中国建筑科学研究院
China Academy of Building Research
建筑环境与节能研究院
Institute of Building Environment and Energy Efficiency

Optimization on Economic Efficiency of a Typical Nearly Zero Energy Residential Building Based on Life Cycle Cost Method

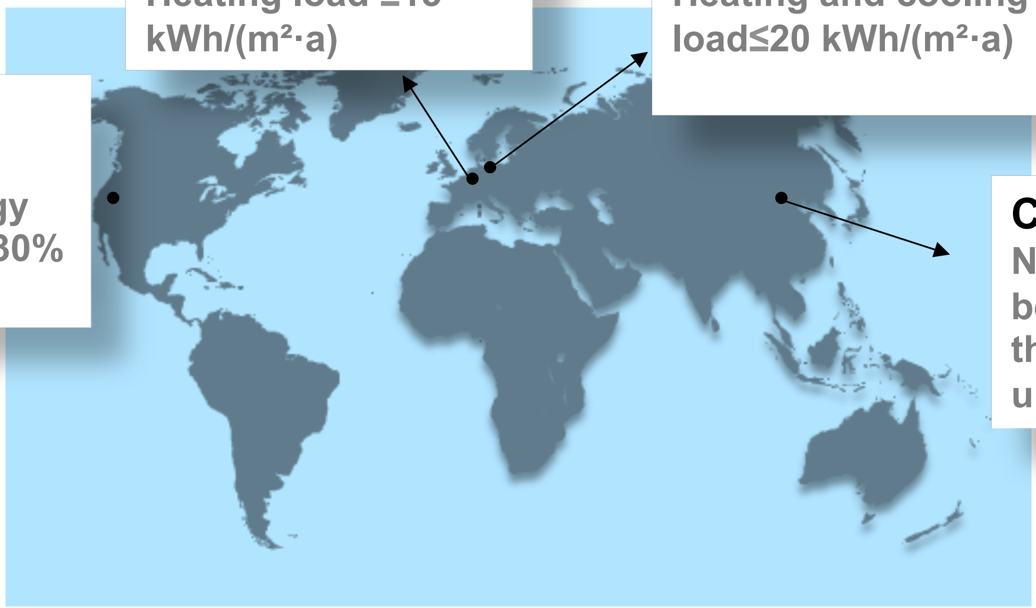
- *Sun Deyu & Li Zheng*

Institute of Building Environment and Energy
China Academy of Building Research

- Background
- Optimization Theory and Method
- Optimization of Typical Residential Building in Cold Areas
- Optimization Results of Building Performance
- Conclusion

Background

Nearly zero energy building (NZEB) has become the development trend of building energy efficiency.



USA：
Reducing building energy use intensity 30% by 2030

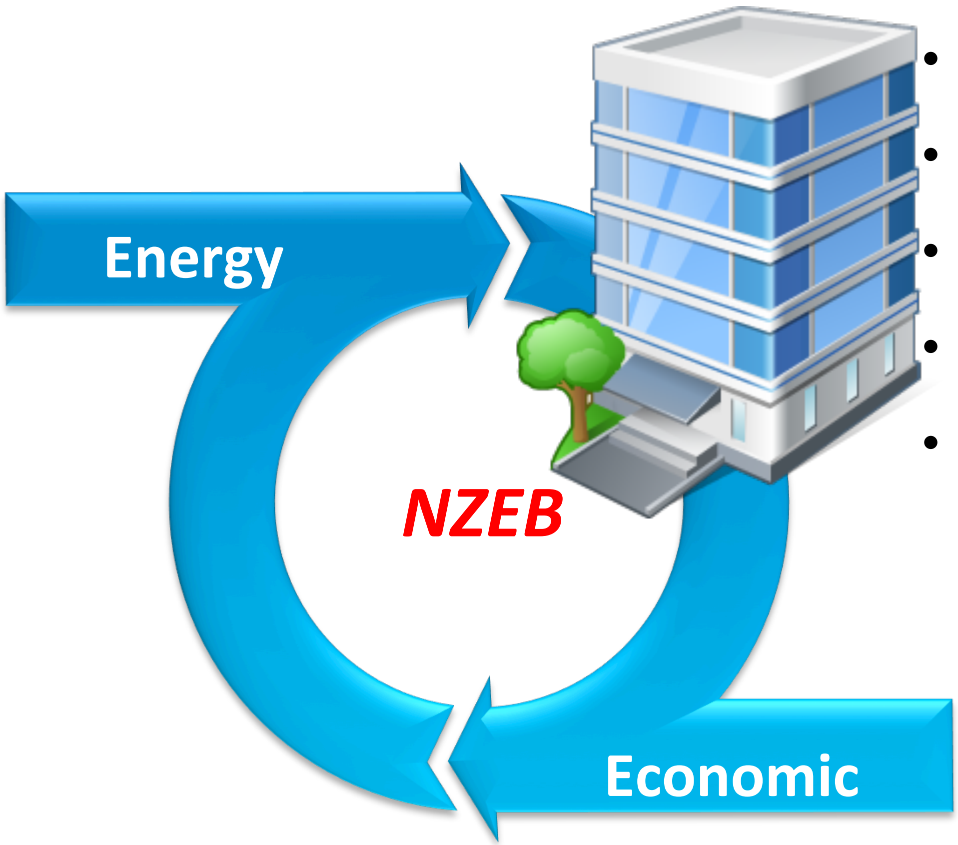
Germany：
Heating load ≤15 kWh/(m²·a)

