EBC

Energy in Buildings and
Communities Programme

Balancing Costs and Benefits of Building Energy Codes: An Evaluation of Methodologies for Assessing Cost-Effectiveness

28 April 2021, 13:30 - 15:30 UTC/GMT

EBC Building Energy Codes Working Group Webinar Series

Webinar Reminders

Energy in Buildings and Communities Programme

- We are recording this webinar so that we can make it available on the EBC website. Your participation indicates your consent.
- We would like everyone to mute themselves to minimize extraneous noise and disable their video.
- Please put questions in comments and we will go over as many as possible during the discussion section (see the chat function at the bottom of the screen).

Meli Stylianou
CanmetENERGY-Ottawa,
Natural Resources Canada

Webinar Overview

EBC
Energy in Buildings and Communities Programme

- Building energy codes are a leading policy instrument for improving building energy performance
- The cost effectiveness of building energy codes is a primary factor considered by adopting jurisdictions and is critical to obtaining stakeholder buy-in and for effective implementation of codes
- Approaches for demonstrating cost-effectiveness can vary considerably across a variety of criteria and economic thresholds

Agenda (Times in UTC/GMT)

Energy in Buildings and Communities Programme

13:30 **Welcome and Introduction |** *Mr. Meli Stylianou, Natural Resources Canada*

13:40 **Upgrading building codes towards zero energy: The pathway of China |** *Dr. Shicong Zhang, China Academy of Building Research*

13:55 **Discussion |** *Moderator: Mr. Meli Stylianou, Natural Resources Canada*

14:05 **Cost-optimal methodology |** *Mr. Pau Garcia Audí, European Commission*

14:20 **Automated building energy simulation and costing using the building technology assessment platform |** *Mr. Chris Kirney, Natural Resources Canada*

14:45 **Cost effectiveness analysis of energy codes in the United States |** *Michael Tillou, Pacific Northwest National Laboratory*

15:05 **Discussion and close |** *Mr. Meli Stylianou, Natural Resources Canada*

Shicong Zhang
China Academy of Building Research

中国建筑科学研究院
China Academy of Building Research

Upgrading Building Codes towards Zero Energy

The pathway of China

Prof ZHANG Shicong

China Academy of Building Research

1. Building Energy Codes Upgrading (1986-2016)

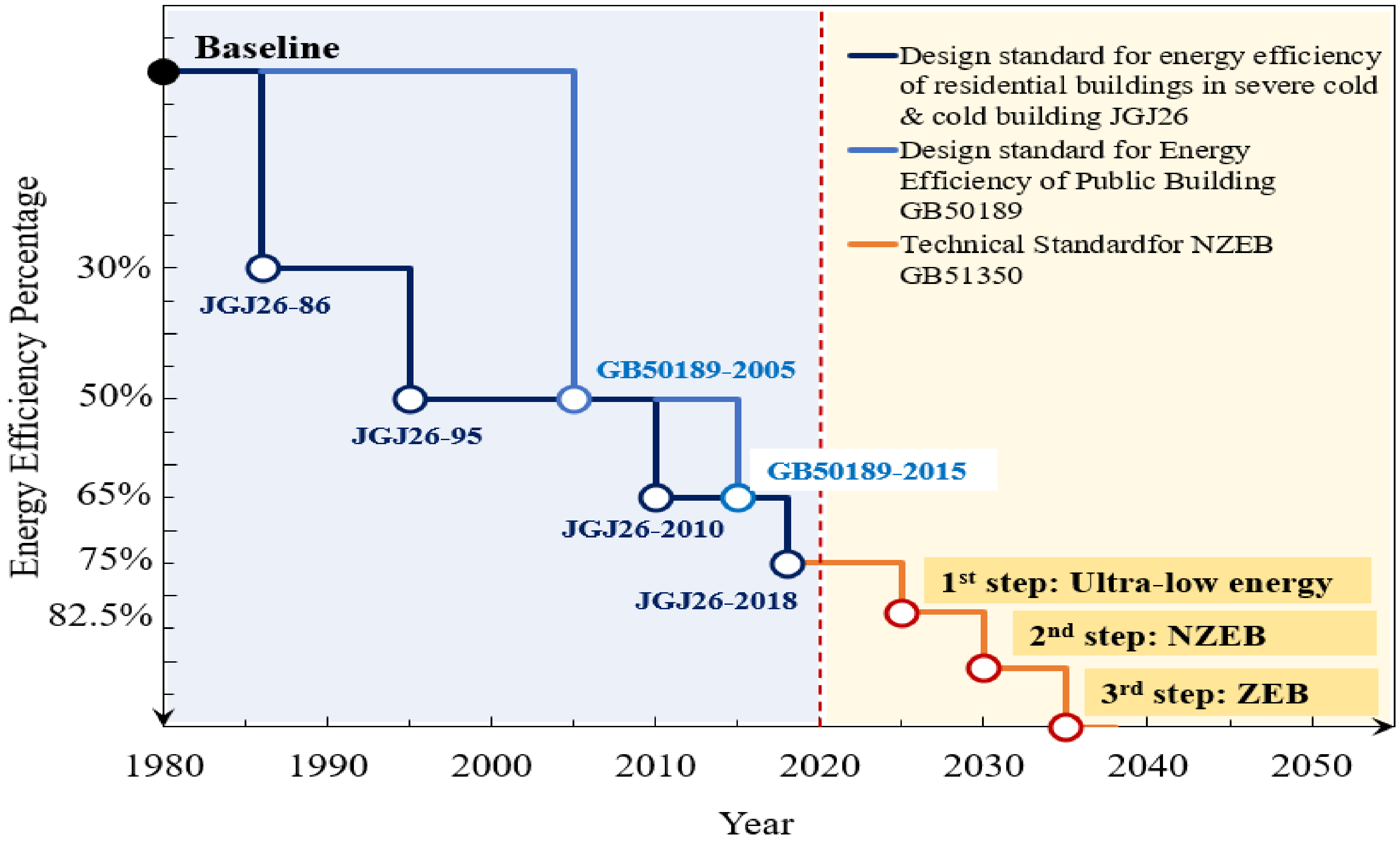
2. Technical Standard for Nearly Zero Energy Building GB/T 51350-2019

3. Mid to Long term Energy Saving Potential (2020-2050)

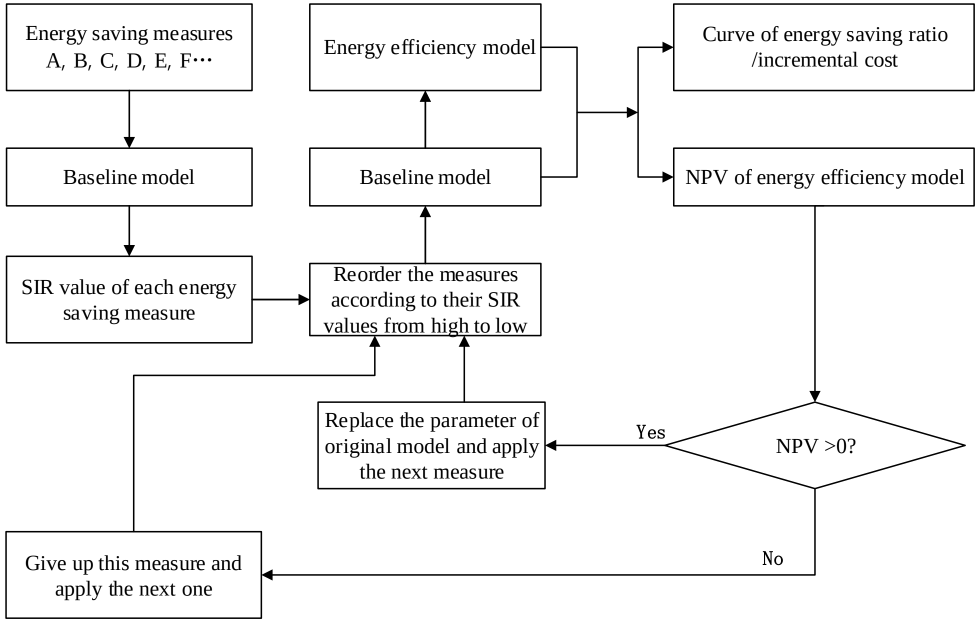
4. Suggestion and Conclusion

1. Building Energy Codes Upgrading (1986-2016)

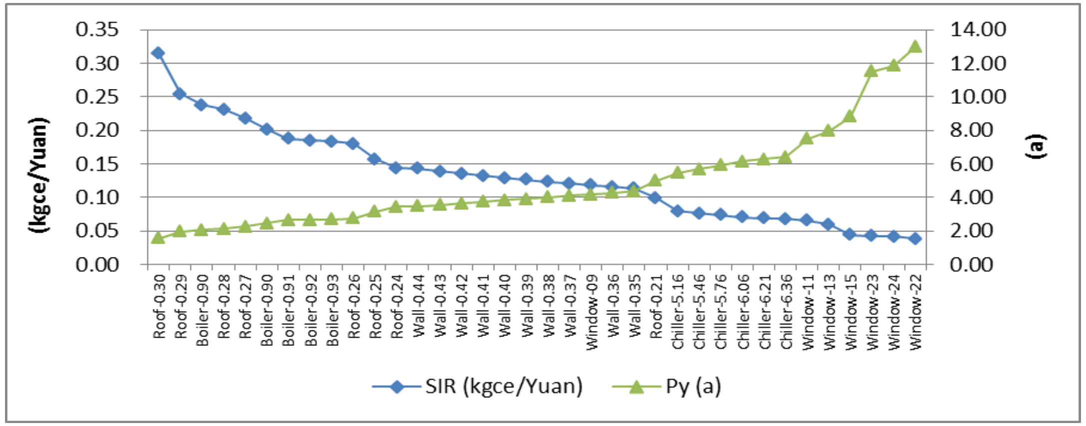
In response to carbon peak and carbon emission targets, the building sector should gradually and comprehensively upgrade building energy efficiency standards to the level of ultra-low energy consumption, near zero energy consumption and zero energy consumption buildings by 2025, 2030 and 2035.



1. Building Energy Codes Upgrading (1986-2016)



Flow chart of the incremental cost optimization analysis with different energy efficiency ratios



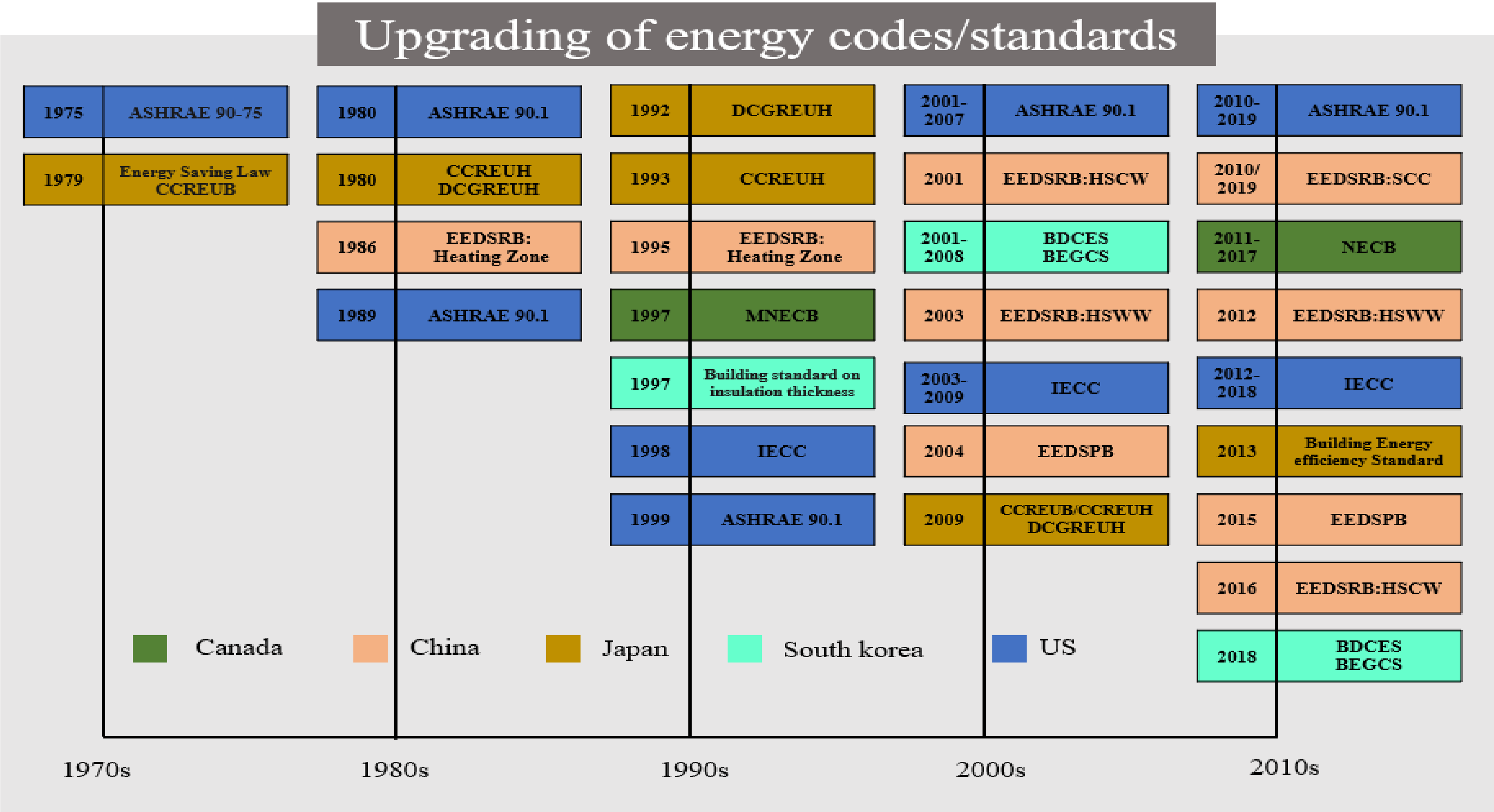
Cost-effective analyses of the single energy efficiency measures

SIR Method

A saving to investment ratio (SIR) method was used to determine the key prescriptive parameters for upgrading the building energy code with different energy reduction ratio requirements, including the U value of walls, roofs and windows; as well as a consideration of the efficiency of boilers and coefficient of performance of water chillers.

