off the lights
  - ❑ LED lights fail in a different way, so control may be an important factor in the light selection

https://www.forbes.com/sites/pikeresearch/2016/04/13/energy-efficient-building/#6fd887e748f8

Payback Period Examples

- Building: Liberty Tower (Dayton, Ohio)
  - ❑ Total cost: $870,000
  - ❑ Annual utility cost savings $99,000
  - ❑ Payback period:

$$Payback = \frac{870{,}000}{99{,}000} = 8.8\ years$$

  - ❑ The project has received $70,000 in utility rebates, making the economic case more practical

$$Payback = \frac{(870{,}000 - 70{,}000)}{99{,}000} = 7.8\ years$$

https://www.forbes.com/sites/pikeresearch/2016/04/13/energy-efficient-building/#6fd887e748f8

Payback Period Examples

- Long payback period for building envelopes:
  - ❑ It is hard to do a building envelope retrofit since owners only 60% of the commercial floorspaces
  - ❑ They do not have a good payback period
  - ❑ Usually there are different motivations to conduct a building envelope retrofit

https://www.forbes.com/sites/pikeresearch/2016/04/13/energy-efficient-building/#6fd887e748f8

Payback Period Examples

EEM	Cost / Unit	Cost	Source
Occupancy Sensors	$1.06/ft^2$	$ 44,991	RSMeans, "5 fixtures per 1000 S.F., including occupancy and time switching"
Condensing Boiler	$20,706 + $13.82/MBH	$ 31,401	RSMeans, commercial gas boilers
Light Power Density Reduction	$4.78/ft^2$	$ 202,886	RSMeans, "Fluorescent high-bay 4 lamp fixture, 1W/sf,59FC, 4 fixtures per 1000 S.F."
Condensing Unit Replacement	$7,909 + $766/ton	$ 132,687	RSMeans, packaged air-cooled refrigerant compressor and condensor
Window Film	$18.93/ft^2$ glazing	$ 182,311	RSMeans, "Solar Films on Glass" average of min/max value
Wall Insulation	$4.78/ft^2$ wall area	$ 927,930	RSMeans, "4 in. EPS insulation, Commercial renovation Exterior Insulation and Finish System",

Payback Period Examples

Energy Efficiency Measures	Simple Payback
Condensing Boiler	9.4
Occupancy Sensors	10.4
Light Power Density Reduction	32.4
Condensing Unit Replacement	41.2
Window Film	70.7
Wall Insulation	247.0

Dahlhausen, M. PSU 2014

AERG EXAMPLE (K-12)

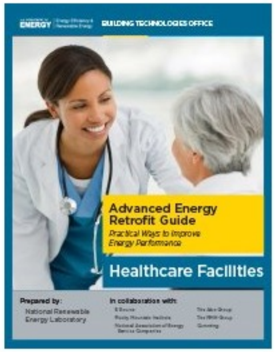
AERG Example

Advanced Energy Retrofit Guides

Buildings

Buildings » Commercial Buildings » Design & Decision Support Guides » Advanced Energy Retrofit Guides

The Advanced Energy Retrofit Guides (AERGs) were created to help decision makers plan, design, and implement energy improvement projects in their facilities. With energy managers in mind, they present practical guidance for kick-starting the process and maintaining momentum throughout the project life cycle. These guides are primarily reference documents, allowing energy managers to consult the particular sections that address the most pertinent topics. Useful resources are also cited throughout the guides for further information. Each AERG is tailored specifically to the needs of a specific building type, with an emphasis on the most effective retro-commissioning and retrofit measures identified by experts familiar with those unique opportunities and challenges. The guides present a broad range of proven practices that can help energy managers take specific actions at any stage of the retrofit process, resulting in energy savings for many years to come.



The Advanced Energy Retrofit Guides (AERGs) help building owners and managers as well as design and construction professionals plan, design, and implement energy-efficiency upgrades in commercial buildings.

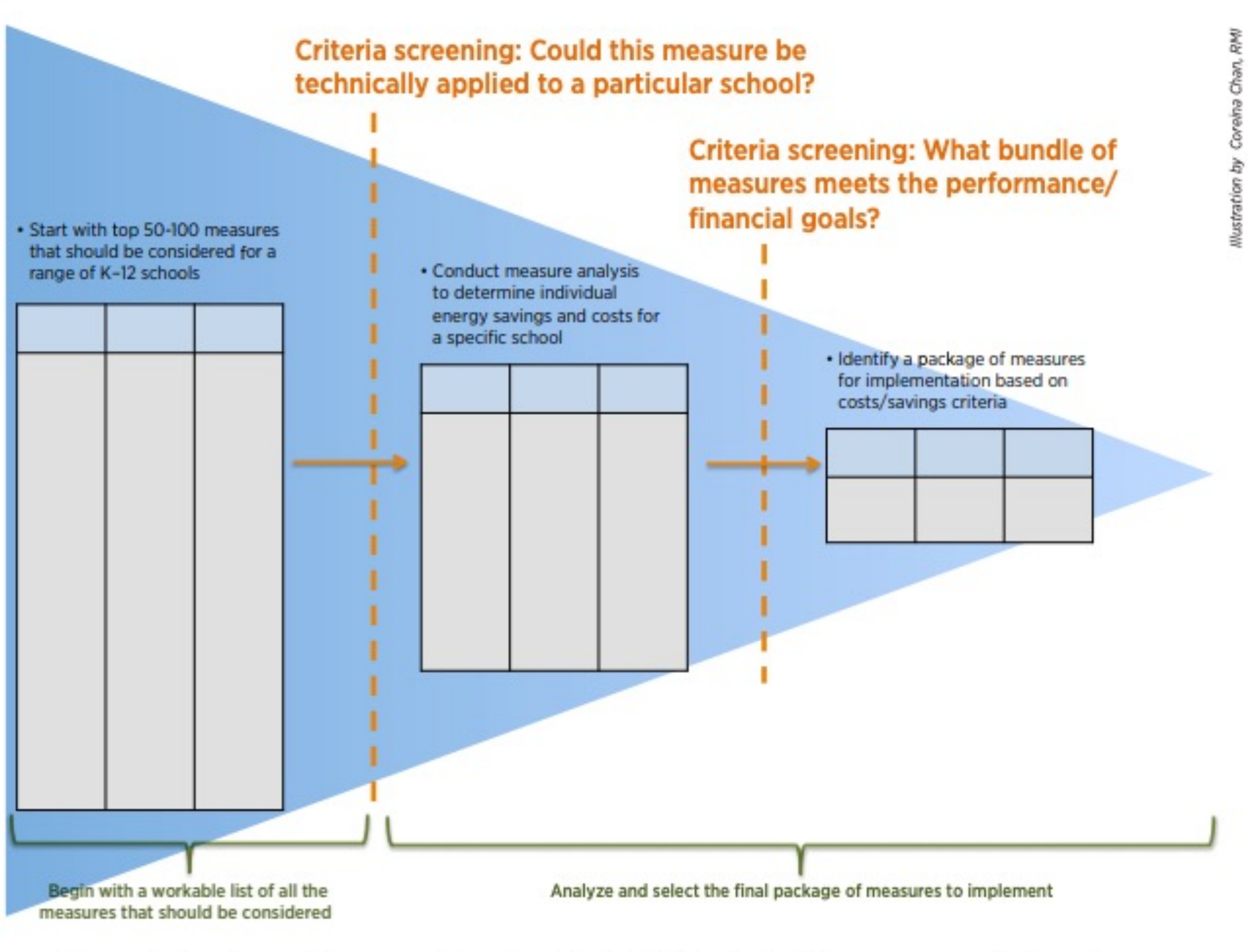
https://www.energy.gov/eere/buildings/advanced-energy-retrofit-guides#:~:text=The%20Advanced%20Energy%20Retrofit%20Guides,throughout%20the%20project%20life%20cycle.