Denmark：
Heating and cooling load≤20 kWh/(m²·a)

China：
Nearly 50 NZEBs has been completed. More than 100 NZEBs are under construction

Chinese government set a goal： By 2020, NZEB≥10 million m2
By 2020, Energy efficiency 20% ↑

Background



- Indoor environmental parameters
- Envelope performance parameters
- Economy parameters
- Equipment performance parameters
- Other parameters

Multi-parameter & Nonlinear Optimization Problem

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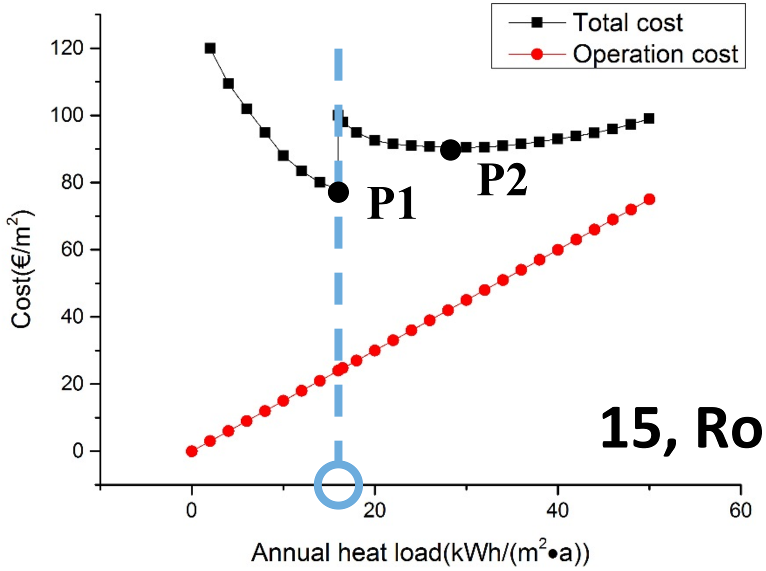
Optimization Theory and Method

- Cost curve of Passive House Institute (PHI)

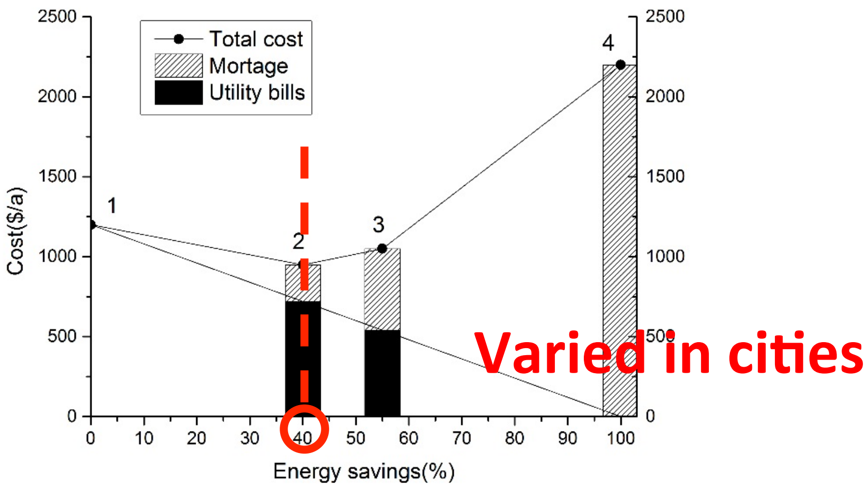


15, Roughly cost optimal

P1： Jump point, ~15kWh/(m^2▪a)， where heat system can be cancelled
P2： Stationary point, ~30kWh/(m^2▪a)