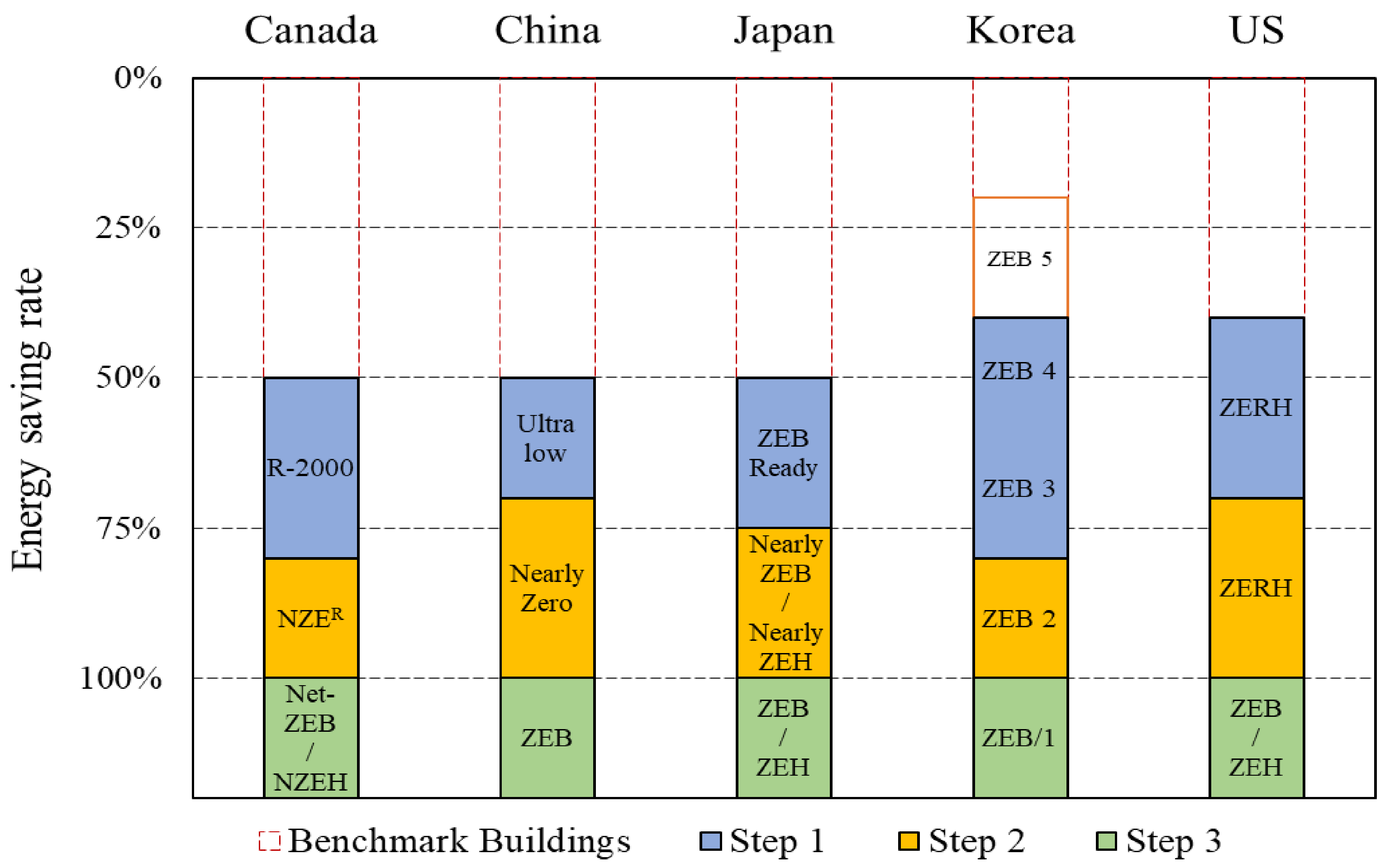
2. Technical standard for nearly zero energy buildings GB/T51350-2019

From the 1970s to the present, the energy saving rate of building energy efficiency standards has been increased by 50-70%, and will be further increased by 50-75% in the future; Since 2010, Zero Energy Buildings have gradually become the target of standard upgrading.



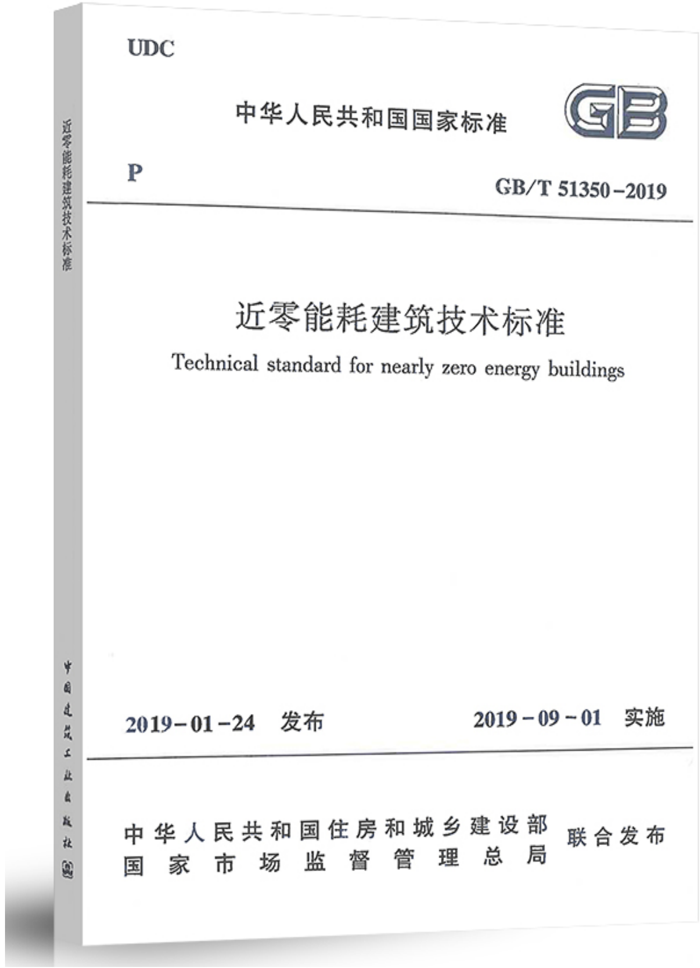
2. Technical standard for nearly zero energy buildings GB/T51350-2019

The three-step development path of gradually improving building energy efficiency has become an international trend, that is, to achieve ultra low energy (50%) first, then to achieve nearly zero energy (60%-75%), and finally to achieve zero energy.



2. Technical standard for nearly zero energy buildings GB/T51350-2019

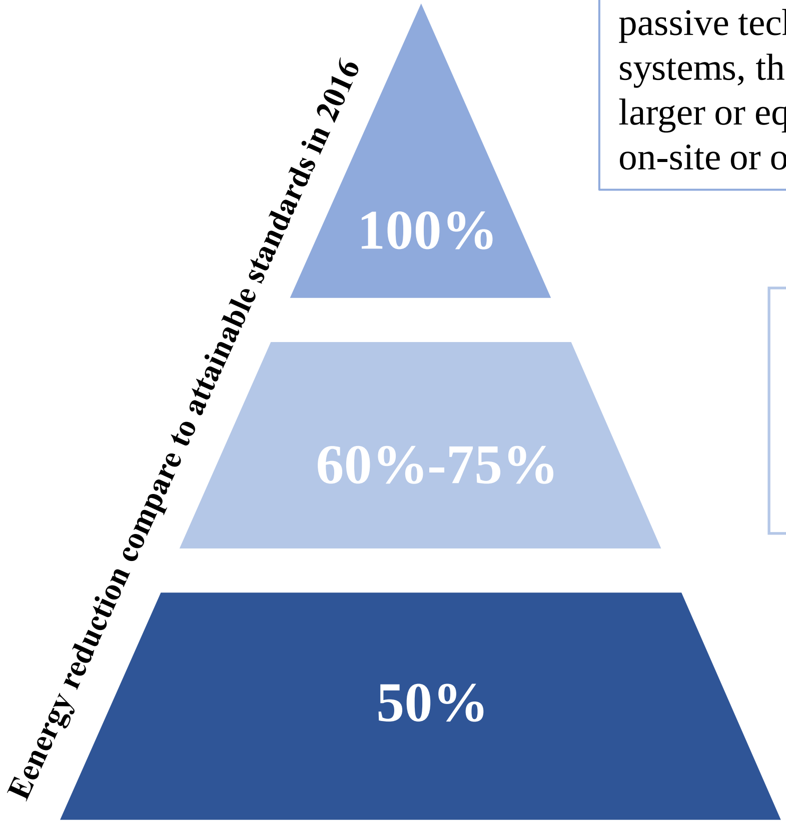
The first Voluntary national standard of zero energy building



- **Clear control indicators：Indoor environment + energy consumption（**Public or Residential， New construction or renovation， Design or operation， All climate zones**）**
- **Performance oriented design**
- **Guiding technical measures**
- **International advanced level**

2. Technical standard for nearly zero energy buildings GB/T51350-2019

- **ZEB technology systems suitable for different climate zones and different building types has been established.**
- **Definitions of ultra-low energy building, nearly-ZEB and ZEB in China**



Zero Energy Building

Adapting to climate conditions, reducing energy demand via passive techniques, improving energy efficiency of building systems, the total amount of energy used by the building is larger or equal to the amount of renewable energy created on-site or off-site.

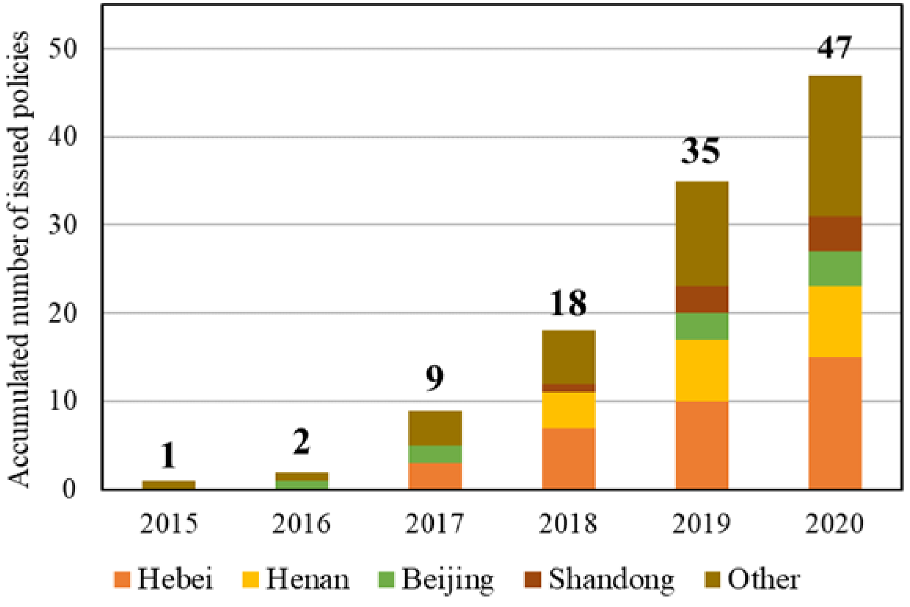
Nearly-Zero Energy Building

Adapting to climate conditions, reducing energy demand via passive techniques, improving energy efficiency of building systems, using renewable energy, and providing comfort indoor environment with extremely low energy consumption.

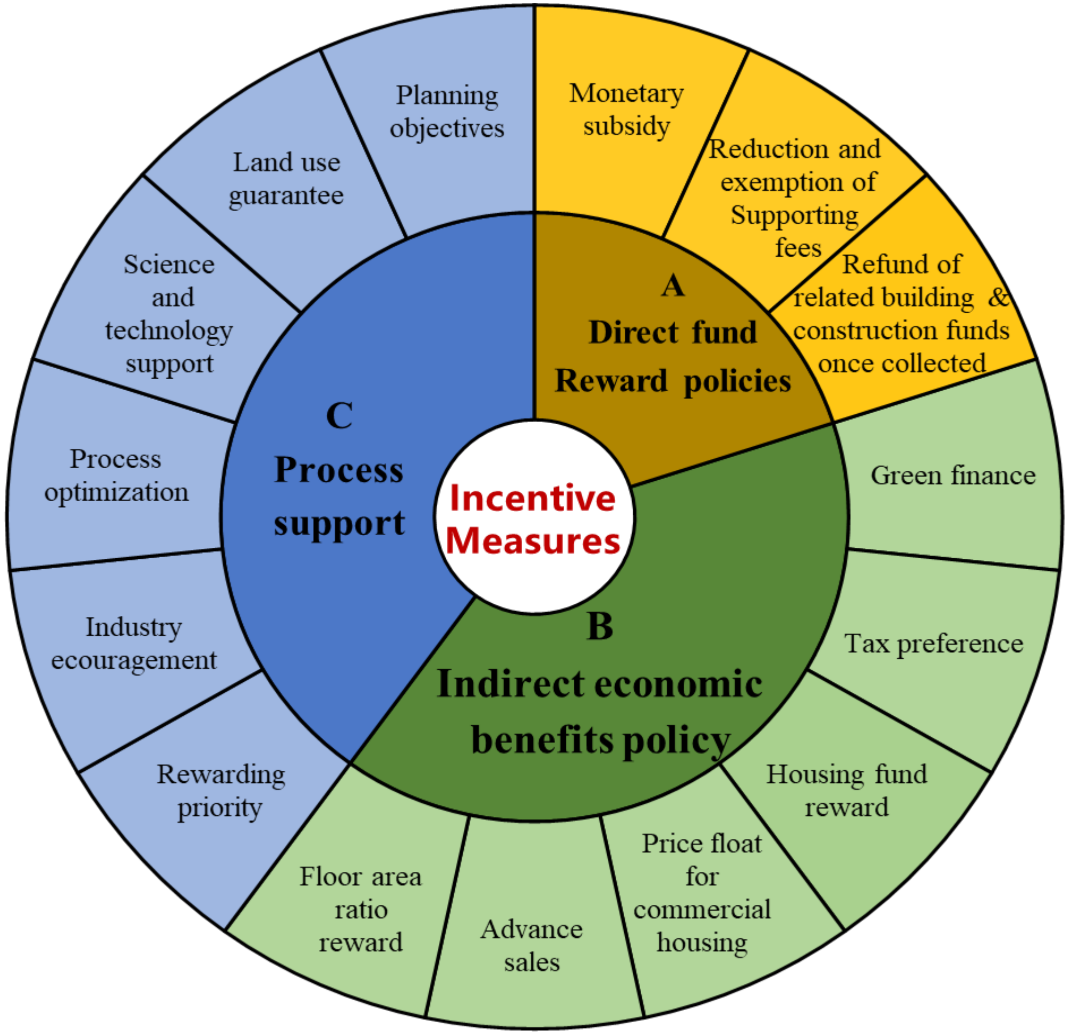
Ultra-low Energy Building

Adapting to climate conditions, reducing energy demand via passive techniques, improving energy efficiency of building systems, and providing comfort indoor environment with low energy consumption.

