CAE 465/526 Building Energy Conservation Technologies

Fall 2022

November 16, 2022

LCCA and measure installation

Built
Environment
Research
@ IIT

Advancing energy, environmental, and sustainability research within the built environment

www.built-envi.com

Dr. Mohammad Heidarinejad, Ph.D., P.E.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
muh182@iit.edu

ANNOUNCEMENT

Announcement

BUROHAPPOLD ENGINEERING

ASHRAE Illinois Institute of Technology Student Branch

Energy Engineering and Commissioning in Buildings

SPEAKER

Energy Engineer, LEED AP

Aaron Kachler

WHEN

November 17th, 2022
12:40 pm – 1:40 pm

WHERE

John T. Rettaliata Engineering Center, RE 242

TALK ABOUT

- ✔ Work Experiences
- ✔ Energy Modeling
- ✔ Careers in Energy Engineering and Commissioning
- ✔ Tips for P.E. exam

For more information, feel free to contact ASHRAE official email ashrae_iit@iit.edu

Interested in Joining

PROJECT & EXAM

Project & Exam

- Project Part 2 submission due tonight
- Assignment 5 is posted (you can submit as your group)
- Final presentation date is finalized
- Thanks to Al for sharing his CVRMSE and NMBE code

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

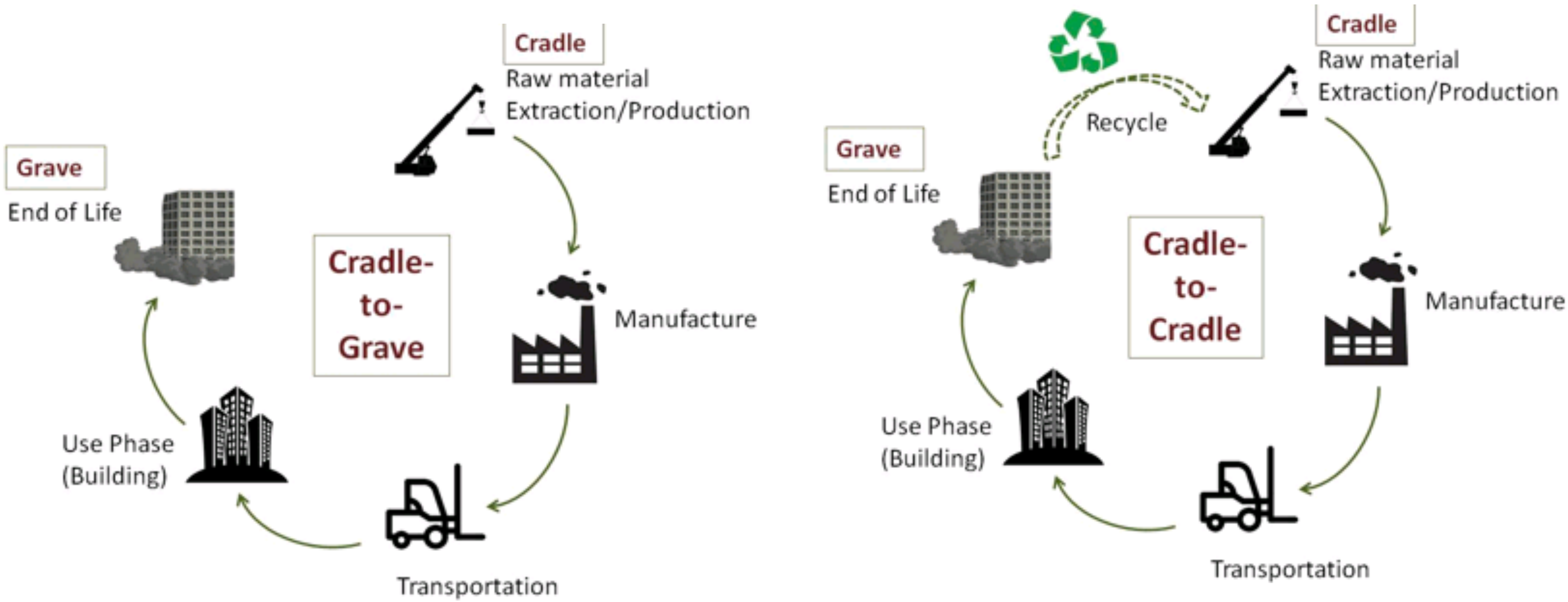
- The detailed description of the phases are:
  - Goal and scope definitions to identify purposes, audiences, and system boundaries
  - Inventory analyses known as LCI requires data collection and calculations to quantify materials and energy inputs and outputs of a building systems
  - Impact assessments 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