Optimization Theory and Method

- Cost curve of Passive House Institute US (PHIUS)

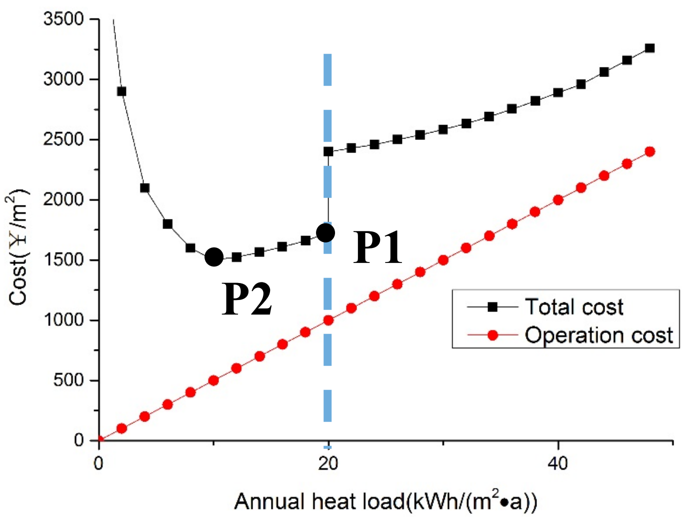


Differences:

- No jump point in the curve, stationary point is cost optimal
- Less benefit from capacity reduction for relatively low-cost heating equipment used in US residential
- Lower fuel prices, weakening the cost per kWh saved