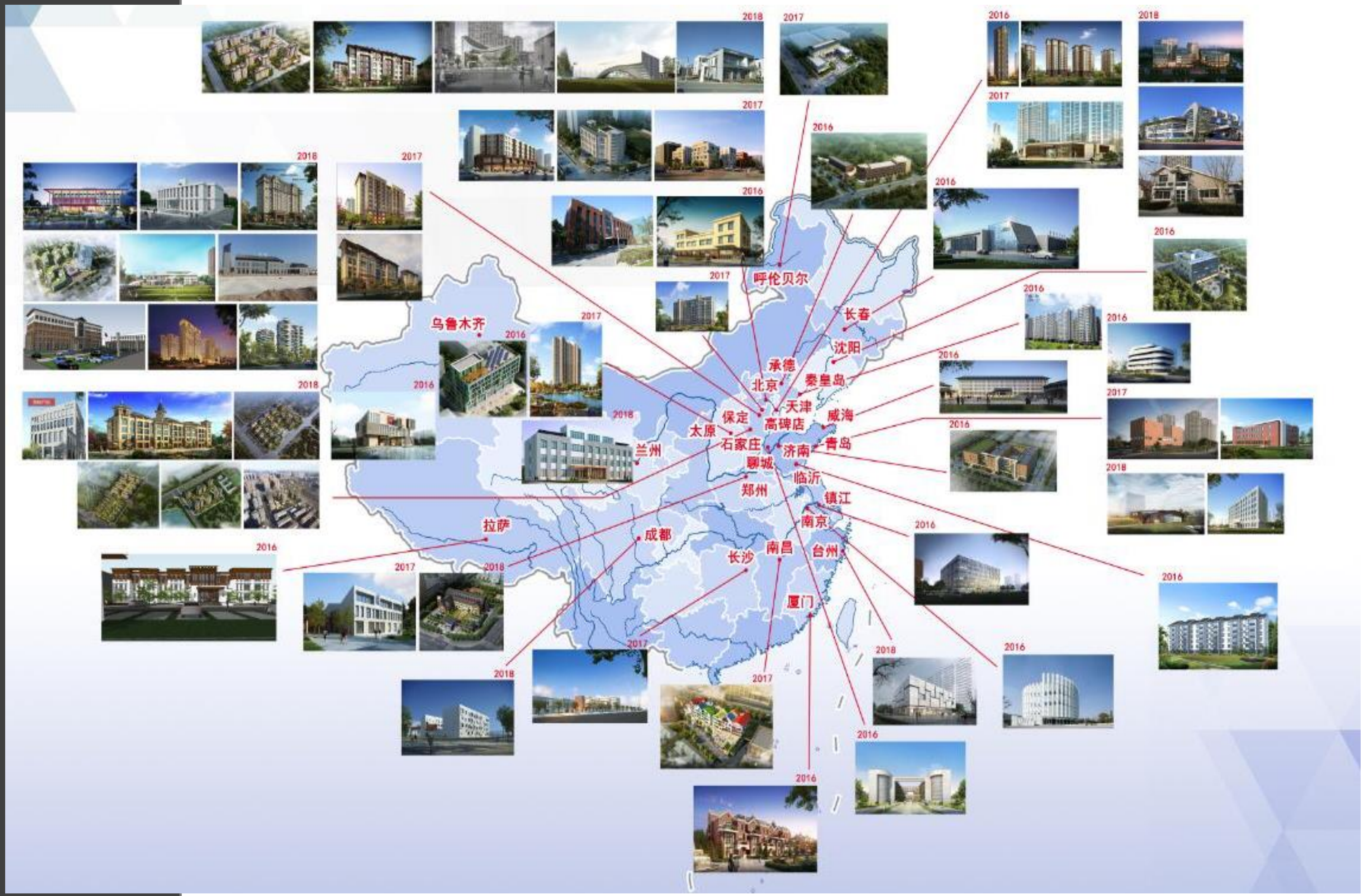
2. Technical standard for nearly zero energy buildings GB/T51350-2019

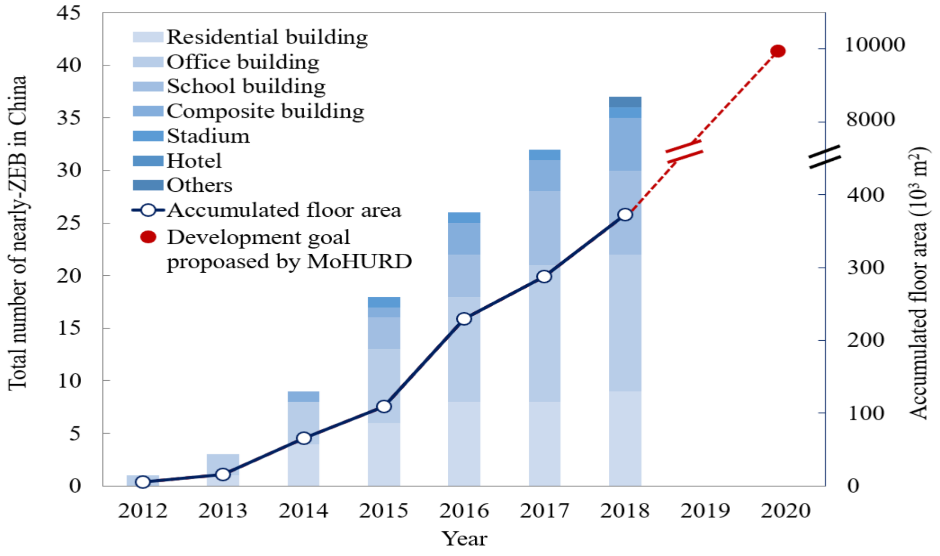


- The 47 NZEB policies consist of 15 types of incentive measures, among which planning objectives measure accounts for the largest ratio of 29% of the 15 types of incentive measures, followed by fund rewards and volume ratio rewards, which account for 25% and 10%, respectively.



2. Technical standard for nearly zero energy buildings GB/T51350-2019





- From small to large buildings
- From single buildings to demonstration communities
- From the cold to the full climatic zones

3. Mid to Long term Energy Saving Potential (2020-2060)

Statement at the General Debate of the 75th Session of the UN General Assembly

- China surprised the world by pledging that it will achieve carbon neutrality before 2060. The target would mean reducing carbon emissions from 16 billion tonnes a year to almost zero over a 40-year period from 2020 to 2060.
- China also reiterated that it will peak its carbon emissions around 2030, which was initially announced in the 2014 China-US climate agreement and confirmed in the Paris Agreement.
- On the one hand, China shows its determination to reboot the economy impacted by the pandemic using an environmentally and climate friendly approach. On the other hand, China doubled down its commitment to global climate protection.

3. Mid to Long term Energy Saving Potential (2020-2060)

Based on population, urbanization rate, per capita area and energy intensity, a medium and long term energy consumption prediction model in the building field was established. The 2060 carbon emission trend of nearly zero energy building under different development was obtained by converting coal consumption value of thermal power supply.

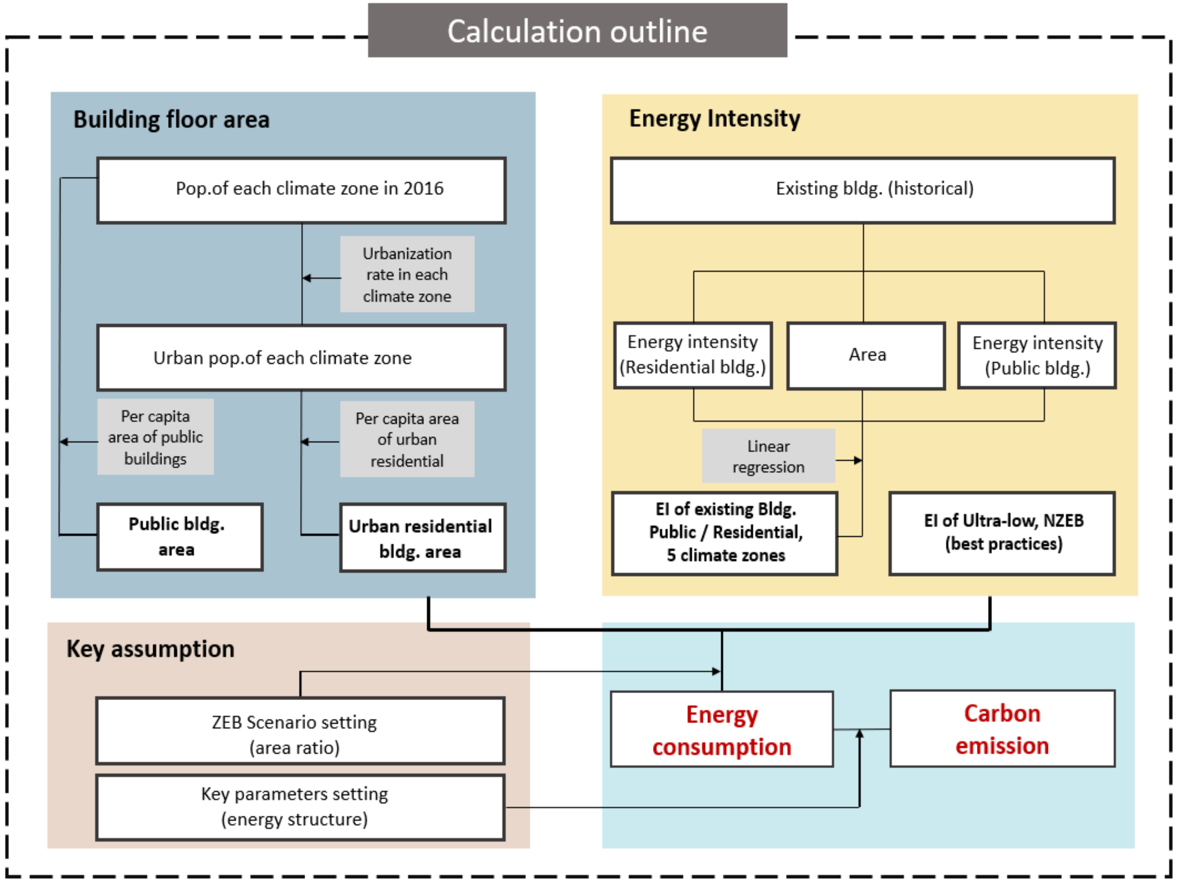


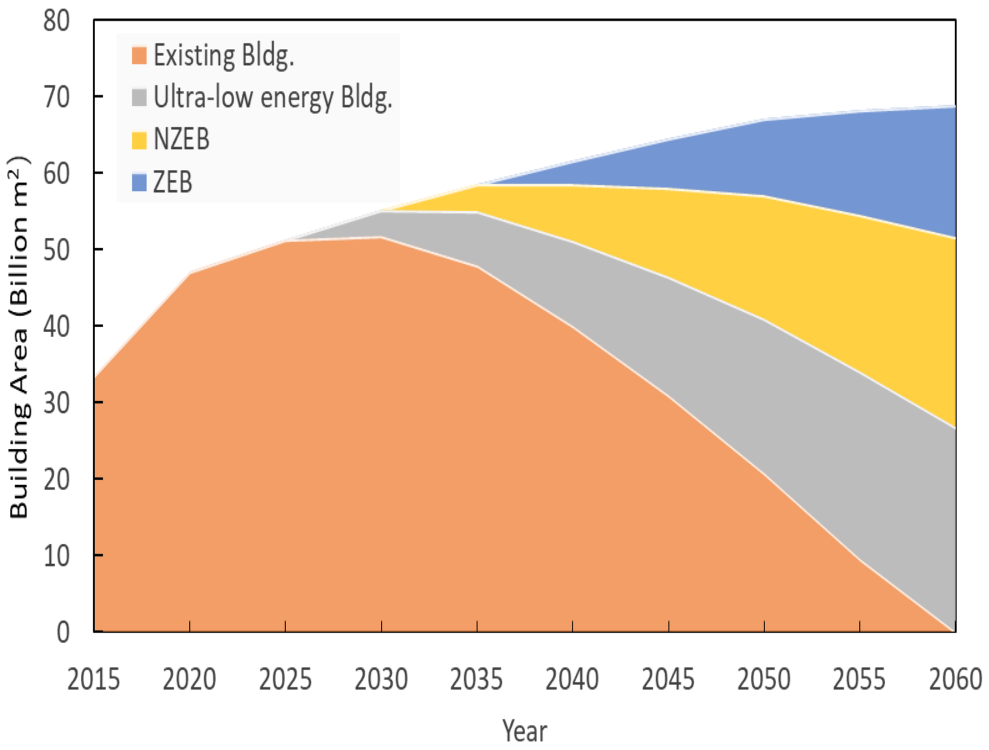
Figure Calculation outline of the energy consumption and carbon emission model of urban buildings considering NZEB

		2015	2030	2060	Reference
Population (billion)		1.38	1.45	1.28	(Zhai et al., 2016)
Urbanization (%)		56.10	70.00	80.00	(ERI, 2014)
Urban residential building area per capita (m^2)		28	41	45	(Yang et al., 2019)
Public building area per capita (m^2)		8	13	18	
Energy intensity of urban residential buildings (kgce/ m^2)	Severe cold/cold	18.8	19.1	20.4	Estimated based on historical data from THUBERC (2017)
	Others	5.1	7.5	11.9	
Energy intensity of public buildings (kgce/ m^2)	Severe cold/cold	24.1	26.5	31.0	
	Others	14.6	17.8	24.0	
Energy intensity of ultra-low energy buildings (kgce/m^2)	Residential buildings	7.6			(Zhang et al., 2020a)
	Public buildings	13.3			
Energy intensity of NZEB (kgce/m^2)	Residential buildings	6.1			
	Public buildings	10.7			
Energy intensity of ZEB (kgce/m2)		0			
Energy structure of urban residential buildings (HVAC, domestic hot water & lighting, exclude northern heating)	Electricity (%)	84.4			(Peng et al., 2018)
	Natural gas (%)	15.6			
Energy structure of public buildings (HVAC, domestic hot water & lighting, exclude northern heating)	Electricity (%)	95.0	93.7	92.0	
	Natural gas (%)	5.0	6.3%	8.0	
Energy structure of northern heating	Coal (%)	78			(THUBERC, 2019)
	Natural gas (%)	15			
	Electricity (%)	1			
	Renewable energy(%)	6			
Electricity carbon emission factor (kg CO_2/kWh)		0.67	0.47	0.37	(Tan et al., 2018)
Thermal carbon emission factor (t CO_2/TJ)		125.75	123.99	121.52	

3. Mid to Long term Energy Saving Potential (2020-2060)

Based on the international trend and the development history and current situation of China's building carbon emissions, five scenarios for the promotion of near-zero energy buildings were established, and the peak time and peak energy consumption of building energy consumption were estimated.

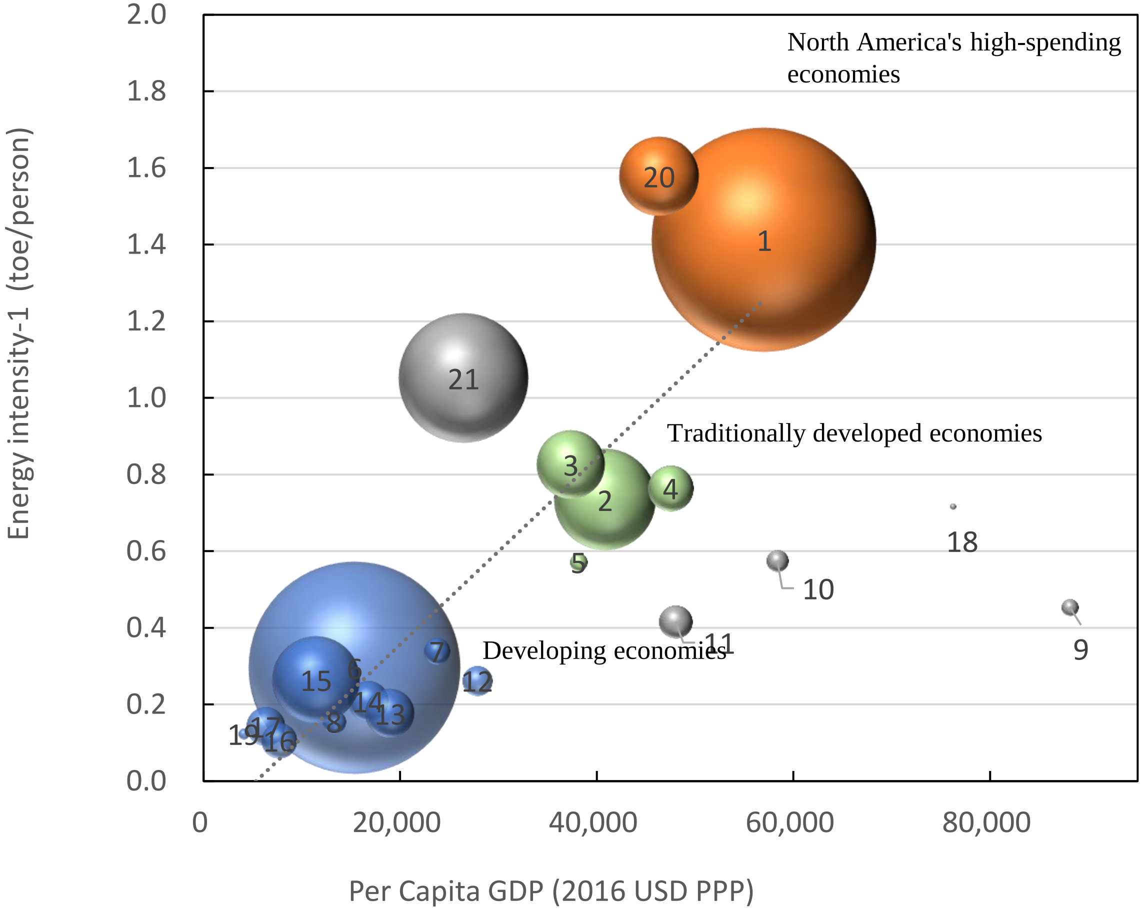
Development trend of energy consumption and CO_2 emissions in building sector
(including energy consumption of residential buildings in urban area and public buildings)



Building area of steady development scenario (S1)

3. Mid to Long term Energy Saving Potential (2020-2050) in APEC region

Based on the analysis of building energy consumption data of 21 economies in the Asia-Pacific region, a building energy intensity influence model based on economic development level, urbanization rate, per capita income and per capita floor area in the Asia-Pacific region is constructed.