AERG Example

	Energy Manager	Custodial Staff	School Board or Financial Manager	Teachers and Students	Community and Parents	Utilities and Auditors
1 Introduction	●	●	●	●	●	●
2 Overview: Plan, Execute, Follow Up	●		●			
3 Existing Building Commissioning	●	●		●		●
4 Building Retrofits	●		●			●
5 Measurement and Verification	●	●				
6 Operations and Maintenance	●	●				
7 Conclusion	●	●	●	●	●	●

https://buildingdata.energy.gov/cbrd/resource/17

AERG Example



https://buildingdata.energy.gov/cbrd/resource/17

AERG Example

Case Study 1: Vigo County School Corporation

Quick Facts

- Facility Name: Vigo County School Corporation
- Facility Type: K-12 Schools
- Location: Terre Haute, Indiana
- Number of Buildings: 29

Photo from NAESCO

Project Description

The Vigo County School Corporation (VCSC) in Terre Haute, Indiana, and under the leadership of Superintendent Daniel Tanoos, partnered with Energy Systems Group to develop and implement comprehensive energy savings performance contracts. VCSC is made up of 3 high schools, 2 alternative schools, 6 middle schools, and 18 elementary schools.

In 1999, VCSC decided to take control over rising operating costs with an assessment of its utility costs, which at the time averaged \$0.845/ft^2. This was compared to other Indiana school facilities that had installed energy retrofits resulting in energy costs as low as \$0.65/ft^2. Of the 19 VCSC schools surveyed, 9 were operating at more than \$0.90/ft^2.

In 2000, VCSC and Energy Systems Group entered into an initial agreement to provide energy-related upgrades at 20 of its facilities. This initial project resulted in a guaranteed cost reduction of more than \$1 million per year over the term of the agreement. To date, Energy Systems Group has met its savings guarantee.

VCSC has implemented more than \$29 million in comprehensive energy improvements and renovation projects in six phases which are estimated to save close to \$35 million over the terms of the contracts.

Environmental Benefits

1. *Removes emissions equivalent to more than 5,200 passenger vehicles per year.*
2. *Creates enough electricity to provide power for more than 3,800 homes per year.*
3. *Planting more than 6,500 acres of forests annually.*

https://buildingdata.energy.gov/cbrd/resource/17

AERG Example

Key EEMs:

- Comprehensive HVAC improvements and replacements
- Lighting systems redesigns and retrofits
- First school in Indiana to be 100% retrofitted with light-emitting diodes (LEDs)
- Electrical system upgrades
- District-wide EMS
- Window replacements
- Hot water pump replacements
- 1.5-kW wind turbine with curriculum for science students
- High school pool improvements.

Installation Costs	M&V Costs	Total Cost Without Incentives	Financial Incentives	Actual Project Costs
$29,922,466	$75,477	$29,977,943	$60,000	$29,862,466

Energy $ Savings	O&M $ Savings	Capital Cost Avoidance	Total Annual $ Savings
$592,321/year	$1,395,838/year	$1,206,457/year	$3,194,616

Energy Cost Intensity Pre-Retrofit	Energy Cost Intensity Post-Retrofit	Energy Cost Intensity ASHRAE 90.1-2004	Simple Payback (years) (Excluding Incentives)
$0.84/ft^2	$0.70/ft^2	$1.40/ft^2	9.3 (9.4)

https://buildingdata.energy.gov/cbrd/resource/17

AERG Example

System	EEM Description	Applicable to:				
		Hot-Humid	Hot Dry	Marine	Cold	Very Cold
Lighting	Replace incandescent lamps in exit signs with LEDs	✓	✓	✓	✓	✓
	Replace T12 fluorescent lamps and magnetic ballasts with high- efficiency T8 lamps and instant-start electronic ballasts	✓	✓	✓	✓	✓
	Replace incandescent lamps with compact fluorescent lamps (CFLs)	✓	✓	✓	✓	✓
	Install wireless motion sensors for lighting in rooms that are used intermittently	✓	✓	✓	✓	✓
	Install photosensors and dimming ballasts to dim lights when daylighting is sufficient	✓	✓	✓	✓	✓
	Replace high intensity discharge (HID) lights with T5 high- output (HO) fluorescents in gymnasiums	✓	✓	✓	✓	✓
	Install more efficient exterior lighting for façades and parking lot	✓	✓	✓	✓	✓
Plug and process loads	Replace cafeteria appliances with ENERGY STAR models	✓	✓	✓	✓	✓
	Install VSD demand control for kitchen hood exhaust fans	✓	✓	✓	✓	✓

https://buildingdata.energy.gov/cbrd/resource/17

AERG Example

System	EEM Description	Applicable to: Hot-Humid	Hot Dry	Marine	Cold	Very Cold
Envelope	Add reflective roof covering	✓	✓		✓	
Service water heating	Install low-flow showerheads in locker rooms	✓	✓	✓	✓	✓
HVAC Heating and cooling	Add evaporative precooling of condenser supply air		✓			
	Add a small condensing boiler to handle the base load and summer load, with current inefficient boiler operating when heating loads are highest	✓	✓	✓	✓	✓
	Install VSDs on chilled-water and hot water pumps	✓	✓	✓	✓	✓
	Replace standard furnace with a high-efficiency condensing furnace	✓	✓	✓	✓	✓
	Install an EMS and replace pneumatic controls with direct digital controls (DDCs)	✓	✓	✓	✓	✓
	Replace oversized, inefficient fans and motors with rightsized National Electric Manufacturers Association (NEMA) premium efficiency models	✓	✓	✓	✓	✓
	Convert CV or dual-duct air handling system to variable air volume (VAV) (add dampers, VSD fan motors)	✓	✓	✓	✓	✓
	Install VSDs on cooling tower fans	✓	✓	✓	✓	✓
HVAC Ventilation	Install a dry-bulb airside economizer	✓	✓	✓	✓	✓
	Upgrade to DCV to reduce OA flow during partial occupancy	✓	✓	✓	✓	✓
	Add heat/energy recovery to the ventilation system	✓	✓	✓	✓	✓

https://buildingdata.energy.gov/cbrd/resource/17

AERG Example

Table E-2 Recommended Temperature Setbacks and Setups for U.S. Climate Zones

Climate Zone	Massive Building		Metal Building	
	Heating Setback (°F)	Cooling Setup (°F)	Heating Setback (°F)	Cooling Setup (°F)
1A	4.3	10.4	4.1	7.7
2A	9.4	13.9	10.1	11.2
3A	9.4	13.1	13.3	12.9
4A	19.4	16.4	20.7	15.3
5A	18	10.8	22.1	13.5
6A	20.5	10.4	23.9	12.7
2B	9.7	20.5	8.6	15.5
3B	7.9	14.2	12.1	13.5
4B	20.7	16.5	21.9	15.8
5B	19.4	10.6	22.1	12.1
6B	19.4	10.3	22.3	12.1
7	20.7	8.8	6.3	11.5
8	22.3	5	23	7.9

https://buildingdata.energy.gov/cbrd/resource/17

CLASS ACTIVITY

Class Activity

- Download the K-12 or office building AEDG

https://www.ashrae.org/technical-resources/aedgs

Class Activity

- Summarize and compare the lighting recommendations

  - https://docs.google.com/spreadsheets/d/1eUYbP00uv7EYI3cB5poRmNHMOfJb292LX-gPelbX1Yo/edit#gid=1106944457

INTRODUCTION TO LIFE-CYCLE ASSESSMENT (LCA)

Intro to LCA

- Life-cycle analysis is ***defined*** as "*a methodology to evaluate the* environmental effects *associated with any given industrial activity from the initial gathering of raw materials from the earth until the point at which all residuals are returned to the earth*"