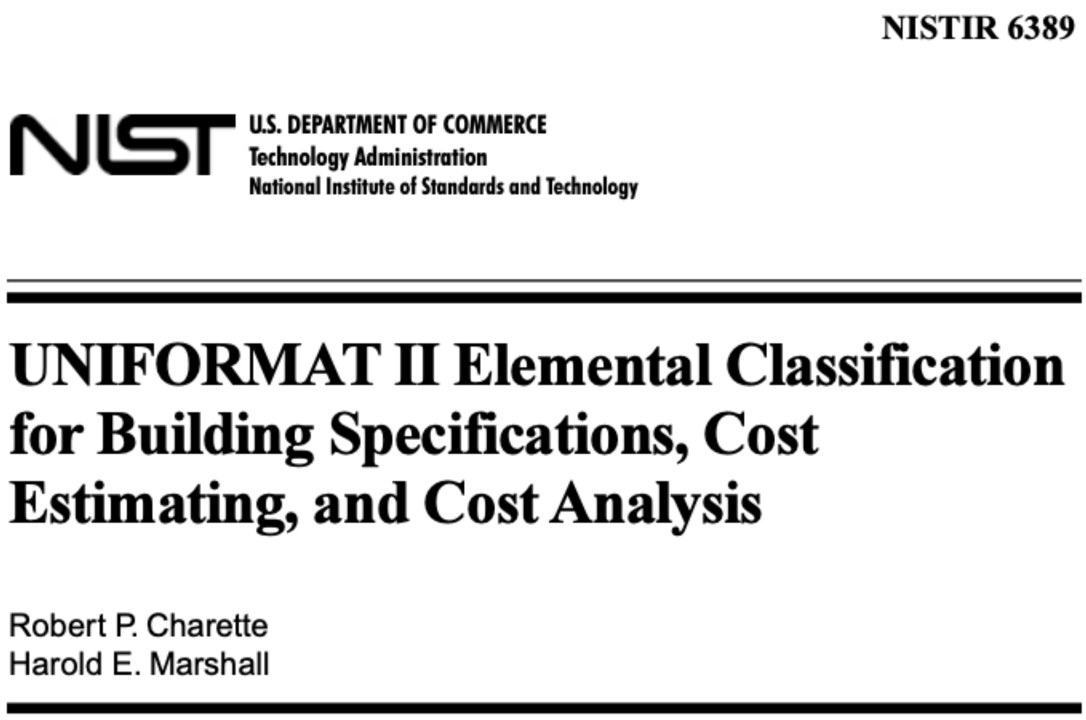
- What are the examples of alternatives:
  - ❑ Different types of systems and components
  - ❑ Various efficiency
  - ❑ The choice of repair or replacement
  - ❑ Consideration of all alternatives

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

Building Life Cycle Cost Analysis Example

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.

Disclaimer: ASHRAE has compiled this information with care, but ASHRAE has not investigated or verified, and ASHRAE expressly disclaims any duty to investigate or verify, any product, service, process, procedure, design, or the like that may be described herein. The appearance of any technical data or editorial material in this publication does not constitute endorsement, warranty, or guaranty by ASHRAE of any product, service, process, procedure, design, or the like. ASHRAE does not warrant that the information in this publication is free of errors. The data are provided "as is" without warranty of any kind. The entire risk of the use of any information in this database is assumed by the user. In no event will ASHRAE be liable to the user for any damages, including without limitation any lost profits, lost savings, or other incidental or consequential damages arising out of the use of or inability to use these data.