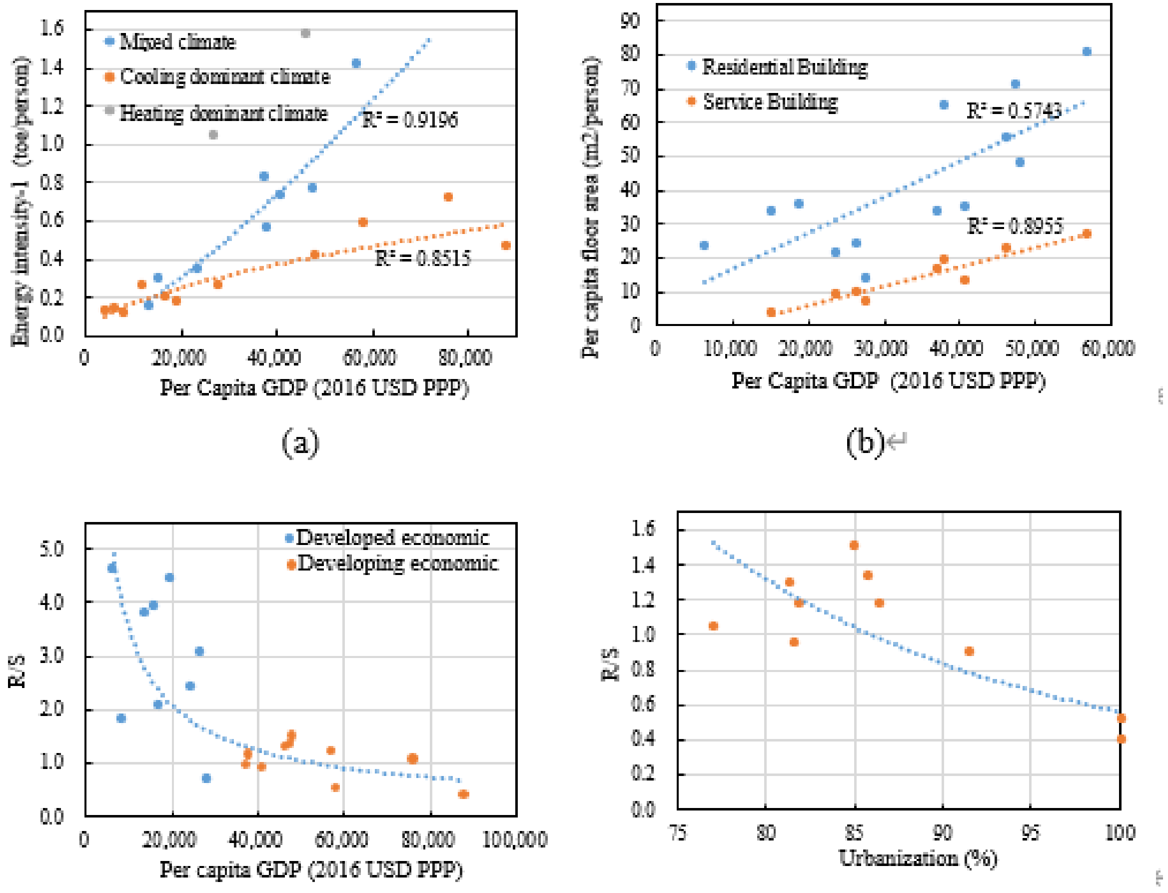
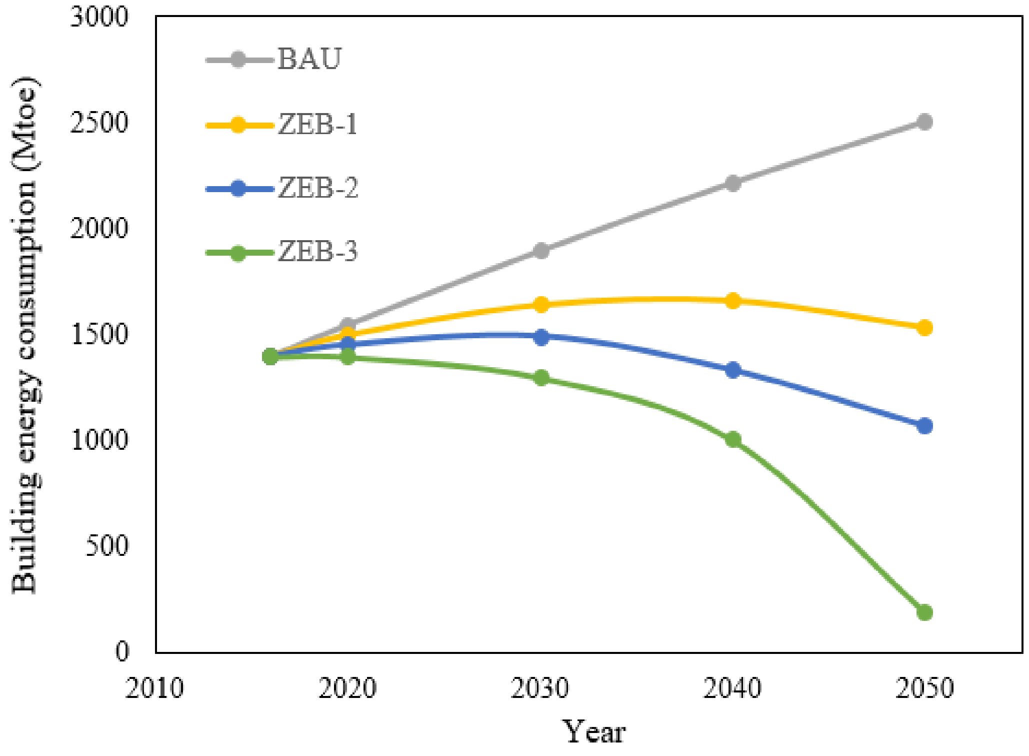
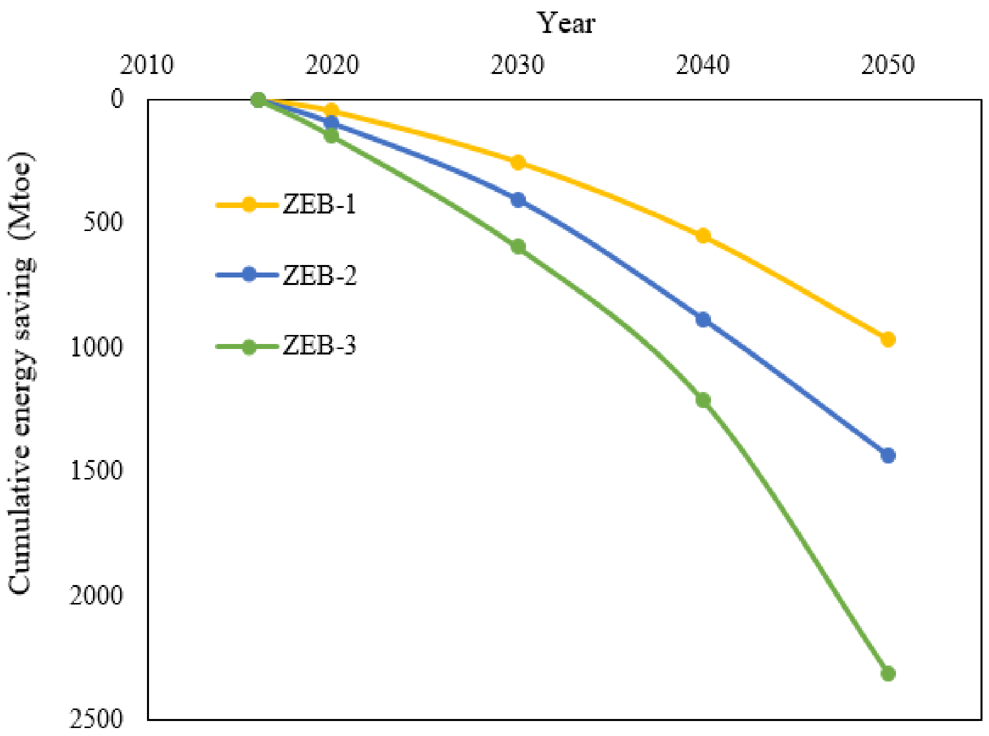


Fig Development trend of building energy in APEC.

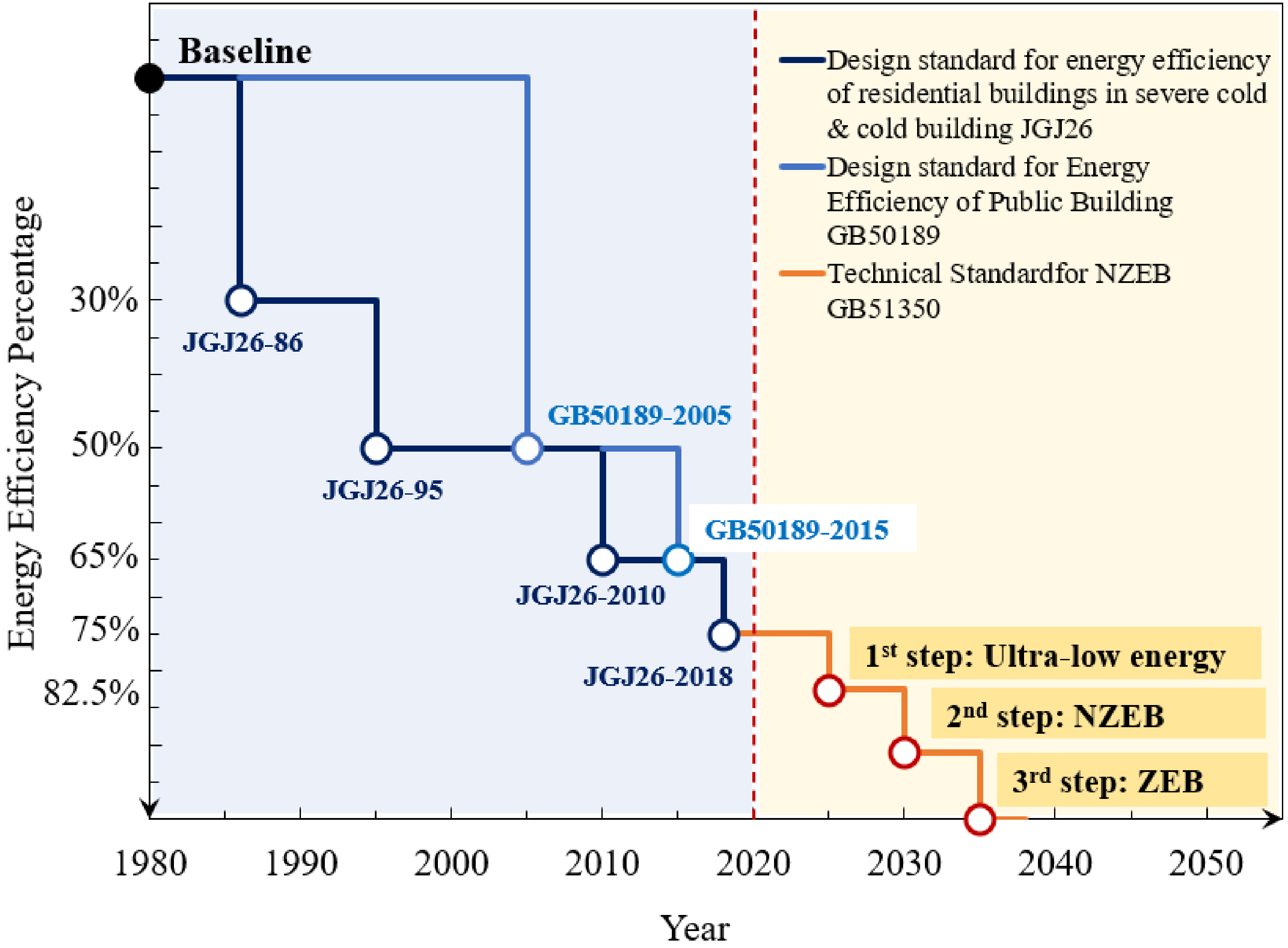
3. Mid to Long term Energy Saving Potential (2020-2050) in APEC region

Different scenarios of ZEB promotion substantially reduce energy consumption by 897.8, 1,402.52 and 1,945.3 Mtoe, respectively. The share of end demand supplied by onsite renewable energy production could reach 11% to 54%. The share of end demand supplied by onsite renewable energy production could reach 11% to 54%.