Environmental Solutions, 2005

Intro to LCA

- LCA is known as:
  - ❑ Life-cycle assessment
  - ❑ Cradle-to-grave analysis

Intro to LCA

- LCA usually has four phases of:
  - ❑ Goal and scope
  - ❑ Inventory analyses
  - ❑ Impact assessments
  - ❑ Interpretation

Intro to LCA

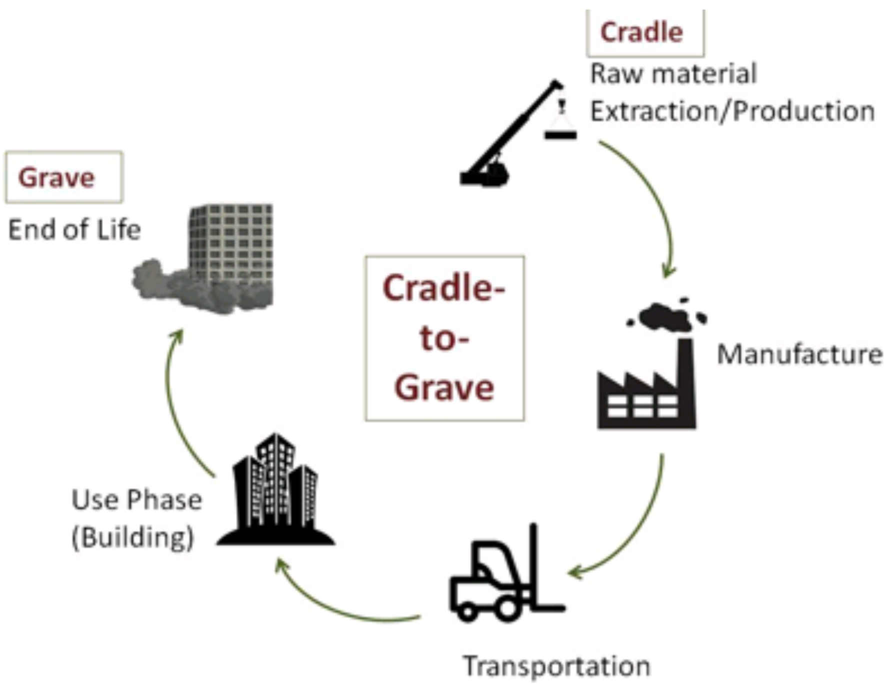
- The detailed description of the phases are:
  - ❑ Goal and scope definitions to identify purposes, audiences, and system boundaries
  - ❑ Inventory analyses known as LCI requires data collection and calculations to quantify materials and energy inputs and outputs of a building systems
  - ❑ Impact assessments phase evaluates the significance of potential impacts based on the LCI
  - ❑ Interpretation phase to evaluate findings and establish final conclusions and recommendations

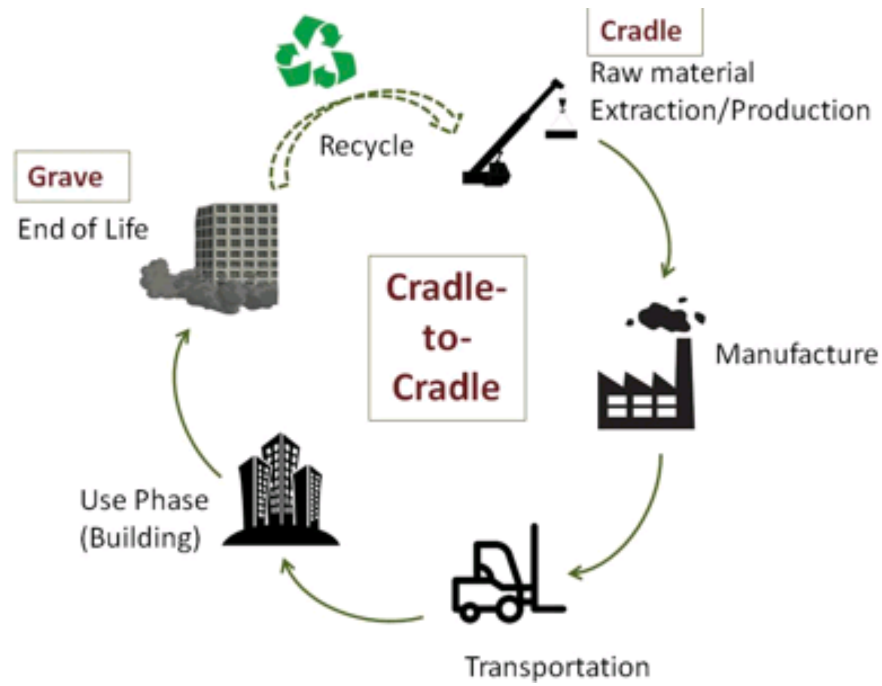
Intro to LCA

- In the context of buildings first the system boundaries need to be defined

- Typical comprehensive building life-cycle assessment covers:
  - ❑ Material manufacture
  - ❑ Transportation
  - ❑ Construction
  - ❑ Operation
  - ❑ Maintenance
  - ❑ Demolition

LCA Phases





http://www.archecology.com/2017/05/31/life-cycle-assessment/

BUILDING LIFE-CYCLE COST ANALYSIS (LCCA)

Building Life-Cycle Cost Analysis

- Similar to the building projects, there are different phases of in the calculation of LCCA:
  - ❑ Capital "initial" cost
  - ❑ Transportation cost
  - ❑ Fuel cost
  - ❑ Operational cost
  - ❑ Maintenance and repair cost
  - ❑ Demolition "resale or salvage" cost
  - ❑ Finance cost
  - ❑ Non-monetary cost (e.g., rebates, taxes)

One time

Recurring

One time

Recurring

Depends

Building Life-Cycle Cost Analysis

- What's the purpose of LCCA?

"Select viable alternatives that may have high initial costs but low operational and maintenance costs"

- Examples are:
  - ❑ Glazing
  - ❑ Efficient HVAC systems

Building Life-Cycle Cost Analysis

- What are the examples of alternatives:
  - ❑ Different types of systems and components
  - ❑ Various efficiency
  - ❑ The choice of repair or replacement
  - ❑ Consideration of all alternatives

Building Life-Cycle Cost Analysis

- Why do we use LCCA?
  - ❑ Requirements of federal and states or private sectors
  - ❑ Evaluation of alternatives suggested by the ASHRAE Energy Codes
  - ❑ Beneficial for the calculation of Return of Investment (ROI)

Building Life-Cycle Cost Analysis Tools

- Early stage design construction costs should follow supported industry formats:
  - ❑ UNIFORMAT II (ASTM) mostly in the US and Canada
  - ❑ Levels 1 and 2 NRM1 (RICS) mostly in the UK

NISTIR 6389

NIST U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology

UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis

Robert P. Charette
Harold E. Marshall

https://arc-solutions.org/wp-content/uploads/2012/03/Charette-Marshall-1999-UNIFORMAT-II-Elemental-Classification....pdf

Capital Cost

- Capital costs for HVAC equipment more difficult than other mass-produced items. Special considerations:
  - ❑ Various size of equipment
  - ❑ Optimal design and cost

Capital Cost

- Capital cost is calculated as:

$$C = C_{ref}\left(\frac{S}{S_{ref}}\right)^m$$

- ❑ C: the cost at size S
- ❑ C_{ref}: the cost at a reference size S_{ref}
- ❑ m: the exponent varies between 0.5 – 1 (~0.6 recommended)
- ❑ This software is a good resource:
  http://www.hcbcentral.com/hcb/hcb.htm

Capital Cost

- It is important to consider the concept of “unit operations”, meaning to group certain portions of a project.