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

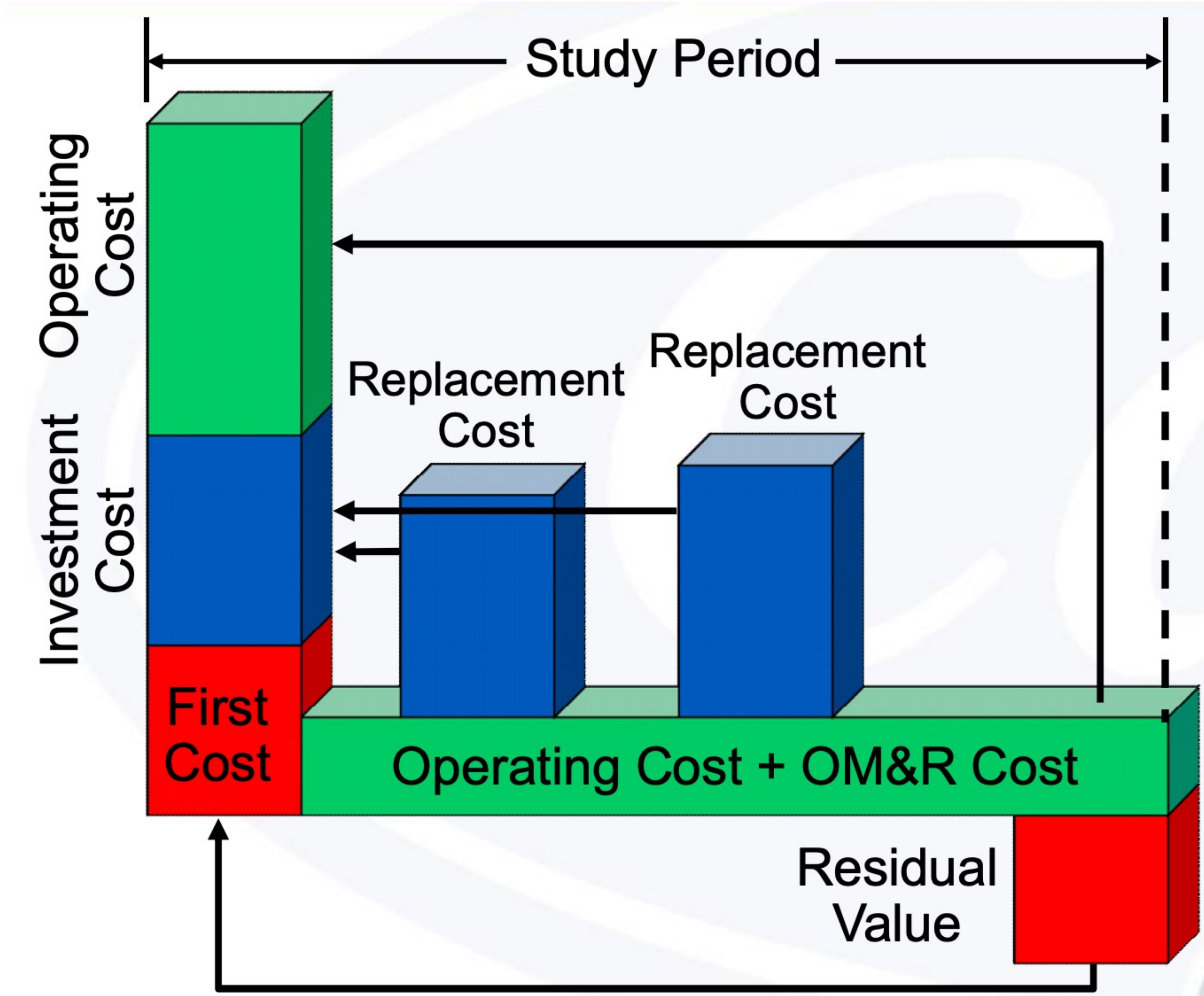
Present Value

- **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:

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

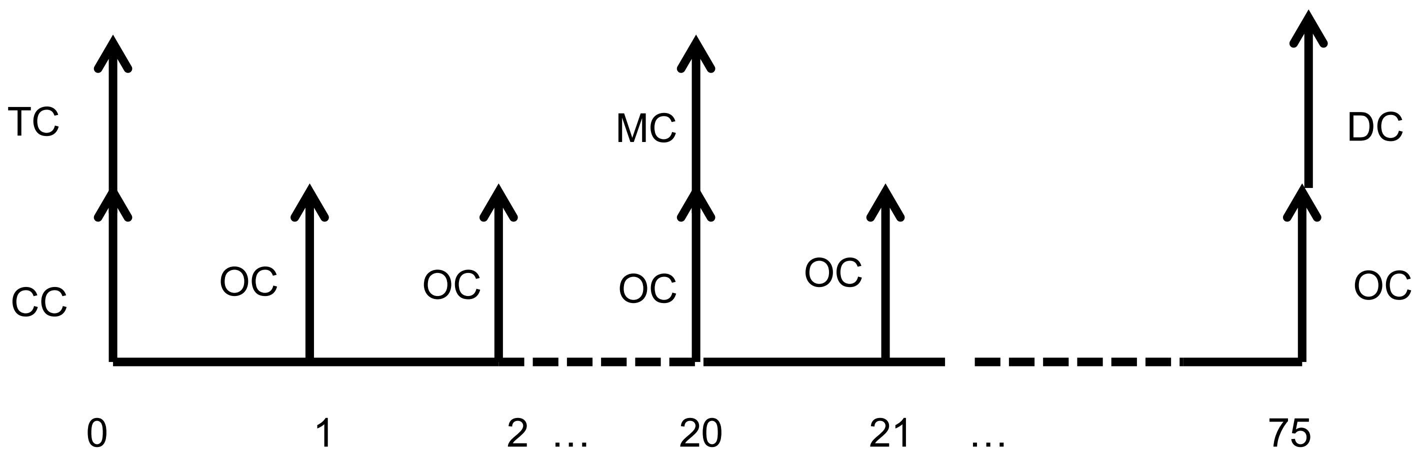
- t: The time of the cash flow
- i : The discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital
- R_t: The net cash flow i.e. cash inflow – cash outflow, at time t