4 Suggestion and Conclusion



1. **From energy to carbon**
2. **From 10 years to 5 years**
3. **From 5 to 1**
4. **Towards Zero**

Thank you for your attention

Prof ZHANG Shicong

China Academy of Building Research

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Energy in Buildings and Communities Programme

Discussion – Q&A

Pau Garcia Audí
European Commission

Cost-optimal methodology

#EUGreenDeal

April 2021

Cost-optimal methodology
Energy Performance of Buildings Directive

Key elements:

- Stepped approach to setting minimum energy performance standards: calculation methodology (Art. 3), setting levels (Art. 4), compliance with cost-optimality (Art. 5)
- Regular reporting – every 5 years (starting in 2013)
- Introduced in the EPBD
- Expanded in Regulation 244/2012 and Guidelines to the Regulation
- Compulsory for single residential buildings, apartment blocks, offices*
- New building and existing buildings undergoing major renovation*
- Over the life-time of the building
  - 30 years for res. buildings and 20 years for non-res.
- Overall energy performance and building elements*

European Commission

Cost-optimal methodology
Rationale

Support in setting minimum energy performance requirements for buildings by providing principles for comparing measures and defining of efficiency levels that are cost-efficient for households and investors

Equivalent level of ambition in all MS, but no harmonisation of requirements (Variety of requirements)

Energy-saving potential not evaluated: Various market failures in the sector make that emphasis is put on upfront investment costs and NOT on LCC, so that the cost effective savings potential in the buildings sector cannot be reaped

Cost-optimal methodology
Calculation steps

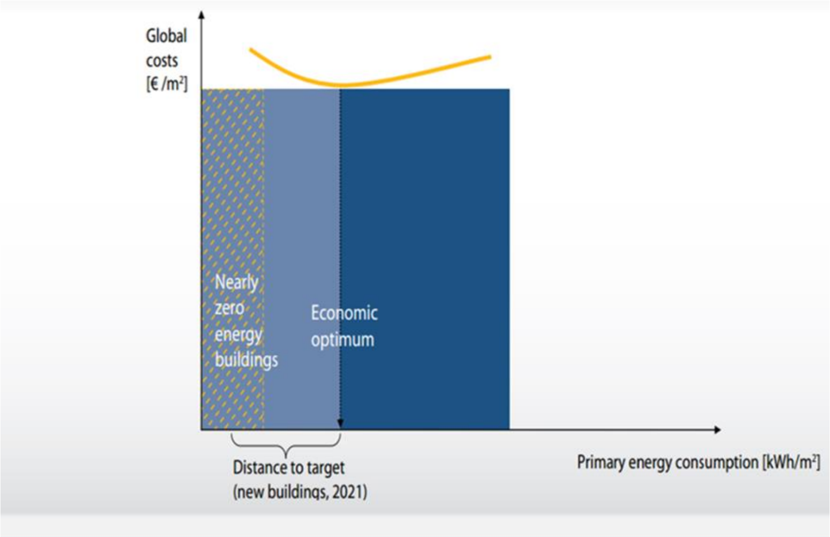


Figure: Beneficial areas in relation to cost optimum and distance to target (example only)

1. Definition of reference buildings

2. Identification of energy efficiency and renewable energy measures

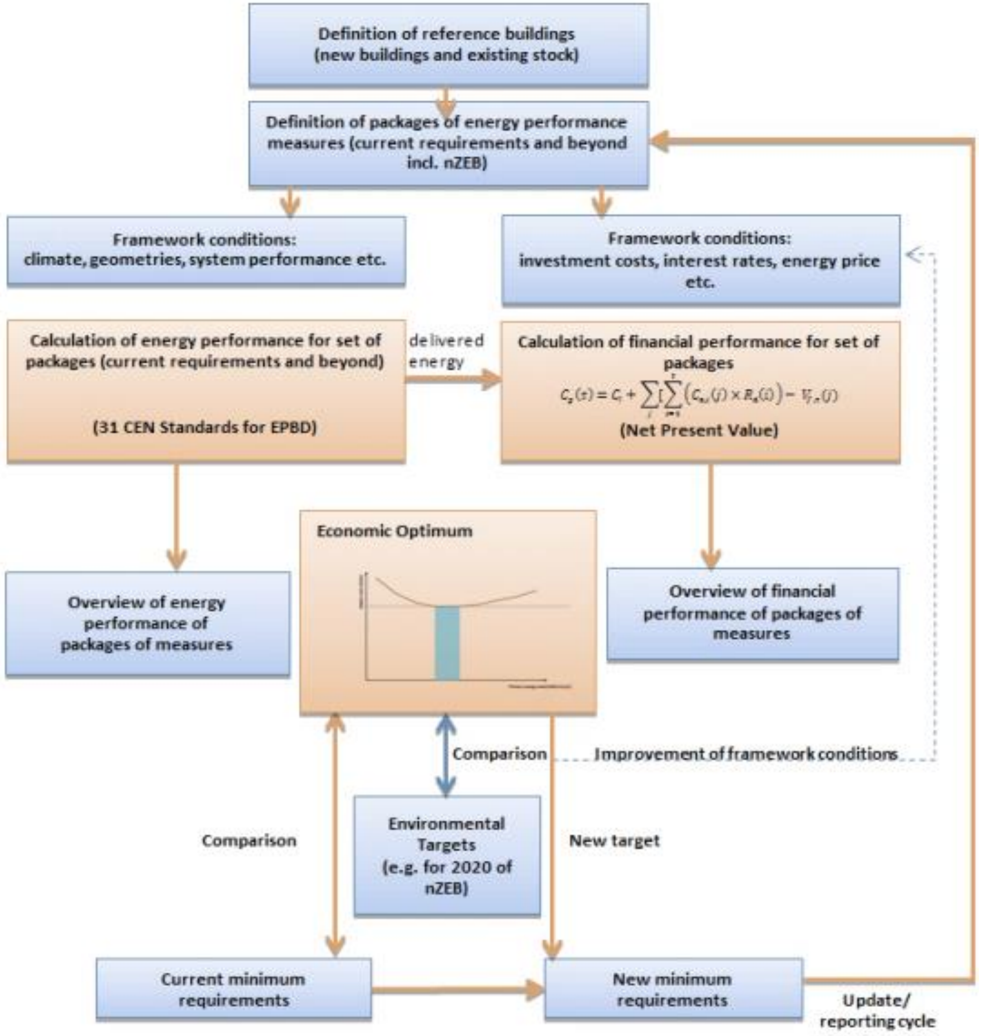
3. Calculation of primary energy demand

4. Calculation of global costs

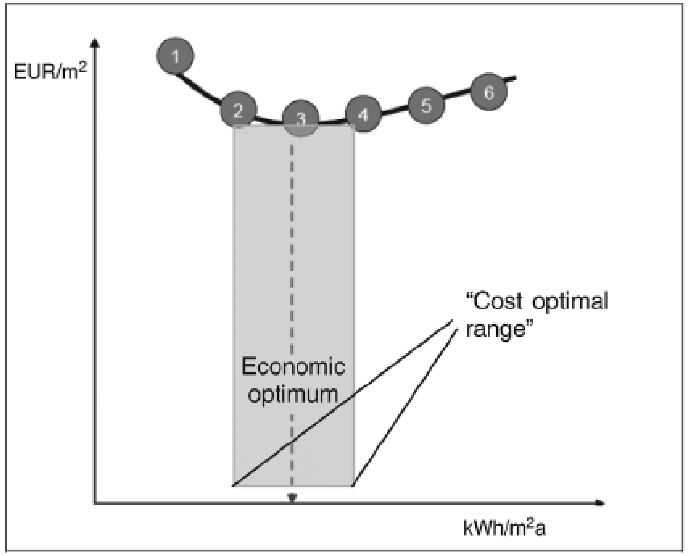
5. Calculation of the gap

European Commission

Cost-optimal methodology
Calculation steps – Calculation of the gap



Implementation steps of cost-optimal methodology(BPIE, 2013)



Cost-optimal methodology
Calculation steps – Definition of reference building

Findings

Scarcity of statistical information available on all building types

Lack of disaggregation according to size, age, construction material, use pattern and climatic zone

Certain reference building cases have not been established

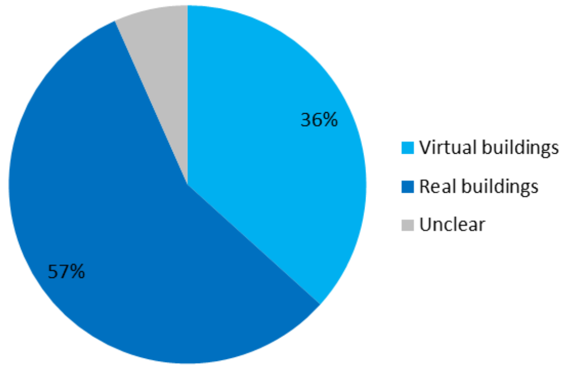
Unreasonable data presented for some reference buildings

Lessons learned

Justify chosen reference buildings and use tables and graphs

National databases (including for EPCs) can contribute describe to set reference buildings

Virtual buildings should be derived from an existing national building typology



European Commission

Cost-optimal methodology
Calculation steps – Identification of measures (EE+RES)

Findings

All aspects that affect directly/indirectly building energy performance (new technologies, passive solutions) not taken into account

Low number of analysed variants developed (less than 10)

Measures / variants to meet NZEB or RES requirements not indicated

Lessons learned

NZEB variants align with NZEB minimum requirements

Consider different and commonly used energy supply systems

Use Pareto analysis to determine the most relevant optimal measures

Use (Excel) Tables to describe the measures/packages clearly

Cost-optimal methodology
Calculation steps – Calculation of energy demand

Findings

The step with least conformity issues

Not clear if Primary Energy Factors (PEFs) used are based on national legislation or not

Not reported / mentioned if the calculation methods are in line with EPBD

Lessons learned

Ensure calculation in accordance with the EPBD

Ensure the use of most recent national PEFs

Use a validated energy demand calculation tool

Cost-optimal methodology
Calculation steps – Calculation of costs

Findings

Difficulties in defining:

- investment costs, maintenance costs, replacement costs (e.g. lower costs for more efficient variants, lifetimes of components), building operation
- energy price developments for all energy carriers used
- the chosen perspective – financial, macroeconomic
- a clear indication about the treatment of taxes, charges and subsidies
- Calculations concerning the discount rates

Lessons learned

Indicate clear discount rates and energy prices used

Indicate clear lifetime of building elements as used in the calculations

Report calculations and indicate the perspective used as national benchmark

Use (excel) tables to report cost categories and cost parameters

Cost-optimal methodology
Calculation steps – Calculation of the gap

Findings

Plans to reduce gap reported only for 2/3 cases

Non-transparent, untraceable and misleading calculation and reporting of (average) gaps

Plans and/or timelines are not plausible or ambitious

Unclear legal status and a biding timeline of the plans

Lessons learned

Calculate average gap in case of more than one reference building assessment

Report a plan outlining appropriate steps to reduce the non-justifiable gap

Prepare the timeline to perform the steps of the plan and describe the legal status

Cost-optimal methodology
Calculation steps – Examples

	New Single Family Building		New Multi Family Building		New Office	
Member State	Primary energy (kWh/m2y)	Global cost (EUR/m2)	Primary energy (kWh/m2y)	Global cost (EUR/m2)	Primary energy (kWh/m2y)	Global cost (EUR/m2)
DK	52	816	40	461	46	365
EL	109	1449	52	1267	114	1316
ES	53	325	45	295	96	430
FI	95	1832	80	1601	91	2240
HU	132	804	138	801	106	116
IE	62	299	66	305	69	699
PL	62	119	57	122	97	101

	Existing Single Family Building		Existing Multi Family Building		Existing Office	
Member State	Primary energy (kWh/m2y)	Global cost (EUR/m2)	Primary energy (kWh/m2y)	Global cost (EUR/m2)	Primary energy (kWh/m2y)	Global cost (EUR/m2)
DK	121	865	58	325	63	375
EL	163	516	107	329	143	355
ES	101	235	102	334	334	343
FI	245	421	97	282	93	298
HU	143	221	113	176	156	123
IE	104	244	88	269	210	457
PL	---	---	---	---	---	---

Cost-optimal methodology
Calculation steps – Examples

Climate	new SFH		new MFH		new Office		new Other n-R	
	PE [kWh/m2y]	GC [EUR/m2]	PE [kWh/m2y]	GC [EUR/m2]	PE [kWh/m2y]	GC [EUR/m2]	PE [kWh/m2y]	GC [EUR/m2]
Mediter.	81	887	105	698	221	648	423	607
Oceanic	86	760	66	746	94	1214	140	992
Continental	81	419	93	356	80	157	67	173
Nordic	77	1882	62	2076	66	1681	120	2481

Climate	existing SFH		existing MFH		existing Office		existing Other n-R	
	PE [kWh/m2y]	GC [EUR/m2]	PE [kWh/m2y]	GC [EUR/m2]	PE [kWh/m2y]	GC [EUR/m2]	PE [kWh/m2y]	GC [EUR/m2]
Mediter.	161	500	148	467	175	396	775*	808*
Oceanic	124	670	142	628	160	682	264	522
Continental	97	329	100	237	112	143	102	166
Nordic	183	643	77	303	78	336	122	236

Cost-optimal methodology
Documentation

Legal documents

- EPBD 2010/31/EU
- EPBD 2018/844/EU
- Regulation 244/2012
- Guidelines to regulation 244/2012

Further information

- Concerted Action EPBD (CA-EPBD)
- CA-EPBD reports from 2011-2015
- CA-EPBD reports from 2011-2018

Thank you

Pau Garcia Audí ENER B.3: Policy Officer

Contact: pau.garcia-audi@ec.europa.eu

Chris Kirney
CanmetENERGY-Ottawa,
Natural Resources Canada

Natural Resources Canada | Ressources naturelles Canada

Automated Building Energy Simulation and Costing using the Building Technology Assessment Platform

April 28, 2021
Chris Kirney

Overview

Purpose

- Support development of building energy codes for new buildings
- Support policy and program decisions regarding energy efficiency in new buildings

How?

- Use the Building Technology Assessment Platform (BTAP) to model the energy performance and related capital costs of several building archetypes
- Apply the changes described by the policy or code to the building models to determine the impact on their energy consumption and related capital and operating costs

Assess buildings built to:

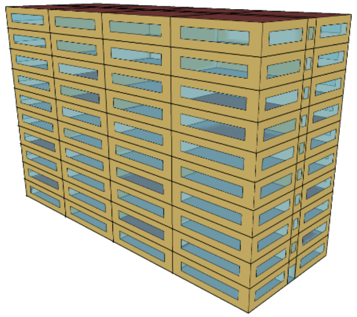
- 2011 National Energy Code of Canada for Buildings (NECB2011)
- NECB 2015
- NECB 2017

What is BTAP?