- The components of unit operations are “unit assemblies” are itemized, priced, and plotted by size of unit operation. For example:
  - Unit Operation = Boiler
  - Unit Assemblies = Burner, air intake, flue, shut of valves, piping, fuel supply, expansion tank, water make up valves, deaerator

Fuel Cost

- Consider energy rates for
  - ❑ Electricity
  - ❑ Natural gas
  - ❑ Steam
  - ❑ Chilled water

Fuel Cost

- Type of rates for electricity
  - ❑ Flat rates
  - ❑ Tiered
  - ❑ Demand response
  - ❑ Time of Use (TOU)

Maintenance and Life Cost

- Examples of maintenance and operational costs:
  - ❑ Labor (e.g., technician to see the HVAC system)
  - ❑ Services
  - ❑ Supplies (e.g., air filter replacement)
  - ❑ Repair (e.g., repairs beyond warranty)

Maintenance and Life Cost

- Different sources are:
  - Building Owners, and Managers Association International (BOMA): https://www.boma.org/
  - RSMeans: https://www.rsmeans.com/
  - National Institute of Buildings Sciences: https://www.wbdg.org/design-objectives/cost-effective/utilize-cost-value-engineering
  - Open BIM Cost Estimator: http://open-bim-cost-estimator.en.cype.com/open_bim_cost_estimator_method_used.htm

Maintenance and Life Cost

	Subsystem Categories	Average Life Cycle
1a.	Roofing – Tile	80 years
1b.	Roofing – Metal, Concrete	50 years
1c.	Roofing – Membrane, Built-up, Shingle, Bitumen, Foam	20 years
2a.	Building Exteriors, Doors, and Windows (Hard)	80 years
2b.	Building Exteriors (Soft)	20 years
3.	Elevators and Conveying Systems	25 years
4.	HVAC – Equipment and Controls	20 years
5.	HVAC – Distribution Systems	40 years
6.	Electrical Equipment	30 years
7.	Plumbing Fixtures	30 years
8.	Plumbing – Rough-in	50 years
9.	Fire Protection Systems	40 years
10.	Fire Detection Systems	20 years
11.	Built-in Specialties and Equipment	25 years
12.	Interior Finishes	15 years

Maintenance and Life Cost

- Examples of life expectancies are:

Equipment Type	Median Service Life (Years)
DX air distribution equipment	>24
Chillers, centrifugal	>25
Cooling towers	>22
Gas hot water boiler, steel	>22
Pneumatic electronic controls	>7
Portable electric hot water heaters	>21

Heating and cooling of buildings book

Building Life Cycle Cost Analysis Example

ASHRAE

ASHRAE Owning and Operating Cost Database
Equipment Life/Maintenance Cost Survey
ASHRAE Research Project 1237-TRP

- **Database Main Page**
  - Project Summary
  - Preferences
- **Model Your Building**
- **Service Life Data**
  - by System Type
- **Maintenance Cost Data**
  - by All Options
  - by Region
  - by State
  - by BOMA Class
  - by Function
  - by Size
- **HVAC Equipment List**
- **Related Documentation**
- **Download Database**
- **Submit HVAC Data**

ASHRAE: Service Life and Maintenance Cost Database

The purpose of this database is to provide current information on service life and maintenance costs of typical HVAC equipment. Engineers depend on accurate owning and operating data to make decisions involving the life cycle and functionality of buildings. However, lack of sufficient up-to-date data makes it difficult to provide a solid basis for those decisions. Previous efforts to collect data through traditional survey methods have produced less than acceptable results.

See more details of goals of this project here: here

Main Features:

- **Equipment Service Life Evaluation** (here): Creates both lists and summaries of service life data customized to match specific criteria.
- **HVAC Maintenance Cost Evaluation** (here): Creates both lists and summaries of maintenance data customized to match specific criteria.
- **Submit HVAC Data** (here): The database is open for public data submissions. Registration is required.

www.ashrae.org/database

Building Life Cycle Cost Analysis Example

- ASHRAE data is collected through RP-1237:

Air Distribution Equipment	Total	Currently in Service							Replaced						
		No. of Units	Equipment Age (years)						No. of Units	Age at Removal (years)					
			Mean	Median	Std Dev	95% C.I.	Maximum	Minimum		Mean	Median	Std Dev	95% C.I.	Maximum	Minimum
Air handling unit, constant volume	209	182	22	20	10.3	1.5	43	3	27	47	52	8.0	3.0	52	26
Air handling unit, dual duct	15	5	34	34	7.4	6.5	42	22	10	27	27	0.5	0.3	27	26
Air handling unit, multizone	208	178	20	20	5.9	0.9	31	3	30	64	64	0.0	n/a	64	64
Air handling unit, variable air volume	831	819	17	18	6.2	0.4	35	0	12	18	19	2.7	1.5	20	12
Air handling unit, variable volume, variable temperature	61	61	16	17	9.0	2.2	31	1	0	n/a	n/a	n/a	n/a	n/a	n/a
Fan coil unit	2452	1252	6	5	3.8	0.2	25	3	1200	52	52	0.0	n/a	52	52
Heat pump, air-to-air	161	25	16	17	3.4	1.3	17	0	136	12	12	0.4	0.1	17	12
Heat pump, water-source	1234	1129	17	18	6.0	0.4	24	1	105	17	17	0.2	0.0	17	16
Packaged DX unit, air-cooled	32	32	12	14	5.9	2.0	24	3	0	n/a	n/a	n/a	n/a	n/a	n/a
Packaged DX unit, rooftop	164	131	11	9	6.6	1.1	22	0	33	21	20	2.8	0.9	27	14
Packaged DX unit, water-cooled	187	177	14	17	9.0	1.3	32	1	10	22	22	0.0	n/a	22	22
Split DX system	129	129	16	16	1.1	0.2	21	12	0	n/a	n/a	n/a	n/a	n/a	n/a
Total	**5683**	**4120**	**14**	**16**	**5.9**	**0.2**	**43**	**0**	**1563**	**45**	**52**	**1.1**	**0.1**	**64**	**12**
AHUs Total	**1324**	**1245**	**18**	**18**	**7.0**	**0.4**	**43**	**0**	**79**	**46**	**52**	**4.7**	**1.0**	**64**	**12**
DX Units Total	**1907**	**1623**	**16**	**18**	**6.2**	**0.3**	**32**	**0**	**284**	**15**	**17**	**1.0**	**0.1**	**27**	**12**

Building Life Cycle Cost Analysis Example

- ASHRAE data is collected through RP-1237:

Cooling Equipment	Total	Currently in Service								Replaced							
		No. of Units	Equipment Age (years)							No. of Units	Age at Removal (years)						
			Mean	Median	Std Dev	95% C.I.	Maximum	Minimum			Mean	Median	Std Dev	95% C.I.	Maximum	Minimum	
Chiller, absorption, indirect-fired, single-stage	6	6	35	35	0.0	n/a	35	35		0	n/a	n/a	n/a	n/a	n/a	n/a	
Chiller, air-cooled reciprocating	9	8	6	7	4.2	2.9	15	1		1	11	11	n/a	n/a	11	11	
Chiller, air-cooled rotary (screw)	8	8	8	5	9.4	6.5	29	2		0	n/a	n/a	n/a	n/a	n/a	n/a	
Chiller, centrifugal	234	200	15	17	7.7	1.1	35	0		34	28	27	4.3	1.4	52	7	
Chiller, water-cooled reciprocating	7	7	18	14	10.9	8.1	32	3		0	n/a	n/a	n/a	n/a	n/a	n/a	
Chiller, water-cooled rotary (screw)	7	5	9	13	5.5	4.8	13	3		2	23	23	4.8	6.6	23	23	
Total	**271**	**234**	**15**	**16**	**7.6**	**1.0**	**35**	**0**		**37**	**27**	**25**	**4.2**	**1.3**	**52**	**7**	
Centrifugal Chiller Total	**234**	**200**	**15**	**17**	**7.7**	**1.1**	**35**	**0**		**34**	**28**	**27**	**4.3**	**1.4**	**52**	**7**	