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:



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

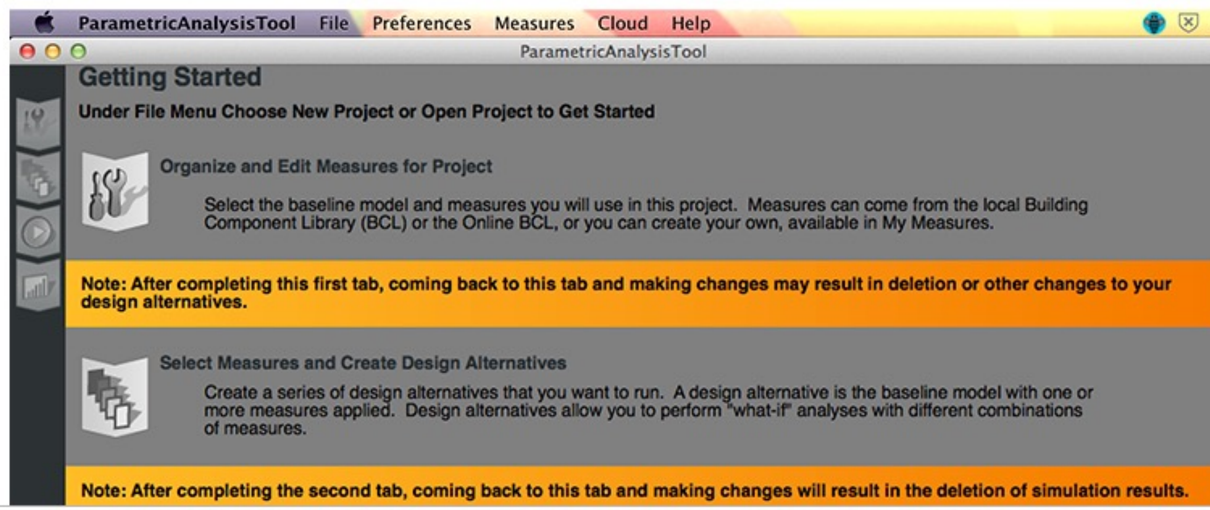
PAT removes the need to hand edit each model to try out different architectures, energy efficiency measures, and mechanical systems. PAT applies scripts to your baseline model and lets you quickly compare many alternatives. OpenStudio has developed a workflow that allows energy modelers to create and 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