A software tool that uses

OpenStudio + OpenStudio-Standards

To automatically create building energy models



Simulated using

EnergyPlus

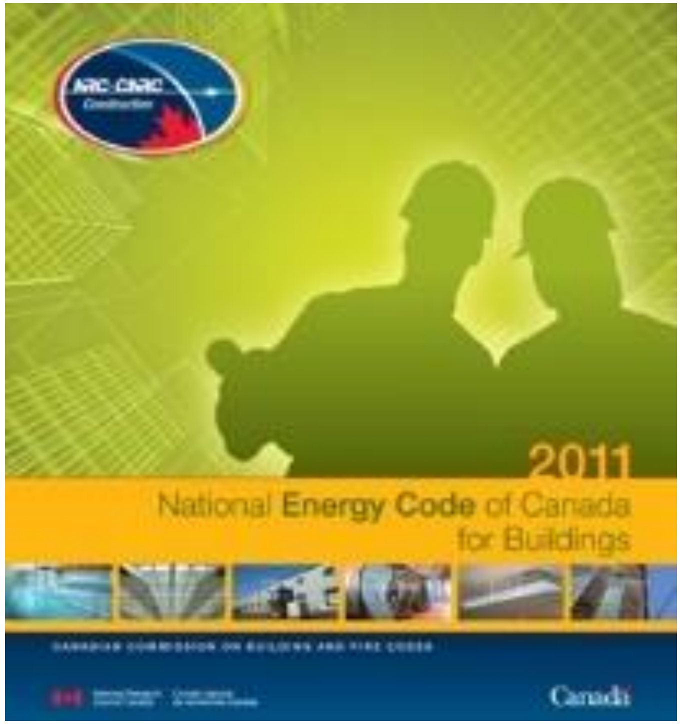
On a large scale via

Parametric Analysis Tool + amazon web services

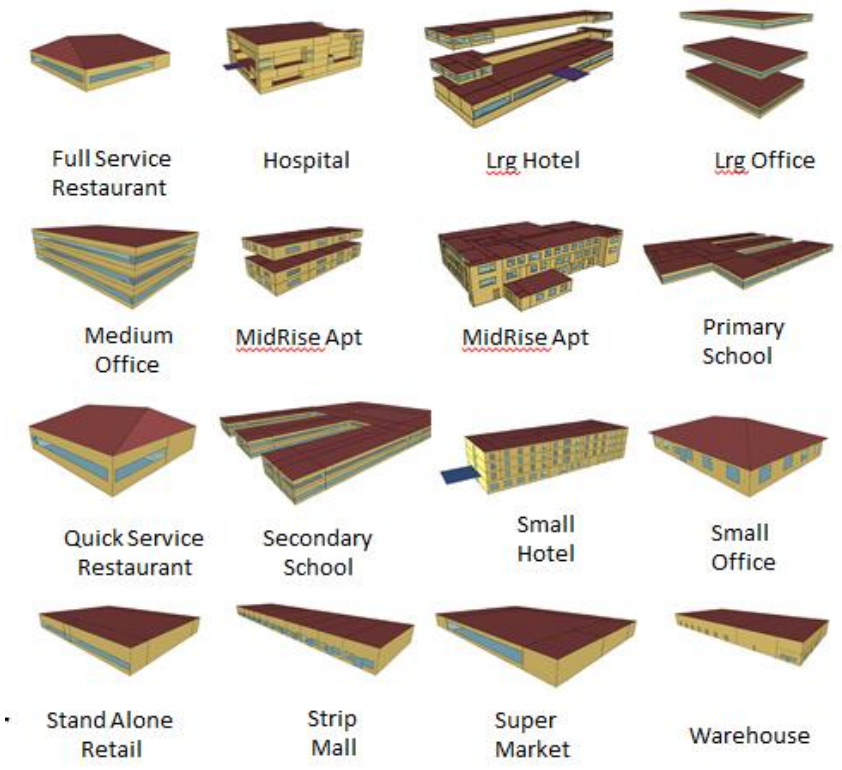
How Does BTAP Define Buildings?

Buildings defined based on National Energy Code of Canada for Buildings (NECB):

- Start with basic building geometry including spaces and NECB space types (offices, meeting rooms, apartments, etc.)
- Assign loads and schedules based on NECB space types
- Assign building envelope characteristics based on weather location
- Apply NECB Heating Ventilation and Air Conditioning (HVAC) system type based on loads, envelope and heating type
- Apply equipment efficiencies



Model Building Energy Performance Across Canada



What about Costing?

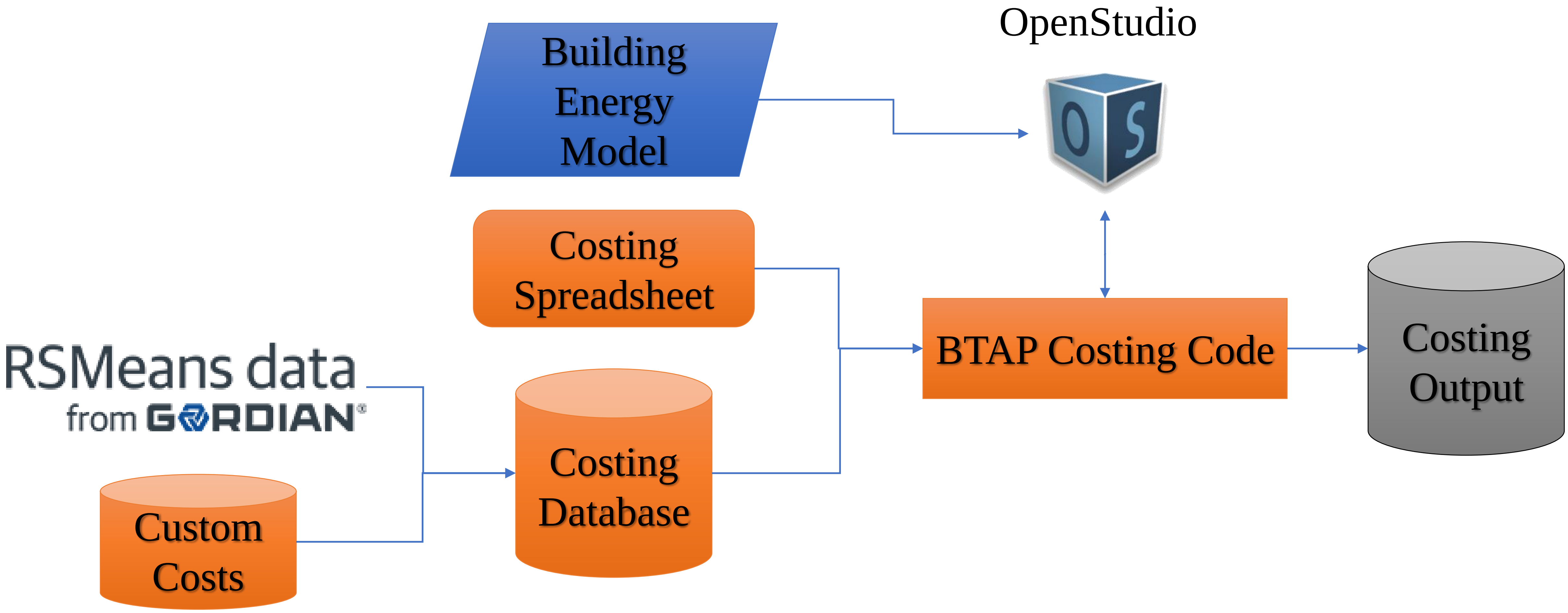
Goals:

- Estimate capital costs of building components related to energy performance
- Apply quickly and consistently across Canada
- Seamless change of costing when building is modified

BTAP Costing:

- Scripts that link model components to costing database via costing spreadsheet
- Building model describes the building
- Costing spreadsheet links model characteristics (space types, envelope or equipment characteristics, number of stories, location) to costed items
- Costing database created using RSMeans data and custom costs

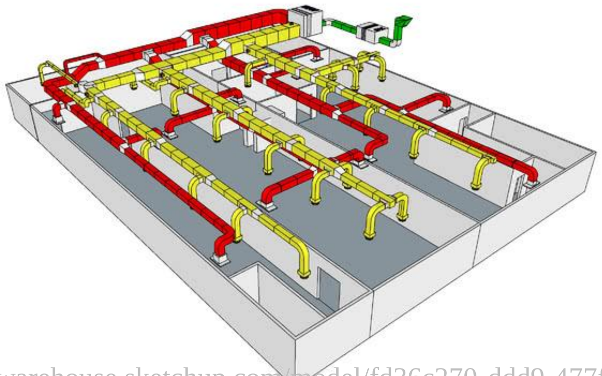
Costing Process:



Examples of costing expertise built into BTAP Costing

LIGHTING COSTS

Fixture types & costs vary by ceiling height, power densities, lighting levels



https://3dwarehouse.sketchup.com/model/fd36c270-ddd9-477f-85ad-3906e534e985/Ducting-System

DUCTING

Logic to determine mechanical room locations, duct run lengths and sizes

https://www.dreamstime.com/stock-photo-wood-framing-house-insulation-d-render-computer-generated-image-isolated-white-background-image74040490

ENVELOPE ASSEMBLIES

Space types mapped to typical envelope assemblies.

E.G. **Dwelling Unit**:

1-4 story building ➔Wood frame

5+ story building ➔Curtain Wall

BTAP Costing Advantages and Limitations

Advantages:

- Dynamic costing changes costs with changes to building loads
- Costing consistently applied with building type and location
- Using cloud computing can simulate the energy performance and related capital costs of thousands of buildings in a few hours

Limitations:

- New construction only
- Only energy performance related components costed
- Best used for comparative analyses (incremental costs)

Case Study: NECB Performance in Nova Scotia

This study examined the differences in **performance** and **cost** between the **NECB 2015** and the **NECB 2017 using BTAP**

Buildings:

- Small, medium and large office
- Mid-rise and high-rise apartments
- Retail stand-alone and retail strip mall

NECB 2017 Performance By Building

Averaged across 3 cities	Energy Savings (MJ/m2/yr)	Energy Cost Savings ($/m2/yr)	Energy Savings (%)	Incremental Capital Costs ($/m2)	Payback (years)
Small Office	**66.4**	**1.3**	**12.1**	**-2.0**	**-2.0**
Medium Office	**45.5**	**1.3**	**8.2**	**-5.1**	**-4.5**
Large Office	**27.3**	**0.8**	**6.5**	**-8.2**	**-10.3**
Retail Standalone	**161.3**	**3.6**	**22.0**	**-43.5**	**-12.1**
Retail Stripmall	**203.4**	**4.1**	**24.2**	**-35.6**	**-8.8**
Midrise Apartment	**21.0**	**0.5**	**2.9**	**9.5**	**19.2**
Highrise Apartment	**9.6**	**0.2**	**1.3**	**8.1**	**45.7**

Negative paybacks due to:

- Fenestration and door to wall ratio
- Reduced capacity of heating, ventilation and air conditioning

Longer paybacks are due to:

- Energy recovery ventilators
- Ducting

Breakdown of Incremental Capital Costing

- Averaged over 3 cities
- Higher Roof / Floor area means higher costs

- Lighting mitigated a majority of the capital costs

- Heating/Cooling capacities were reduced, costing less

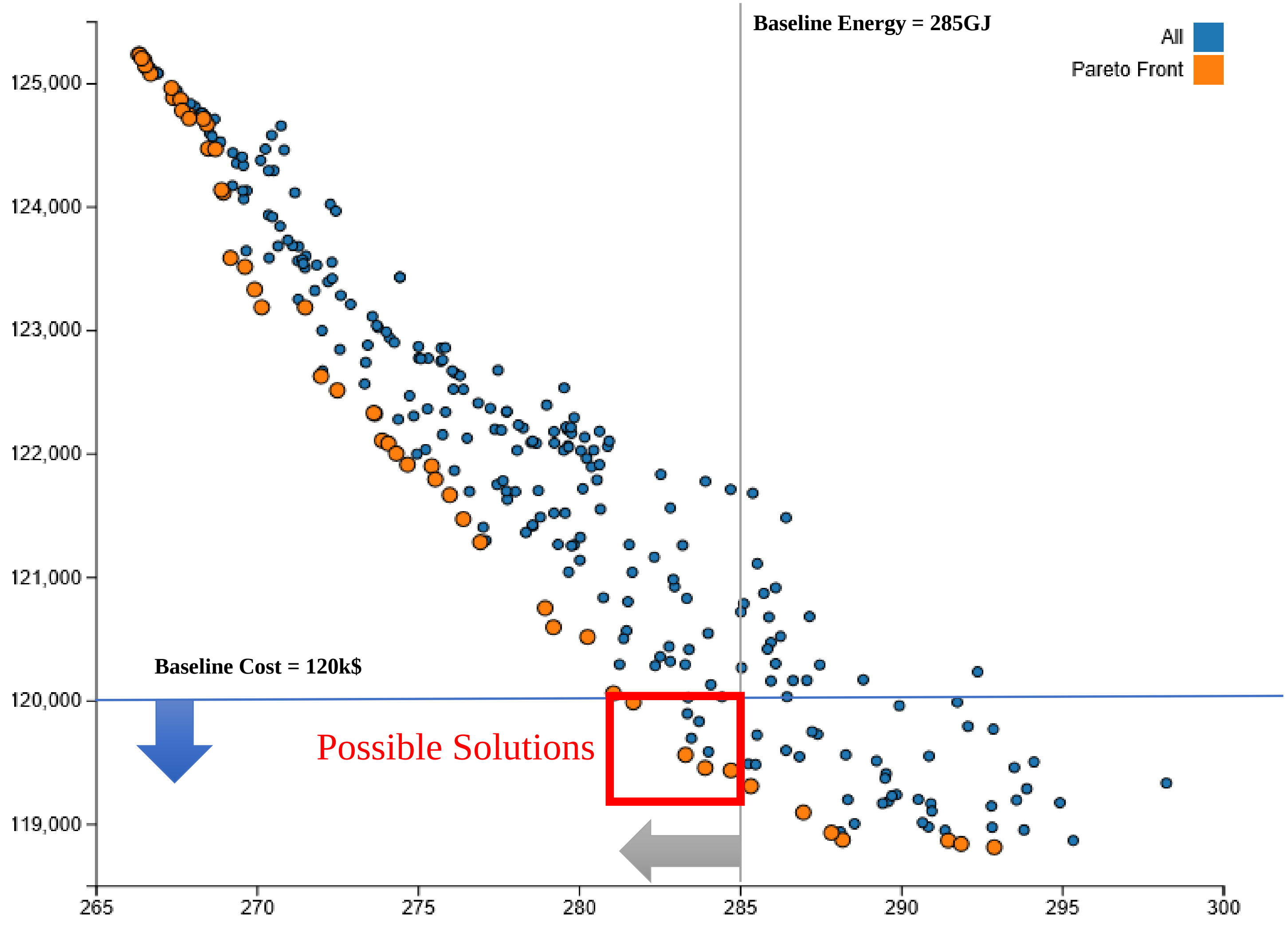
- Lower loads meant smaller air handling unit requirements. Exception was apartment units now required energy recovery ventilators.

Average Cost Change NECB2015-17 ($/m2)	Envelope	Lighting	Heating & Cooling	Service Hot Water	Ventilation	Total
SmallOffice	5.76	-5.63	-0.35	0.00	-1.79	-2.01
MediumOffice	1.97	-5.63	-0.44	0.00	-1.02	-5.12
LargeOffice	0.83	-5.81	-0.09	0.00	-3.12	-8.19
RetailStandalone	5.66	-29.41	-0.70	0.00	-19.08	-43.54
RetailStripmall	5.67	-37.90	-1.56	0.00	-1.80	-35.60
MidriseApartment	1.92	-0.23	-4.18	0.00	11.95	9.47
HighriseApartment	1.54	-0.09	-1.47	0.00	8.08	8.06

What else can it do?