Building Life Cycle Cost Analysis Example

- ASHRAE data is collected through RP-1237:

tel:139%20109%2017%20117%2093%2016

	Total	Currently in Service							Replaced						
		No. of Units	Equipment Age (years)						No. of Units	Age at Removal (years)					
			Mean	Median	Std Dev	95% C.I.	Maximum	Minimum		Mean	Median	Std Dev	95% C.I.	Maximum	Minimum
Boiler, electric hot water	4	4	16	19	7.6	7.5	22	5	0	n/a	n/a	n/a	n/a	n/a	n/a
Boiler, cast iron	18	12	23	22	9.3	5.3	32	1	6	33	34	1.0	0.8	34	31
Boiler, steel fire-tube, forced draft, hot water	18	10	11	9	6.8	4.2	20	4	8	14	10	6.1	4.2	25	10
Boiler, steel fire-tube, forced draft, steam	10	10	34	35	8.5	5.2	43	20	0	n/a	n/a	n/a	n/a	n/a	n/a
Boiler, steel fire-tube, natural draft, hot water	12	11	14	14	4.0	2.4	21	9	1	15	15	n/a	n/a	15	15
Boiler, steel water-tube, forced draft, hot water	27	24	12	3	14.0	5.6	42	1	3	18	16	0.9	1.0	21	16
Boiler, steel water-tube, forced draft, steam	3	3	34	35	1.2	1.3	35	33	0	n/a	n/a	n/a	n/a	n/a	n/a
Boiler, steel water-tube, natural draft, hot water	47	35	13	15	11.2	3.7	37	0	12	17	17	2.9	1.6	23	11
Total	**139**	**109**	**17**	**17**	**10.2**	**1.9**	**43**	**0**	**30**	**19**	**17**	**4.7**	**1.7**	**34**	**10**
Steel Gas-Fired Boilers Total	**117**	**93**	**16**	**15**	**10.4**	**2.1**	**43**	**0**	**24**	**16**	**16**	**5.2**	**2.1**	**25**	**10**

PRESENT VALUE

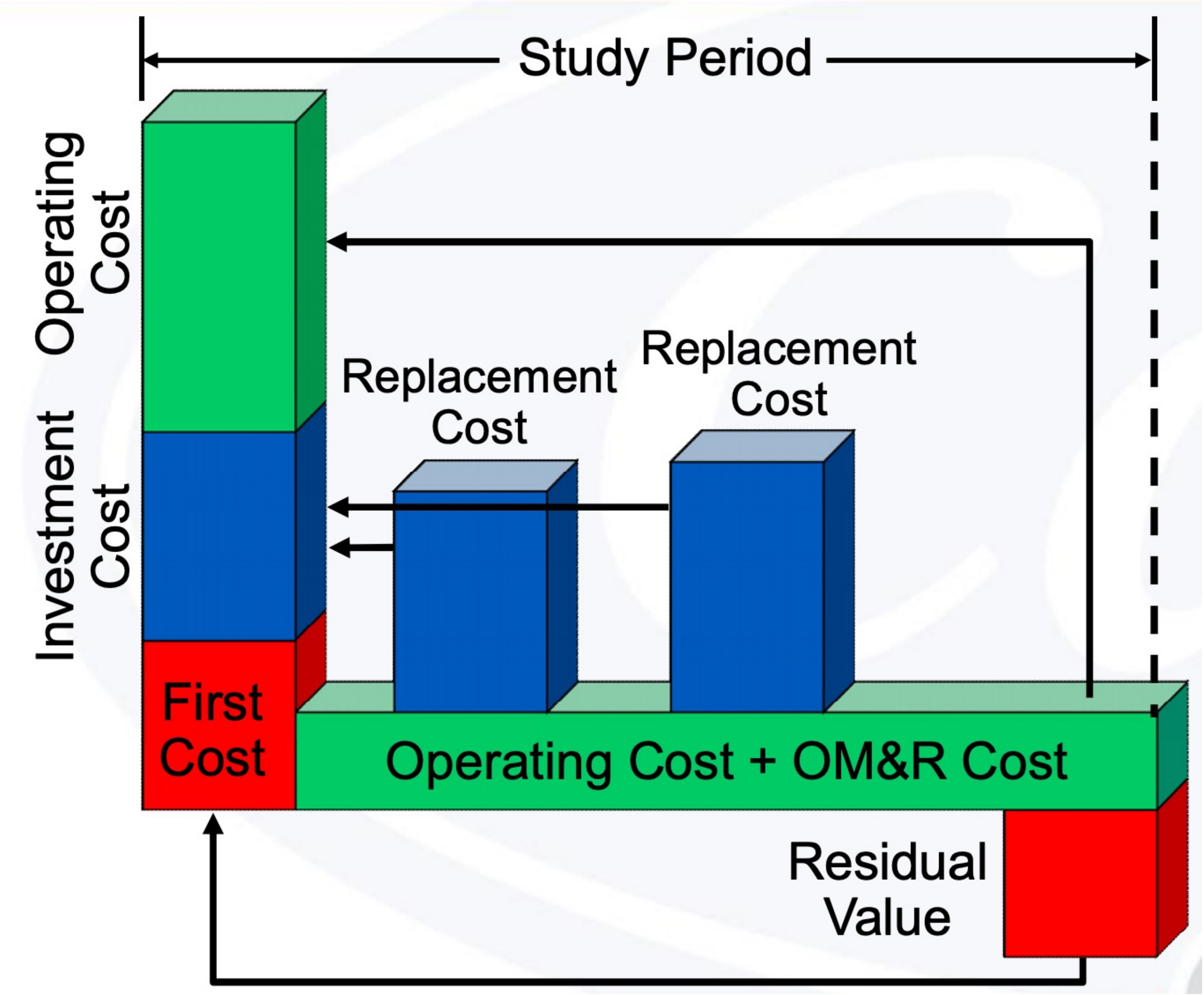
Present Value

- **Present value** (PV) or present discounted value is a future amount of money that has been discounted to reflect its current value, as if it existed today.
- The present value is always less than or equal to the future value

$$PV = \frac{C}{(1+i)^n}$$

- ❑ C: is the future amount of money that must be discounted
- ❑ n: is the number of compounding periods between the present date and the future date
- ❑ i: is the interest rate for one compounding period

Present Value



http://siglercommercial.com/wp-content/uploads/2017/12/TDP-903C_v1.0_Life-Cycle-Costing-CF.pdf

Net Present Value

- **Net present value** (NPV) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values of the individual cash flows of the same entity:

$$NPV\ (i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

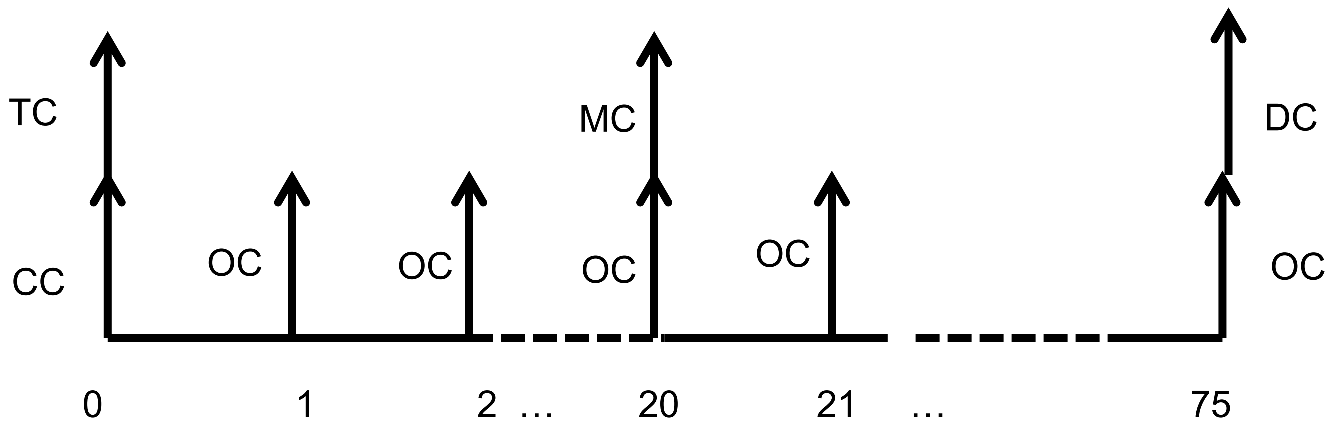
- t: The time of the cash flow
- i : The discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital
- R_t: The net cash flow i.e. cash inflow – cash outflow, at time t