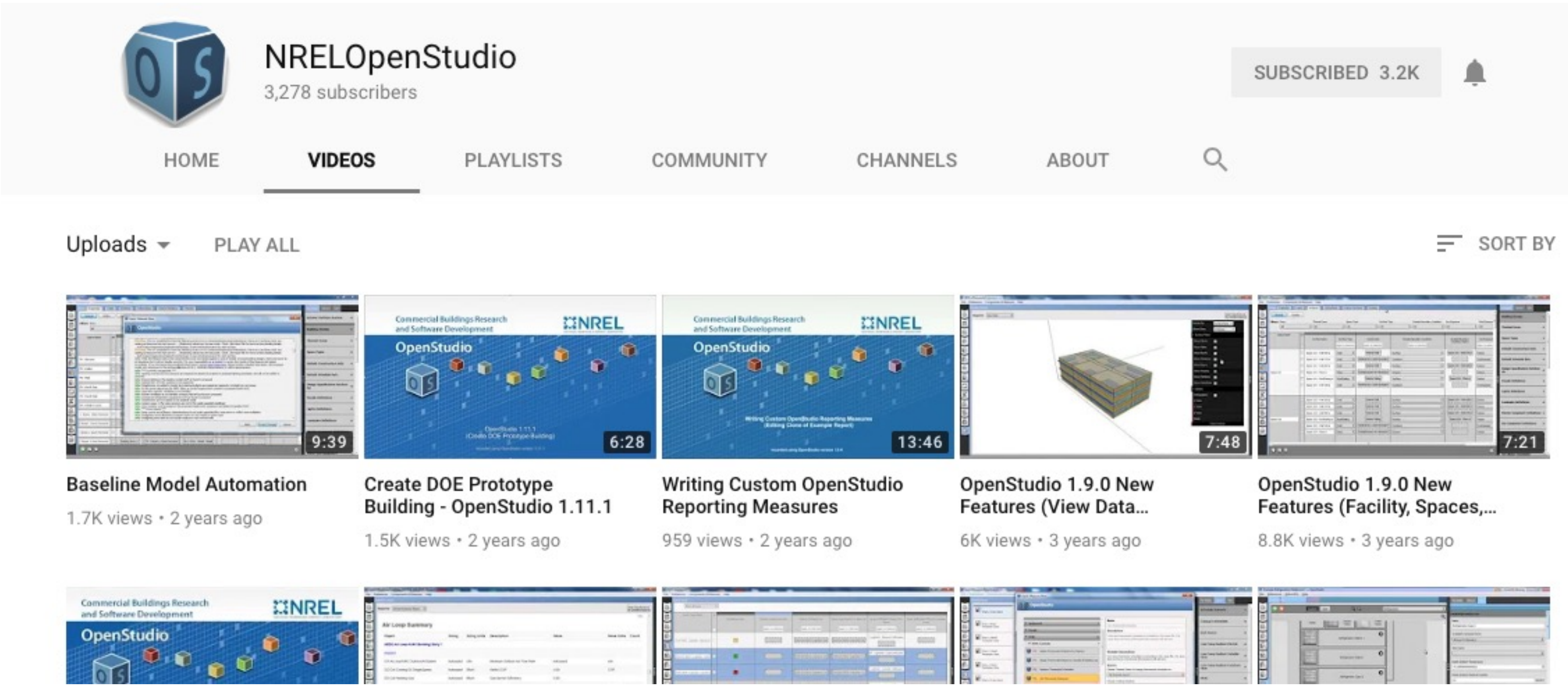
The Parametric Analysis Tool Quick Start Guide (PDF) provides an introduction to the interface and workflow for creating multiple design alternatives from a seed model.

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?

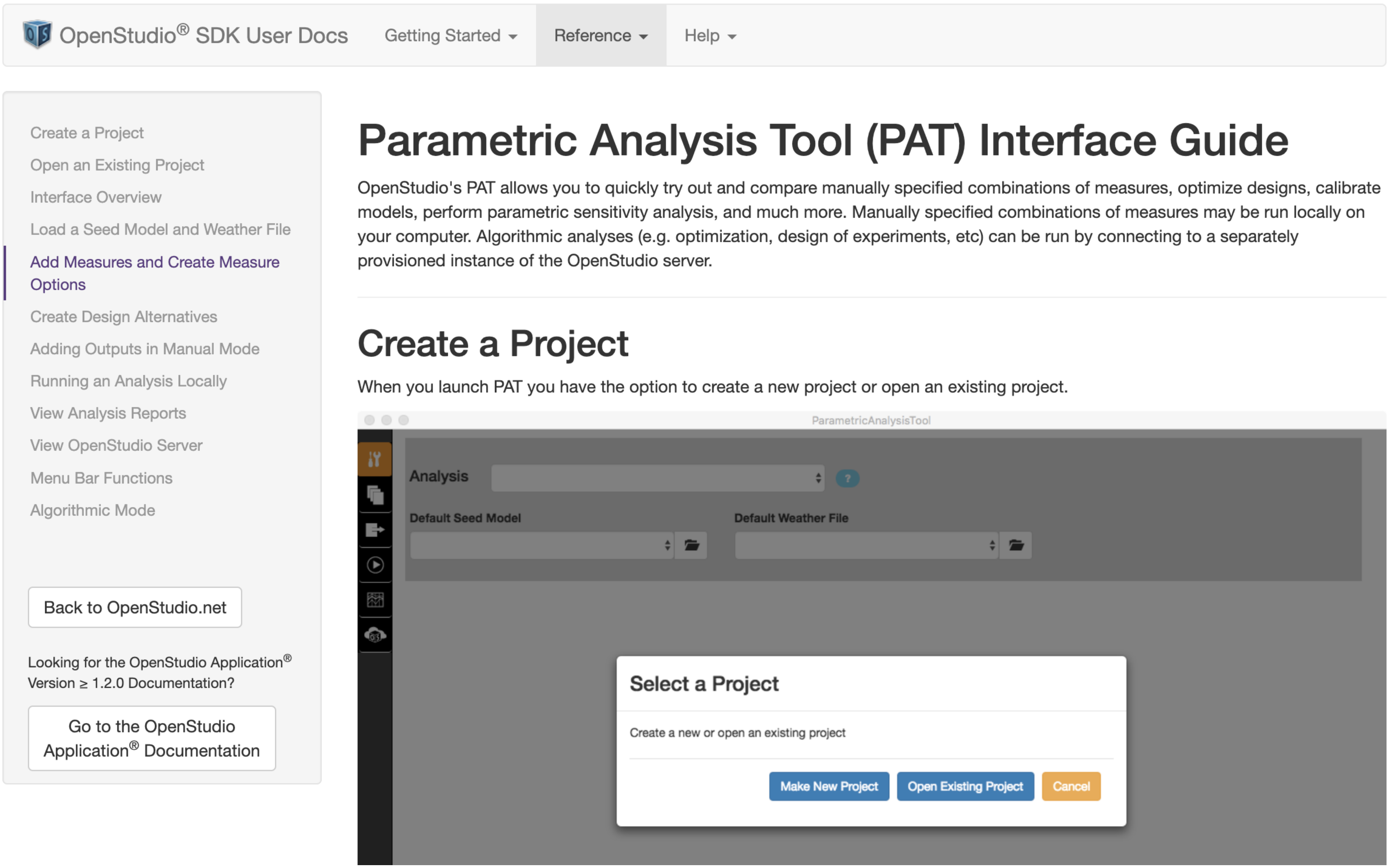
https://www.youtube.com/user/NRELOpenStudio/videos