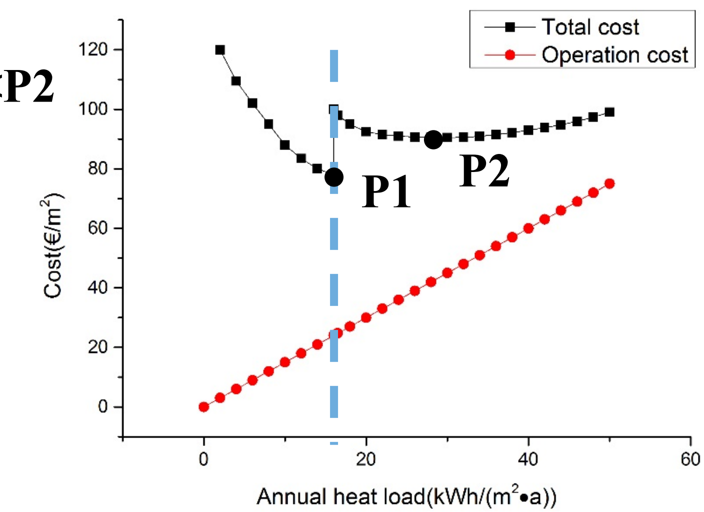
Optimization Theory and Method

- Cost curve in China cold areas



P1>P2　　**P1<P2**

Or

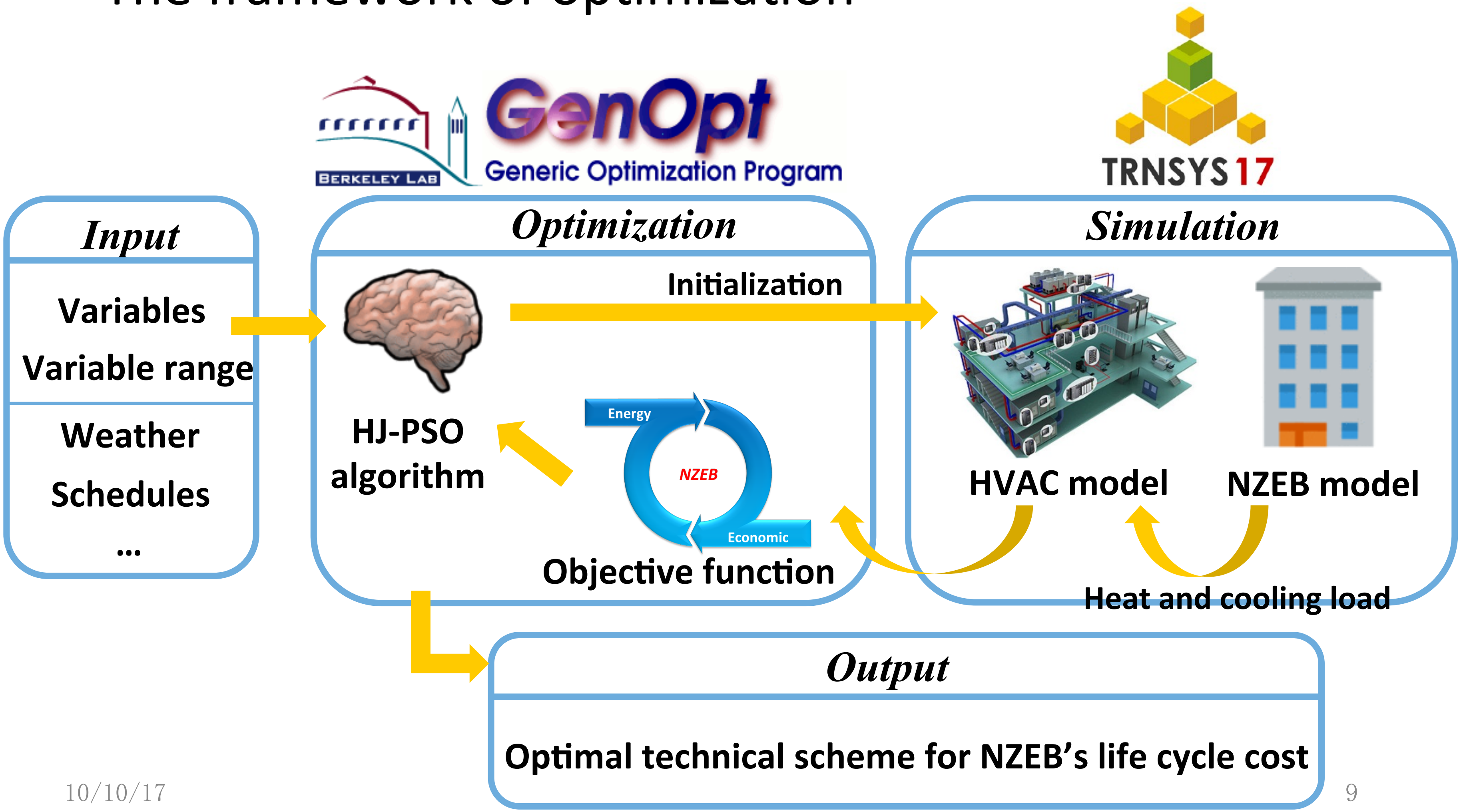


P1：Jump point, where heat equipment can be integrated with air-conditioning equipment

P2：Stationary point ⇨ **Judge the position of P1 & P2**

Optimization Theory and Method

- The framework of optimization



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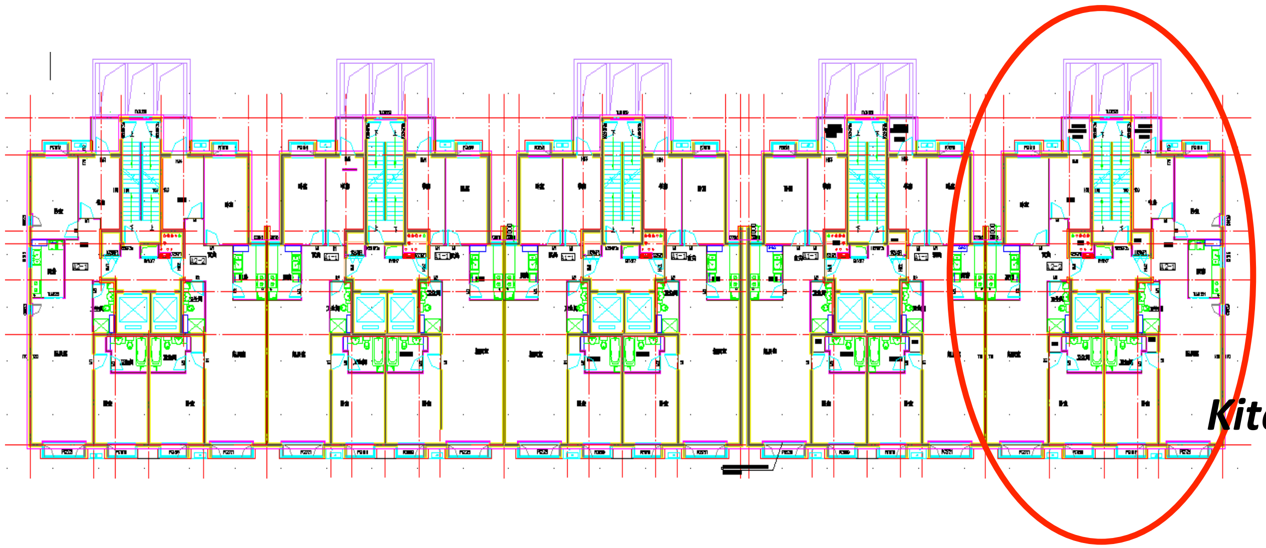
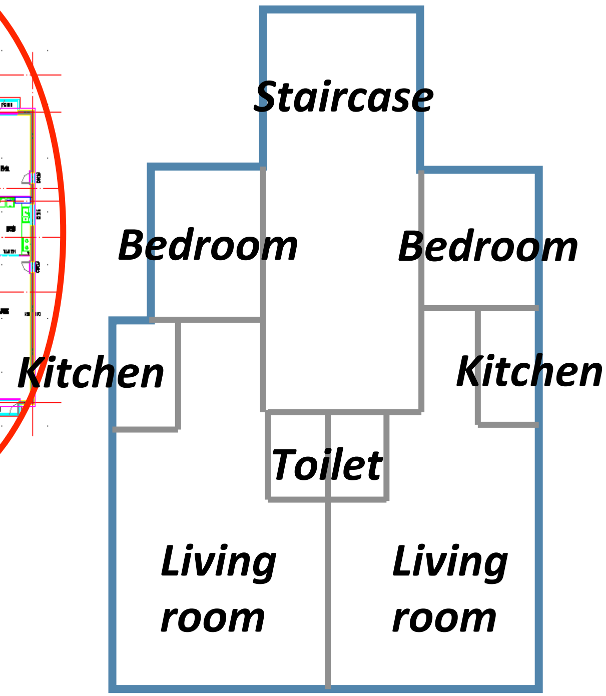
Typical building model