Net Present Value

If...	It means...	Then...
NPV > 0	the investment would add value to the firm	the project may be accepted
NPV < 0	the investment would subtract value from the firm	the project should be rejected
NPV = 0	the investment would neither gain nor lose value for the firm	We should be indifferent in the decision whether to accept or reject the project. This project adds no monetary value. Decision should be based on other criteria, e.g., strategic positioning or other factors not explicitly included in the calculation.

Net Present Value

- Draw the cash flow:



CLASS ACTIVITY

Class Activity

- Spend 10 to 20 minutes to propose a few EEMs
  - ❑ Enclosure
  - ❑ Window
  - ❑ Lighting
  - ❑ Plug load
  - ❑ HVAC

- Complete this table:
  - ❑ https://docs.google.com/spreadsheets/d/1eUYbP00uv7EYI3cB5poRmNHMOfJb292LX-gPelbX1Yo/edit#gid=532010071

MEASURE INSTALLATIONS

Measure Installations

- Two options:
  - ❑ Parametric Analysis Tool (PAT)
  - ❑ OpenStudio Measure tab

PARAMETRIC ANALYSIS TOOL (PAT)

PAT

Back to OpenStudio®

Parametric Analysis Tool (PAT) Interface Guide

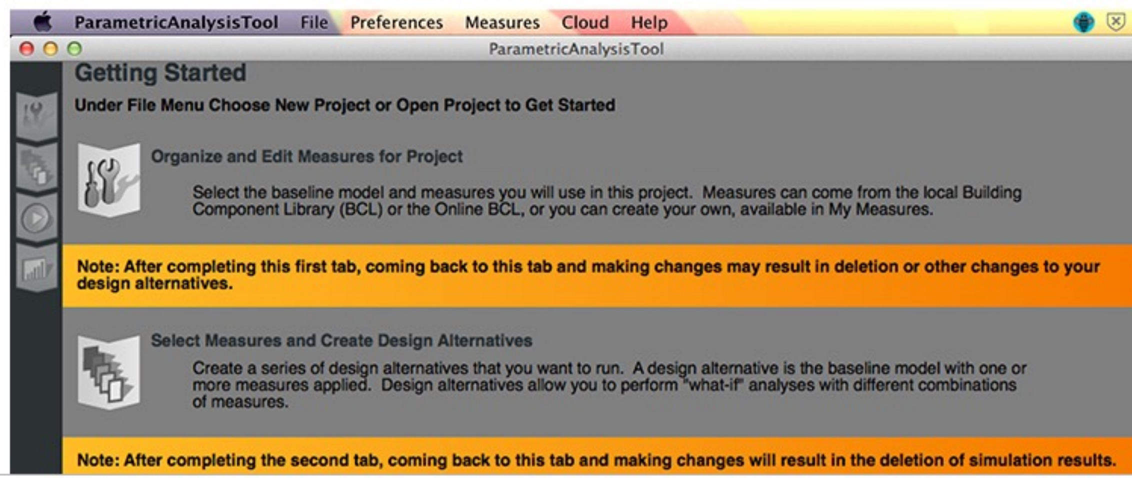
PAT removes the need to hand edit each model to try out different architectures, energy efficiency measures, and mechanical systems. PAT applies scripts to your baseline model and lets you quickly compare many alternatives. OpenStudio has developed a workflow that allows energy modelers to create and run a customized parametric analysis using commercially available cloud computing services. This workflow will enable anyone to perform powerful parametric studies in a reasonable time for a relatively low cost.

Creating a Project

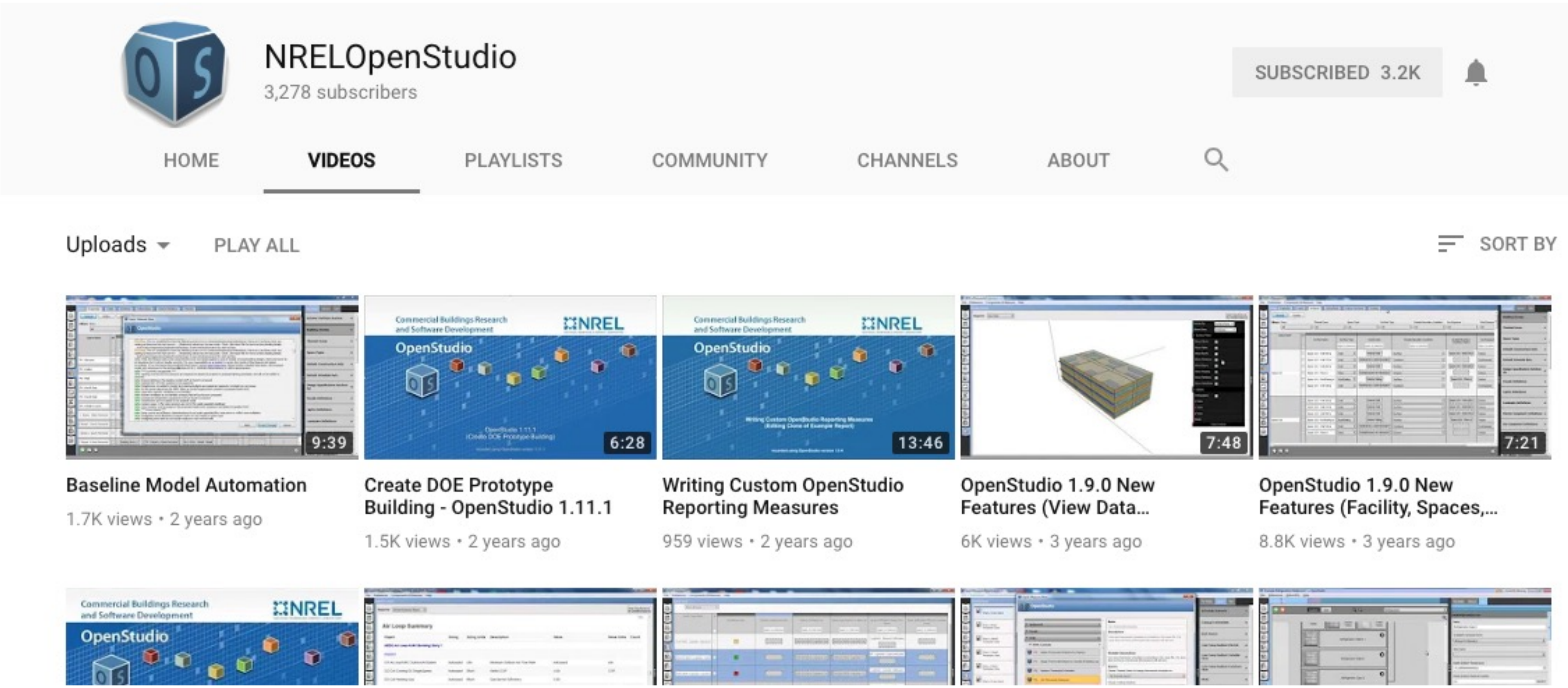
The Parametric Analysis Tool Quick Start Guide (PDF) provides an introduction to the interface and workflow for creating multiple design alternatives from a seed model.