OpenStudio Cloud Management Console

Analysis Results — Envelope Optimization



Update Chart

Select x and y variables to update the chart

X btap_results.total_end_uses_gj

Y btap_results.total_envelope_cost

Update Chart

Pareto Front

Save this pareto front for later use

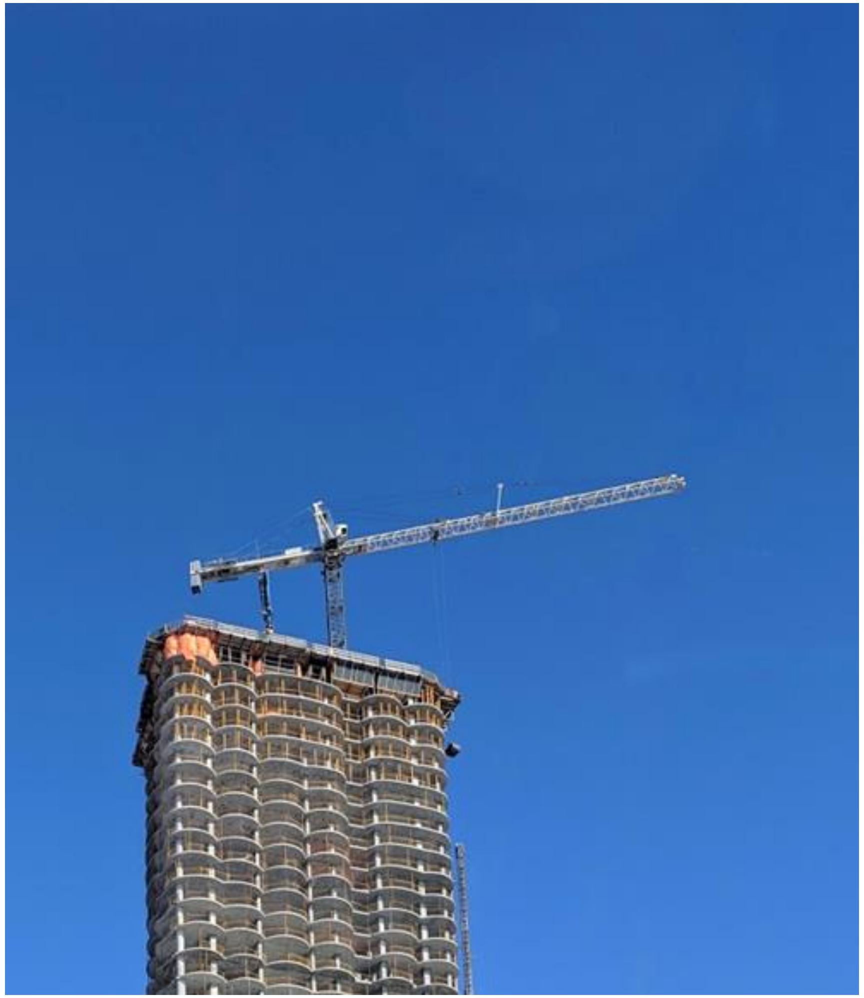
X btap_results.total_end_uses_gj

Y btap_results.total_envelope_cost

Name

Save Pareto Front

Conclusions and Next Steps



Conclusions:

- Procedurally create models of new building
- Many locations across Canada
- Estimate capital and energy costs of energy conservation measures
- Inform policy makers on cost and benefit of changes to building energy related codes or policies for new buildings

Next Steps:

- Include more energy conservation measures
- New building codes (NECB 2020 when released)
- Costing for energy code addressing retrofit of existing buildings

Acknowledgments & Questions

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Canada

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Cost Effectiveness Analysis of Energy Codes in the United States

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Senior Building Researcher

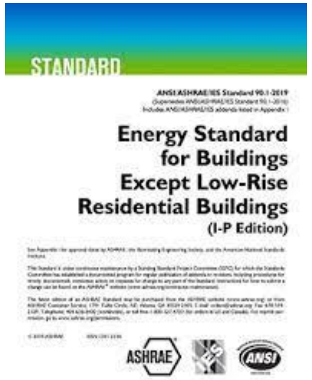
U.S. DEPARTMENT OF ENERGY BATTELLE

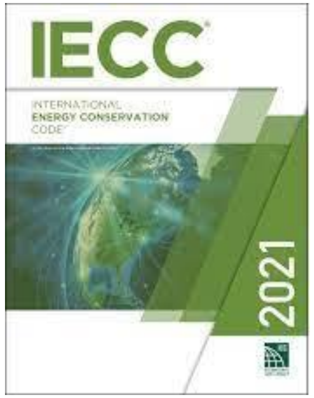
PNNL is operated by Battelle for the U.S. Department of Energy

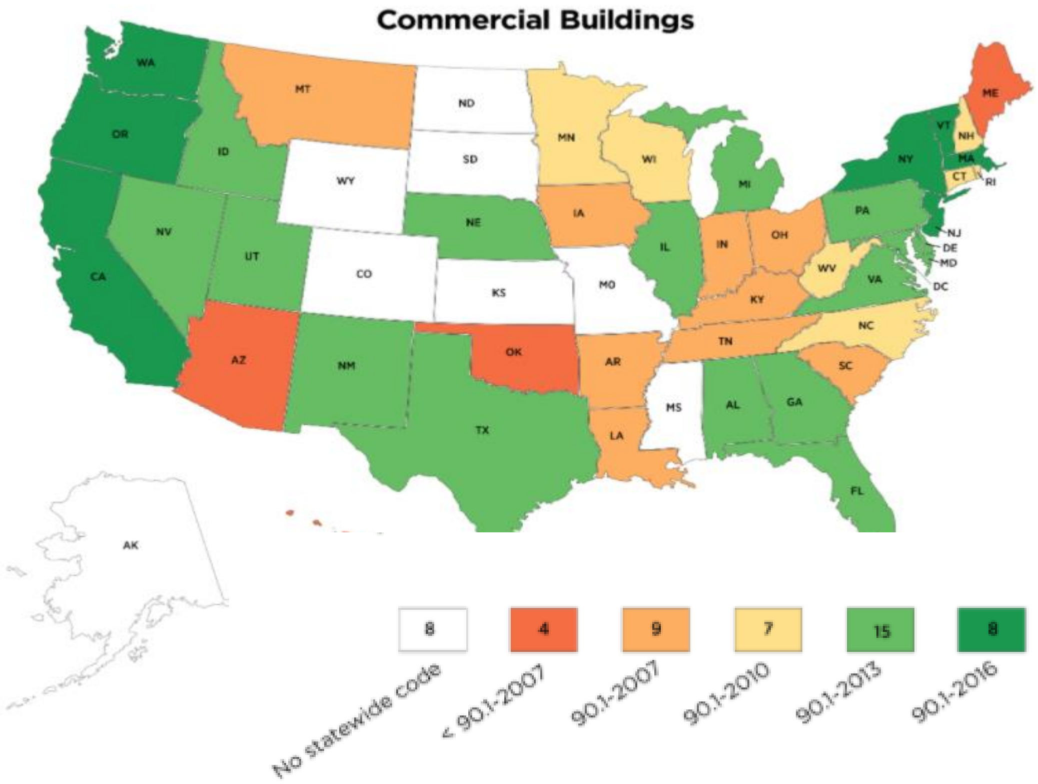
US Energy Code Background

Two national model energy codes

- **ANSI/ASHRAE/IES Standard 90.1** (commercial)
- **IECC** (commercial and residential)







ASHRAE 90.1: Rigorous cost effectiveness process for change proposals

IECC – encourages cost effectiveness but no specific criteria to follow

Individual States: Allowed to adopt modified versions of NMEC's. Many have their own LCCA criteria for cost effectiveness.

Estimating Energy and Energy Cost Savings

- Calculated using annual whole building simulation using Energy Plus at an hourly timestep.
- 16 commercial prototype buildings and 2 residential prototypes
- 16 ASHRAE climate zones in the United States
- Energy costs based on annual blended unit costs

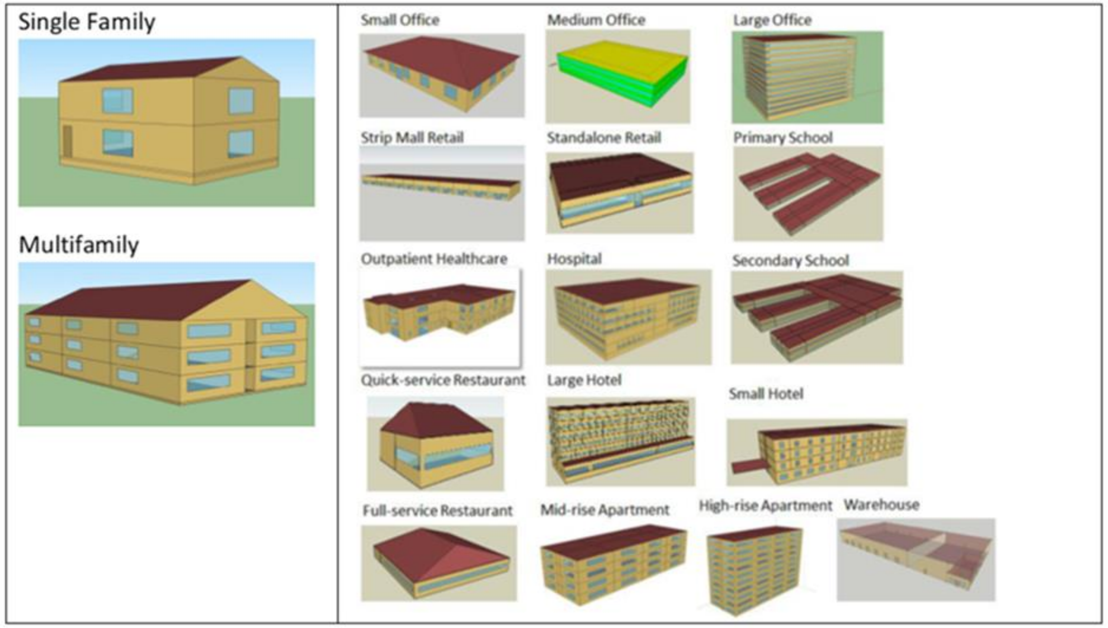


Table A.1. Model Code U.S. Climate Zone Locations

Climate Zone	Climate Zone Type	Thermal Condition	IECC - R		ASHRAE 90.1	
			Representative Location	Average Solar Insolation (kWh/ft2 day)	Representative Location	Average Solar Insolation (kWh/ft2 day)
1AT	Very Hot-Humid	9000 < CDD50°F	Honolulu, HI	0.55	--	
1A	Very Hot-Humid	9000 < CDD50°F	Miami, FL	0.54	Honolulu, HI	0.55
2A	Hot-Humid	6300 < CDD50°F £ 9000	Houston, TX	0.50	Tampa, FL	0.54
2B	Hot-Dry	6300 < CDD50°F £ 9000	Phoenix, AZ	0.61	Tucson, AZ	0.61
3A	Warm-Humid	4500 < CDD50°F £ 6300	Memphis, TN	0.48	Atlanta, GA	0.49
3B	Warm-Dry	4500 < CDD50°F £ 6300	El Paso, TX	0.61	El Paso, TX	0.61
3C	Warm-Marine	HDD65°F £ 3600	San Francisco, CA	0.52	San Diego, CA	0.53
4A	Mixed-Humid	CDD50°F £ 4500 and HDD65°F £ 5400	Baltimore, MD	0.45	New York, NY	0.43
4B	Mixed-Dry	CDD50°F £ 4500 and HDD65°F £ 5400	Albuquerque, NM	0.60	Albuquerque, NM	0.60
4C	Mixed-Marine	3600 < HDD65°F £ 5400	Salem, OR	0.39	Seattle, WA	0.37
5A	Cool-Humid	5400 < HDD65°F £ 7200	Chicago, IL	0.42	Buffalo, NY	0.40
5B	Cool-Dry	5400 < HDD65°F £ 7200	Boise, ID	0.48	Denver, CO	0.53
5C	Cool-Marine	5400 < HDD65°F £ 7200	--		Port Angeles, WA	0.38
6A	Cool-Humid	7200 < HDD65°F £ 9000	Burlington, VT	0.41	Rochester, MN	0.43
6B	Cool-Dry	7200 < HDD65°F £ 9000	Helena, MT	0.43	Great Falls, MT	0.43
7	Very Cold	9000 < HDD65°F £ 12600	Duluth, MN	0.41	International Falls, MN	0.40
8	Sub-Arctic	12600 < HDD65°F	Fairbanks, AK	0.29	Fairbanks, AK	0.29

Estimating Incremental Costs

Installed Costs: Material, labor, construction equipment, commissioning, overhead and profit.

Maintenance Costs: Additional maintenance costs are included as a separate item.

Replacement Costs: Included when the expected life of a component is less than the analysis period.

Residual Costs: Cost of a code change remaining at end of the LCC study period

- Data obtained from a combination of published and professional sources.
- National Studies use climate zone specific costs. State level studies use State specific cost adjustments.
- Adjustment Parameters are applied to base labor and material costs to better reflect actual costs.

Cost Estimate Adjustment Parameters	Adjustment	
New Construction Labor Cost	52.6%	Accounts for benefits, taxes, insurance overhead and profit.
New Construction Material Cost	15%-26%	Accounts for material waste, sales tax and profit
Replacement Additional Labor Allowance	65%	Added labor for demolition, protection, cleanup, and lost productivity
Replacement Labor Cost	62.3%	Same as new construction with slightly higher allowance for overhead.
Replacement Material Cost Adjustment	26%-38%	same as new construction with slightly higher allowances.
Project Cost Adjustment	28.8%	Subcontractor general conditions and general contractor overhead and profit

Calculating Cost Effectiveness – Economic Scenarios

Scenario 1: *Publicly-Owned Method* (commercial studies)

- Represents government or public ownership (without borrowing or taxes)
- Economic inputs established for Federal projects

Scenario 2: *Privately-Owned Method* (commercial and residential studies)

- Represents private ownership (includes loan and tax impacts)
- Typical residential and commercial economic inputs, considers tax impacts, interest and depreciation.
- For both Residential and Commercial studies, the First Cost is treated as a Loan with payments distributed over the LCC study period.

Scenario 3: ***ASHRAE 90.1 Committee Scalar Method*** (commercial studies)

- Private ownership perspective
- Economic inputs established by 90.1 ASHRAE Standing Standard Project Committee
- Alternative LCC approach for **individual energy efficiency changes** with a defined useful life, taking into account first costs, annual energy cost savings, annual maintenance, inflation, energy escalation, and financing impacts.

Calculating Cost Effectiveness – Economic Parameters

COMMERCIAL ECONOMIC PARAMETERS (2016)

Parameter	Symbol	Scenario 1 (Publicly-Owned Method)	Scenario 2 (Privately-Owned Method)	Scenario 3 (ASHRAE 90.1-2016 Scalar Method)
Period of Analysis	L	30 years*	30 years*	40 years*
Energy Prices		Latest national annual average prices based on current DOE Energy Information Administration (EIA) data**		$0.1013/kWh $1.00/therm blend†
Energy Escalation Rates		Price escalation rates taken from 2013 *NIST Handbook 135 Supplement*‡‡	National Institute of Standards and Technology (NIST) year-by-year rates (same as scenario 1)	NIST year-by-year rates (same as scenario 1) plus 2.38% inflation
Loan Term	M_L	N/A	$M_L = L$ (same as period of analysis)	$M_L = L$ (same as period of analysis)
Loan Interest Rate	I	N/A	6.00%	7.00%
Nominal Discount Rate	D_n	N/A	6.00% (same as loan rate)	9.34%
Real Discount Rate	D_r	3.0%	4.06%	5.0%
Inflation Rate	R_{INF}	N/A	1.87% annual	2.38% annual
Property Tax Rate	R_P	N/A	2.04%	N/A
Income Tax Rate, federal	R_{TF}	N/A	34.0%	0%‡
Income Tax Rate, state	R_{TS}	N/A	State values vary; highest marginal corporate rate used	0%‡

* Study period shown is for full code or standard analysis, for individual measures, measure life may be used as the study period.
** Average EIA prices from EIA. State prices from EIA are used for individual state analysis. National analysis of Standard 90.1 may use the Scenario 3 prices established by ASHRAE.

RESIDENTIAL ECONOMIC PARAMETERS (2016)

Parameter	Value
Mortgage Interest Rate	5%
Loan Term	30 years
Down-payment Rate	10% of home price
Points and Loan Fees	0.7% (non deductible)
Analysis Period	30 years
Property Tax Rate	0.9% of home price/value
Income Tax Rate	25% federal
Inflation Rate	1.6% annual
Home Price Escalation Rate	Equal to Inflation Rate

Calculating Cost Effectiveness - Metrics

Life-cycle cost net savings: *NPV of savings = PV(Incremental Benefits) – PV (Incremental Costs)*
(a.k.a., NPV or LLC)

Savings-to-investment ratio: $$SIR = \frac{PV(Benefits)}{PV(Costs)}$$

Simple payback: $$SP = \frac{First\ Cost}{Energy\ Savings}$$

Cash flow – Annual net positive cash flow used in Residential studies, reflects homeowner’s ability to pay their mortgage.