PAT

- Useful links:
  - https://www.youtube.com/watch?v=3rmEIK_OB28
  - https://www.youtube.com/watch?v=4g5nJzDoh58
  - https://www.youtube.com/watch?v=9WgUhiJ785I
  - https://www.youtube.com/watch?v=0llNfGNe5x0

PAT

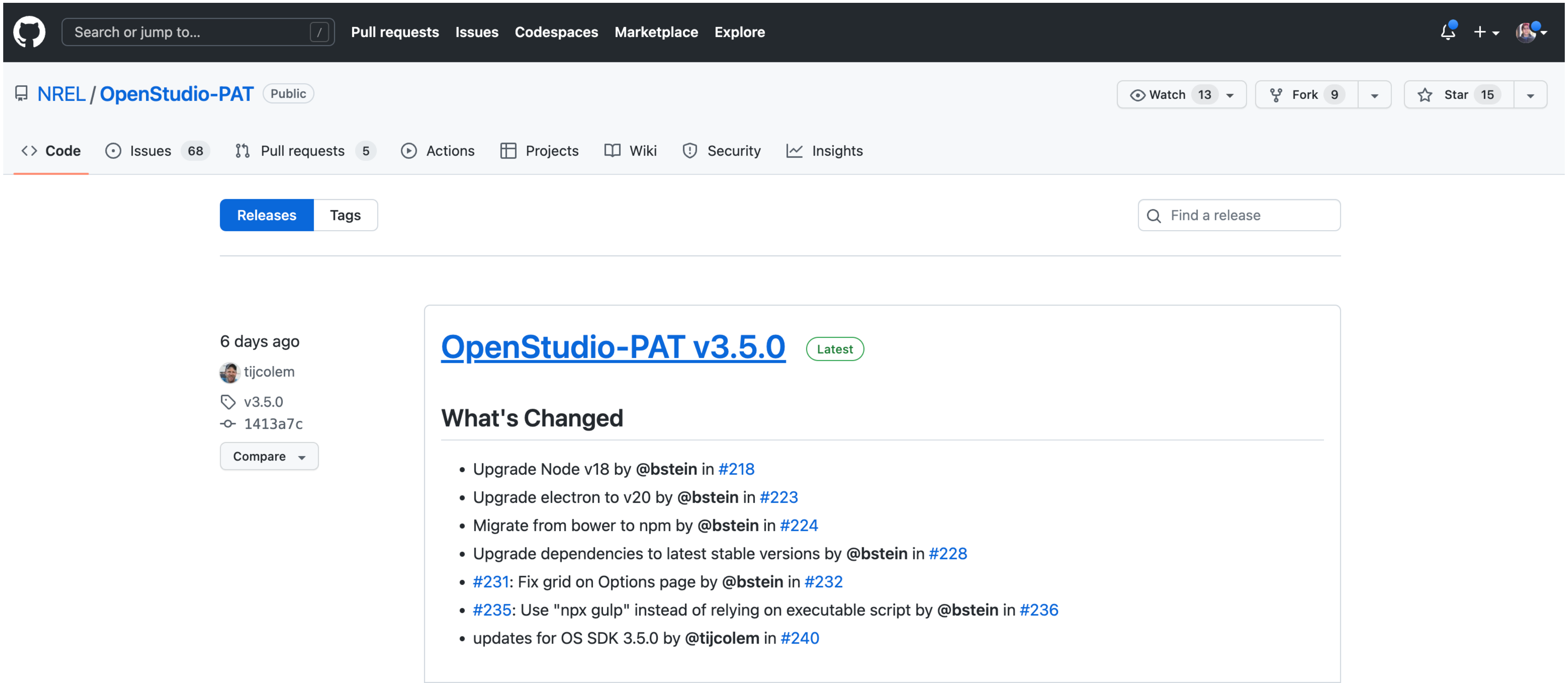
- Useful instructions:



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

PAT

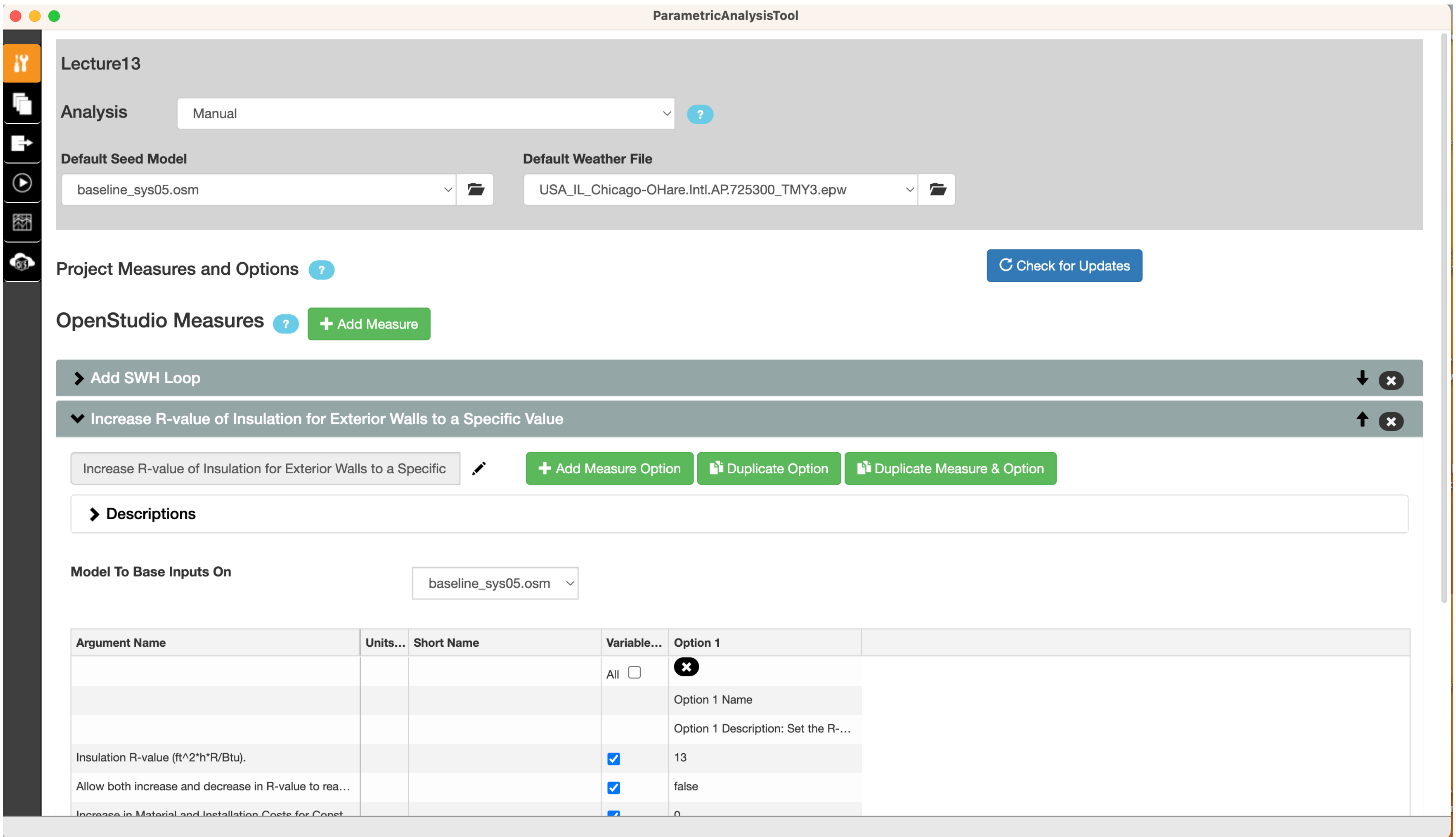
- You can download it form here:



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

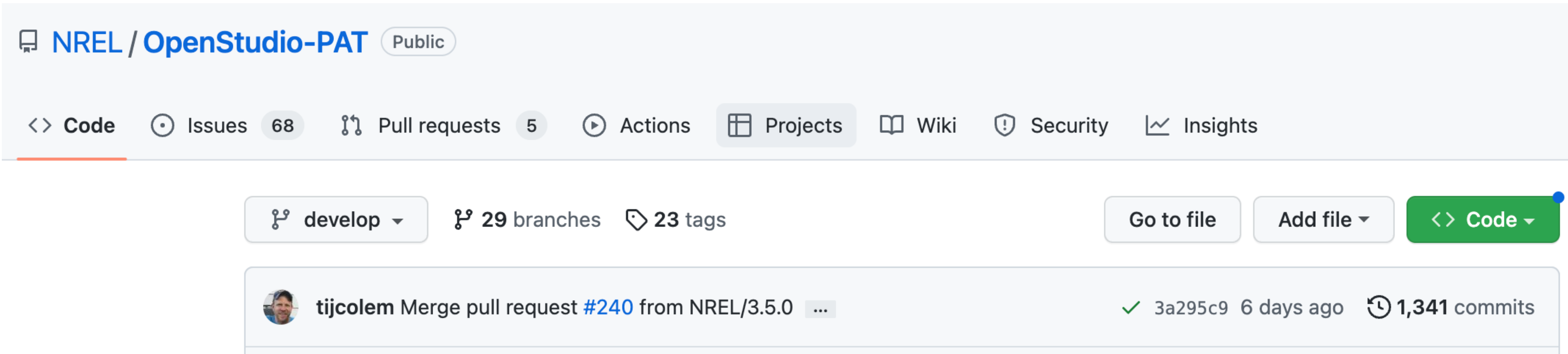
PAT

- You can define measure alternatives:

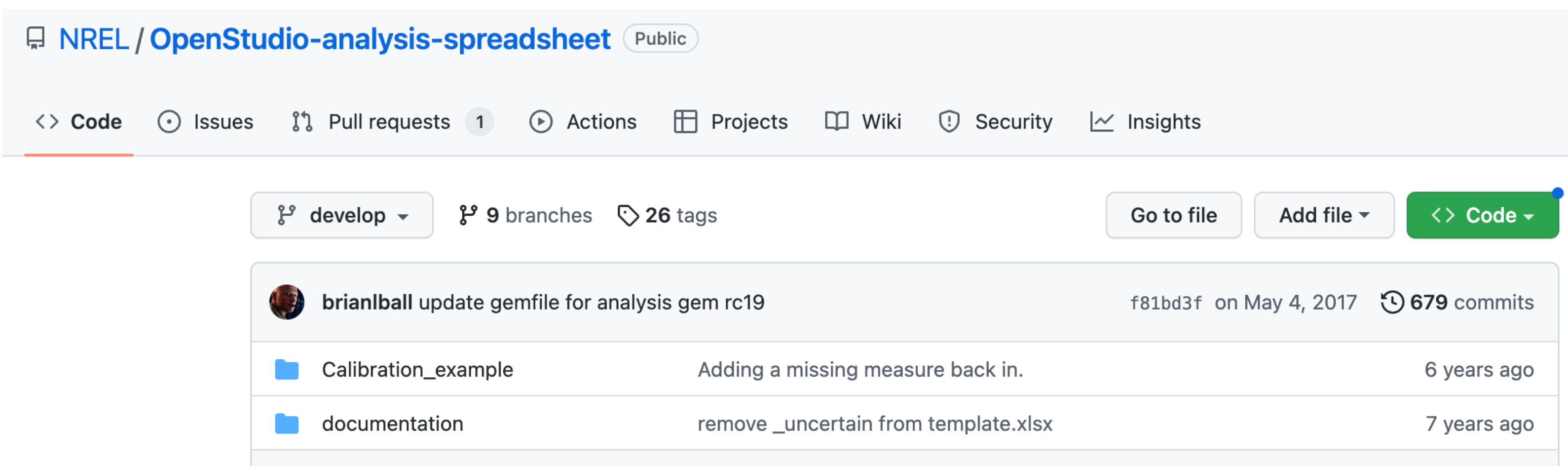


PAT

- 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