When you first open PAT you will see the screen below. It shows the workflow:

1. Organize and edit measures for project
2. Select measures and create design alternatives
3. Run simulations
4. Create and view reports



PAT



How many of you have watched any videos related to OpenStudio?

https://www.youtube.com/user/NRELOpenStudio/videos

PAT

- Useful links:
  - https://www.youtube.com/watch?v=3rmElK_OB28
  - https://www.youtube.com/watch?v=4g5nJzDoh58
  - https://www.youtube.com/watch?v=9WgUhiJ785I
  - https://www.youtube.com/watch?v=0lINfGNe5x0

PAT

- Useful instructions:

OpenStudio® SDK User Docs | Getting Started | Reference | Help

Back to OpenStudio.net

Looking for the OpenStudio Application® Version ≥ 1.2.0 Documentation?

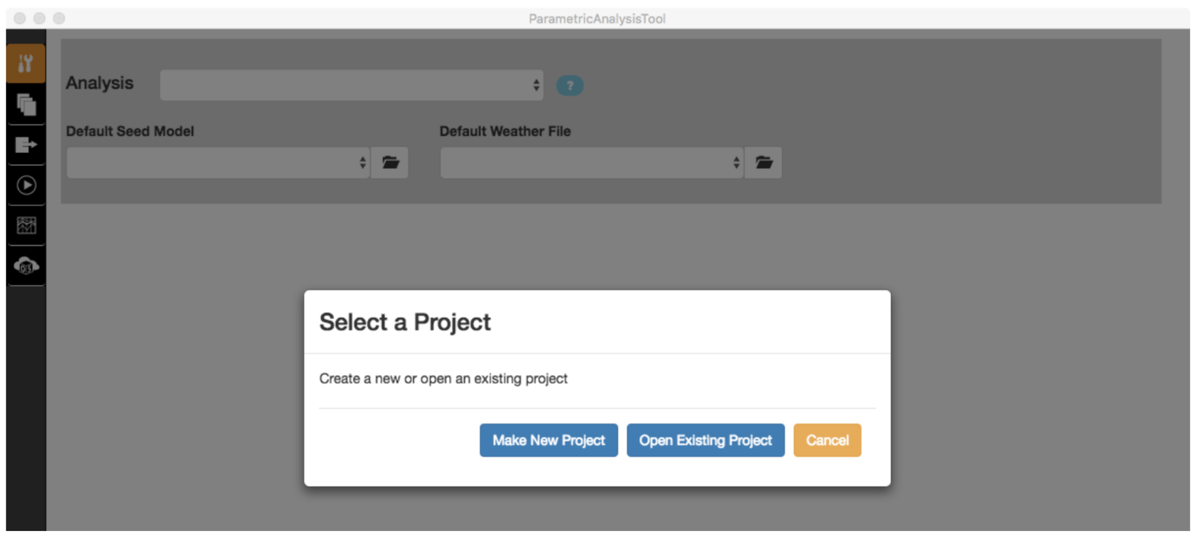
Go to the OpenStudio Application® Documentation

Parametric Analysis Tool (PAT) Interface Guide

OpenStudio's PAT allows you to quickly try out and compare manually specified combinations of measures, optimize designs, calibrate models, perform parametric sensitivity analysis, and much more. Manually specified combinations of measures may be run locally on your computer. Algorithmic analyses (e.g. optimization, design of experiments, etc) can be run by connecting to a separately provisioned instance of the OpenStudio server.

Create a Project

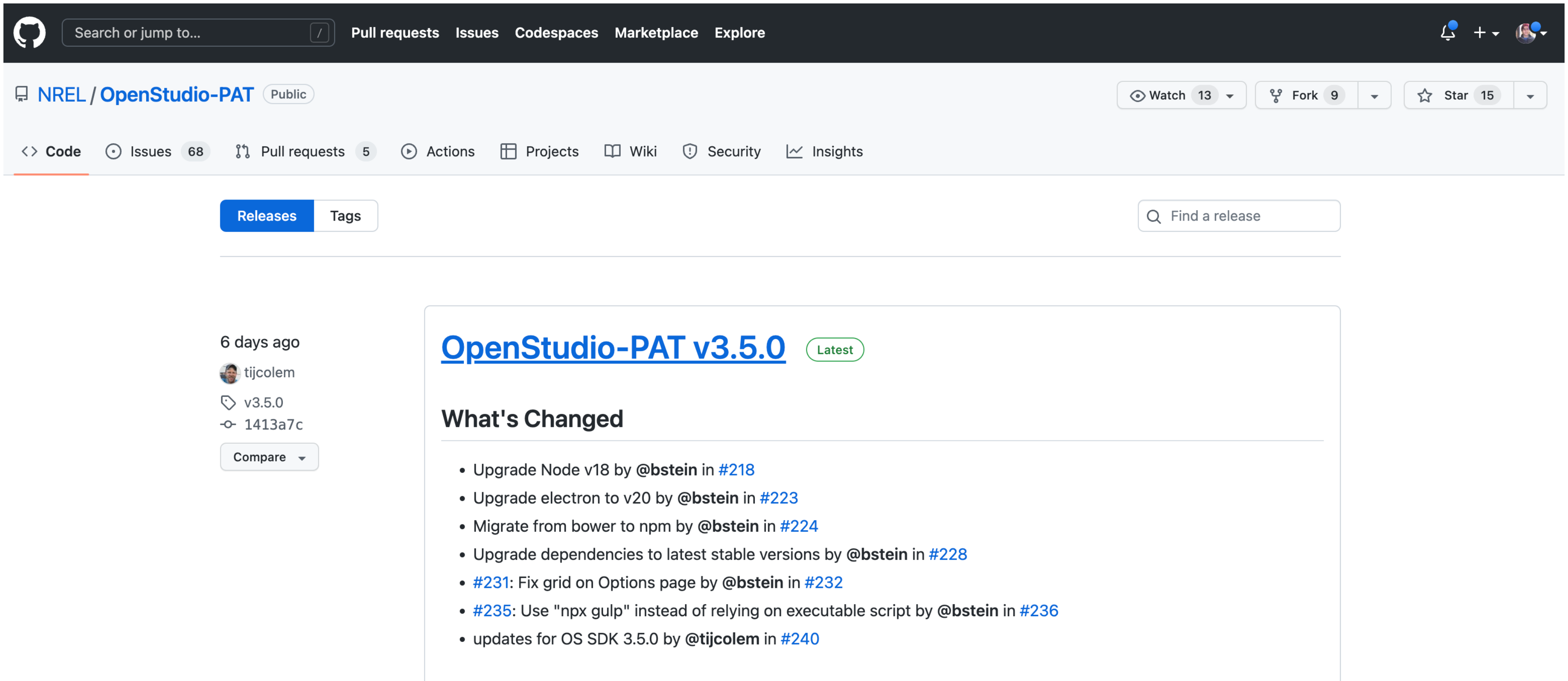
When you launch PAT you have the option to create a new project or open an existing project.



https://nrel.github.io/OpenStudio-user-documentation/reference/parametric_analysis_tool_2/