ASHRAE 90.1 Scalar Ratio: $$SR = \frac{First\ Cost}{Energy\ Cost\ Savings + Maintenance\ Savings}$$

SR is compared to a pre-determined SR Limit based on a measure’s useful life.

If the SR < SRL than a measure is deemed cost effective.

ASHRAE 90.1 Expanded Scalar Ratio: $$SR_{EX} = \frac{First\ Cost + PV(Replacement\ Costs) - PV(Residual\ Costs)}{Annual\ Energy\ Cost\ Savings - Increased\ Annual\ Maintenance\ Costs}$$

Used by PNNL in developing a National cost effectiveness scalar ratio metric when multiple measures are evaluated.

Calculating Cost Effectiveness – Weighting Factors

When calculating State and National cost effectiveness the results are aggregated based on different weighting factors for Commercial and Residential Buildings.

Commercial cost effectiveness metrics are developed by aggregating the energy and economic results across different building types and climate zones using **new construction floor area** weighting factors.

Residential cost effectiveness metrics are developed by aggregating energy and economic results based on foundation type, heating system type, climate zone and building type using **new permit** weighting factors.

Commercial Cost Effectiveness – ASHRAE 90.1-2016

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National Analysis

- **ASHRAE 90.1 Committee Scalar Method**
- Metrics: LCC, Simple Payback and Expanded Scalar Ratio.
- Uses a subset of climate zones and prototype buildings. (~50% of new construction floor area)

State Level analysis:

- **Scenario 1 (Public Method)** and **Scenario 2 (Private Method).**
- Metrics: NPV Savings (LLC) and Simple Payback
- Weighting factors, first costs, energy and economic parameters are all specific to each State.
- Uses same subset of prototype buildings as National study.

Prototype Model	Climate Zone and Location					
Life Cycle Cost Net Savings, $/ft^2	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	$2.20	$2.17	$2.21	$1.88	$2.19	$2.13
Large Office	$0.95	$1.08	$0.43	$1.34	$1.59	$1.18
Standalone Retail	$12.54	$12.40	$12.16	$12.22	$12.08	$12.28
Primary School	$5.46	$5.62	$4.23	$5.00	$5.74	$5.32
Small Hotel	$5.99	$5.80	$5.51	$6.00	$6.44	$6.03
Mid-rise Apartment	$2.06	$1.96	$2.02	$1.68	$2.54	$2.03
Weighted Total	$6.63	$7.00	$6.01	$5.91	$7.57	$6.68
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	2.1	2.0	1.9	4.1	2.1	2.4
Large Office	6.9	6.6	10.2	7.1	4.9	6.8
Standalone Retail	6.6	7.0	7.6	7.8	7.8	7.3
Primary School	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Small Hotel	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Mid-rise Apartment	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Weighted Total	Immediate	Immediate	Immediate	1.1	0.1	0.03
Scalar Ratio, Limit = 18.25[1]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	1.26	1.11	0.91	3.30	1.08	1.55
Large Office	8.47	8.11	10.63	8.43	5.12	8.07
Standalone Retail	(46.36)	(51.93)	(62.66)	(53.77)	(60.57)	(54.73)
Primary School	(6.99)	(5.82)	(7.01)	(3.69)	(5.86)	(5.78)
Small Hotel	(16.34)	(17.24)	(18.79)	(15.26)	(13.92)	(15.85)
Mid-rise Apartment	(17.61)	(17.95)	(18.21)	(15.45)	(22.19)	(18.08)
Weighted Total	(21.64)	(24.83)	(27.95)	(21.56)	(33.51)	(25.74)

ASHRAE 90.1-2016 NATIONAL COST EFFECTIVNESS RESULTS

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National Residential Cost Effectiveness: IECC 2015

Scenario 2 – Privately Owned Method

- Metrics: LCC, Simple Payback and Cash Flow
- Analysis considers:

US climate zones: All US Climate zones

Building Type: Single Family, Low-rise Multifamily

Foundation: Crawlspace, Heated Basement, Unheated Basement and Slab-on-grade

Heating Types: Heat Pump, Oil Furnace, Gas Furnace and Electric Resistance

Table ES.1. Life Cycle Cost Savings for the 2015 IECC

Climate Zone	Compared to the 2012 IECC ($/residence)	Compared to the 2009 IECC ($/residence)
1	+193	+4,418
2	+119	+5,725
3	+156	+6,569
4	+154	+8,088
5	+153	+7,697
6	+142	+11,231
7	+200	+17,525
8	+438	+24,003

Table ES.2. Simple Payback Period for the 2015 IECC

Climate Zone	Compared to the 2012 IECC (Years)	Compared to the 2009 IECC (Years)
1	0.0	6.6
2	3.8	8.1
3	3.4	7.9
4	1.4	5.1
5	1.6	3.9
6	1.0	4.9
7	0.0	3.1
8	0.2	2.2

Table ES.3. Impacts on Consumers' Cash Flow from Compliance with the 2015 IECC

	Compared to the 2012 IECC		Compared to the 2009 IECC	
Climate Zone	Net Annual Cash Flow Savings (for Year 1)	Years to Cumulative Positive Cash Flow	Net Annual Cash Flow Savings (for Year 1)	Years to Cumulative Positive Cash Flow
1	+$ 13	0	+$ 103	1
2	+$ 5	1	+$ 103	2
3	+$ 6	0	+$ 125	2
4	+$ 7	0	+$ 236	1
5	+$ 5	0	+$ 263	1
6	+$ 6	0	+$ 340	1
7	+$ 8	0	+$ 672	0
8	+$ 18	0	+$ 1,024	0

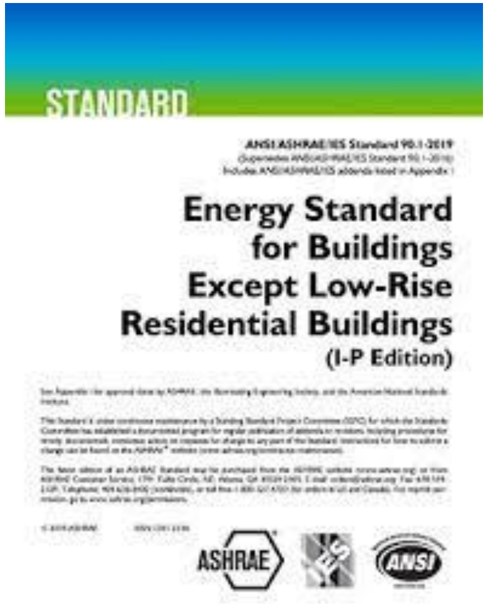
Time of Use Energy Pricing

California Title 24: Time Dependent Valuation (TDV)

- Hourly electricity cost profiles for each CA climate zone. Based on detailed models of CA electric grid operation.
- Account for variations related to time of day, seasons, geography and generation fuel type.
- Incentivizes efficiency measures that affect high-cost peak demand through load shifting.

ASHRAE 90.1-2022 TOU Pricing

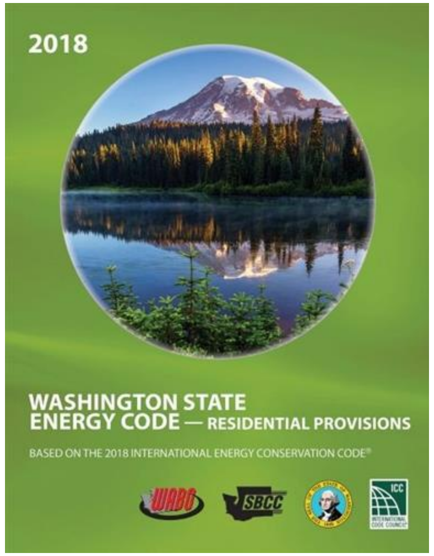
- Adopted an optional TOU cost metric for evaluating electric efficiency measures
- On-peak/Off-Peak rates for both Winter and Summer periods.
- Intended for efficiency measures that reduce peak electric demand, provide demand flexibility and promote load shifting.
- A measure to reduce lighting power by 20% shows increased energy cost savings of 80%-100% using a TOU electric rate.
- Freely shared Excel based TOU calculator
  https://drive.google.com/file/d/1At7NCrXzJJce_Wex5gbHg43t9JcmL4hT/view?usp=sharing



Cost of Carbon

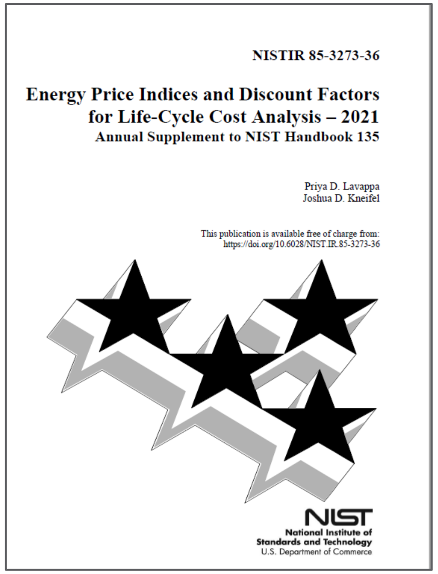
Washington State

- Energy code cost effectiveness includes social cost of carbon (SC-CO2)
- Carbon emissions equalized between heating source fuels
- Incentivizes high-efficiency heat pumps & renewable energy generation



Life Cycle Costing Manual for the US Federal Energy Management Program

- Guidance for incorporating a cost of carbon.
- Describes three scenarios based on analysis done by US Environmental Protection Agency in 2010. (*Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009: H.R. 2454 in the 111th Congress)*
- Cost per kg of CO_2 and electricity CO_2 emission rate adjustment factors projected out to 2051 for each Scenario
- Not used for Energy Code cost effectiveness


NISTIR 85-3273-36

Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2021
Annual Supplement to NIST Handbook 135

Priya D. Lavappa
Joshua D. Kneifel

This publication is available free of charge from:
https://doi.org/10.6028/NIST.IR.85-3273-36

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Evaluating Societal Benefits of Energy Codes

Carbon Emissions and Social Cost of Carbon

- ASHRAE 90.1-2019 determination will include calculations of carbon emissions savings (tons/kft^2-yr) and social cost of carbon impact ($/$kft^2$-yr).

Impact on Job Creation

- Analysis estimates the DOE Appliance Equipment Standard creates 8 jobs per US$M of energy savings on consumer bills based on studies using the IMSET (Impact of Sectoral Energy Technologies) modeling framework.
- An economic analysis of improved building energy codes should yield similar results.
- The PNNL Building Codes Program is currently evaluating two new metrics
    1. *Primary*: Economic benefits as a factor of total utility bill savings ($) returned to the economy, and;
    2. *Secondary*: Jobs created by increased energy efficiency achieved through energy codes (# jobs),

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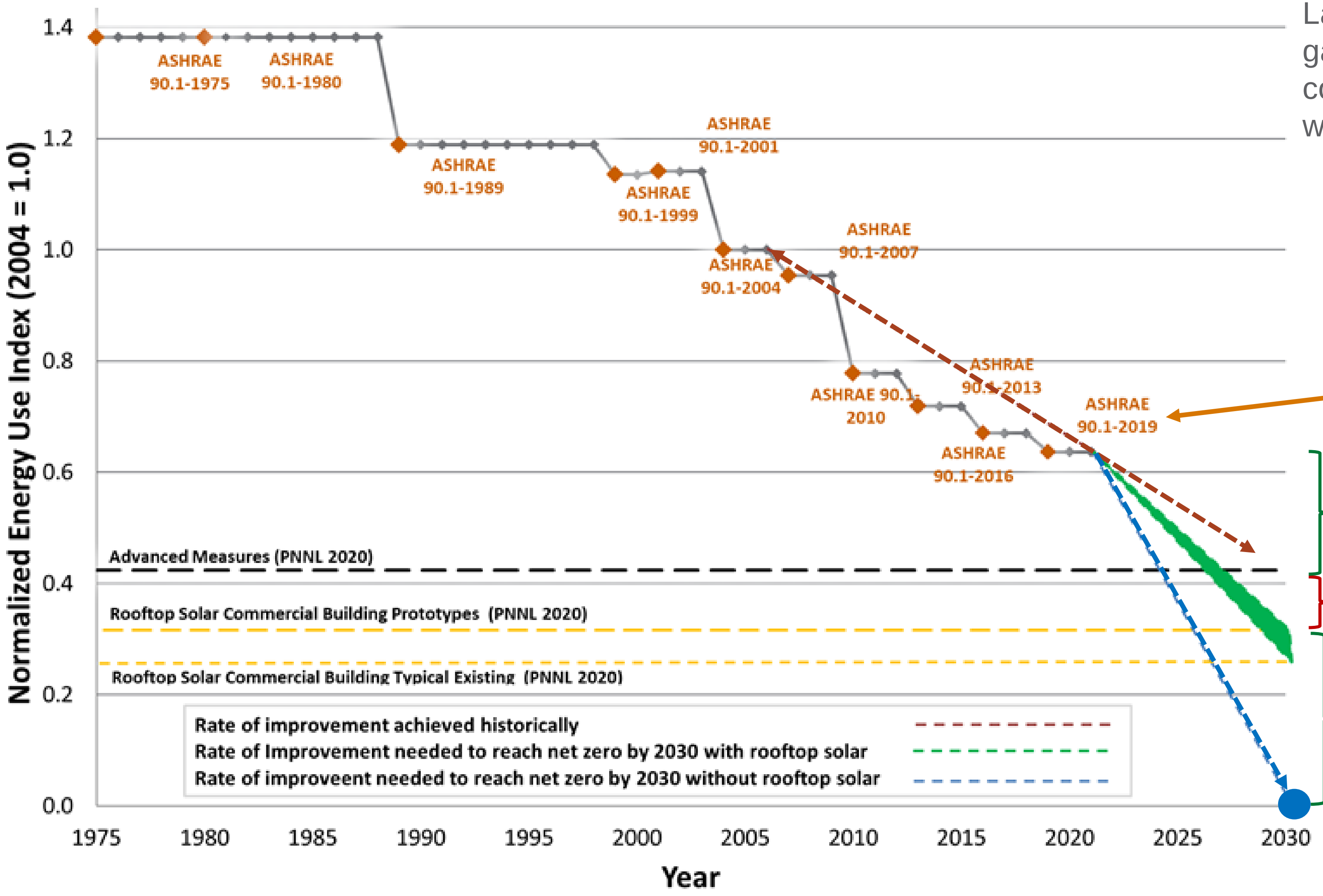
Moving Energy Codes to NZE

Latest reporting on the efficiency gap for achieving net zero commercial and residential buildings with model energy codes.



Current Code

Potential for additional energy efficiency

15% Gap for Commercial , 12% for Residential

Potential for On-site renewables

NZE Target

Thank you

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https://www.energycodes.gov

EBC

Energy in Buildings and
Communities Programme

Discussion – Q&A

Energy in Buildings and
Communities Programme

Thank you

Webinar slides & recording:

https://www.iea-ebc.org/
working-group/building-energy-codes