PAT

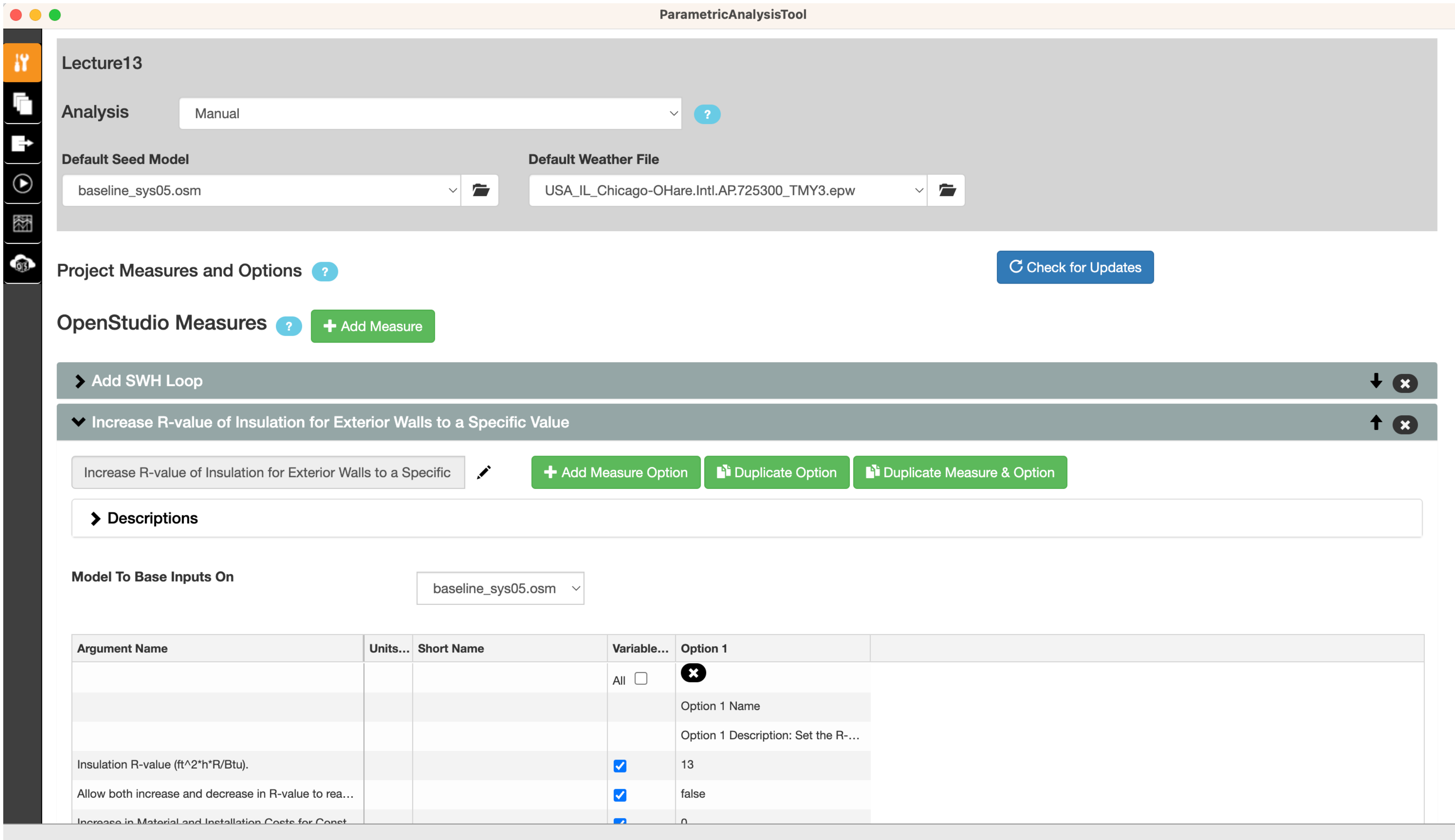
- You can download it form here:



https://github.com/NREL/OpenStudio-PAT/releases

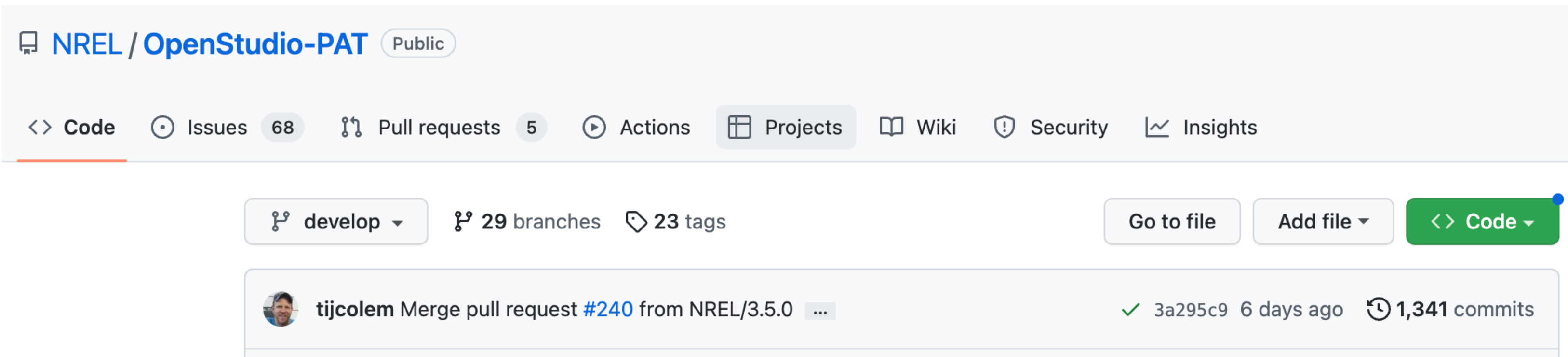
PAT

- You can define measure alternatives:

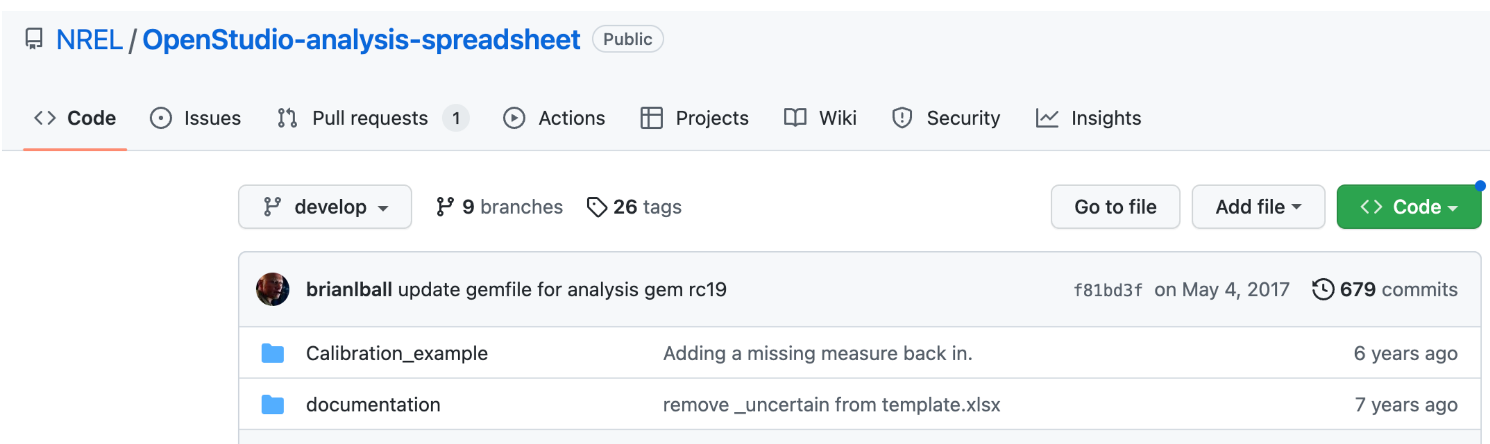


PAT

- Those who are interested in automated calibration or coding (Optional)



https://github.com/NREL/OpenStudio-PAT



https://github.com/NREL/OpenStudio-analysis-spreadsheet

OPENSTUDIO MEASURE OPTION

OpenStudio Measure Option

- You can also use the OpenStudio App