- *Located in Beijing*
- *27 floors, 35593 m^2*
- *Hourly weather file from IWEC(International Weather for Energy Calculations)*



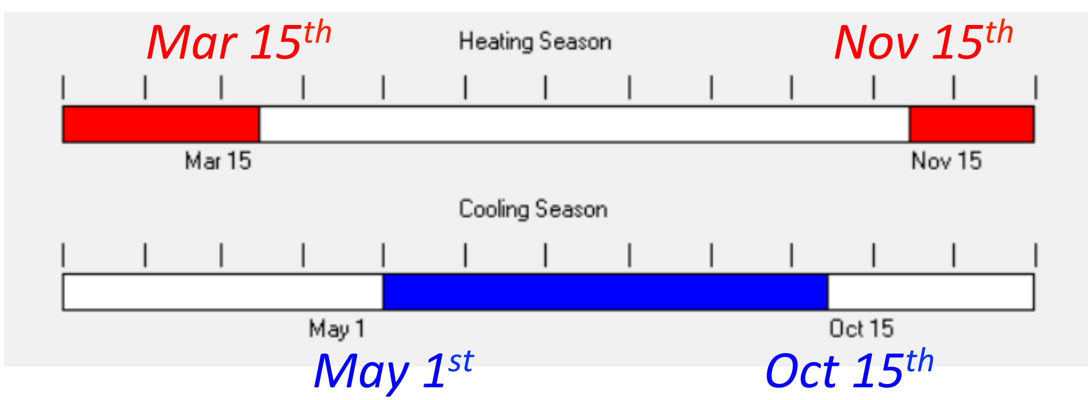


Set point of HVAC system

Room type	Indoor design air parameter	
	summer	winter
Living room	26℃, 60%	20℃
Bedroom	26℃, 60%	20℃
Toilet	26℃, 60%	20℃
Kitchen	26℃ (No humidity control)	20℃
Staircase	\	5℃

Heating season

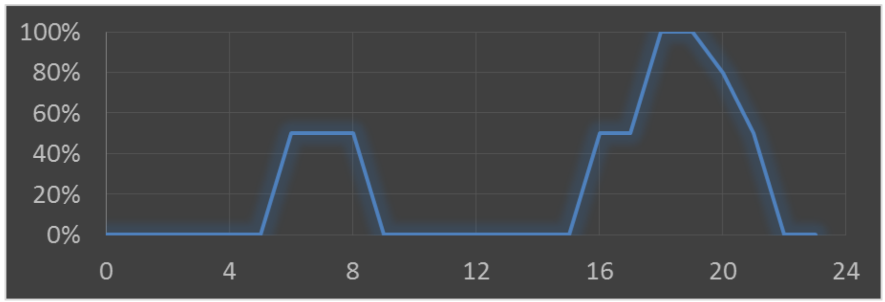
Cooling season



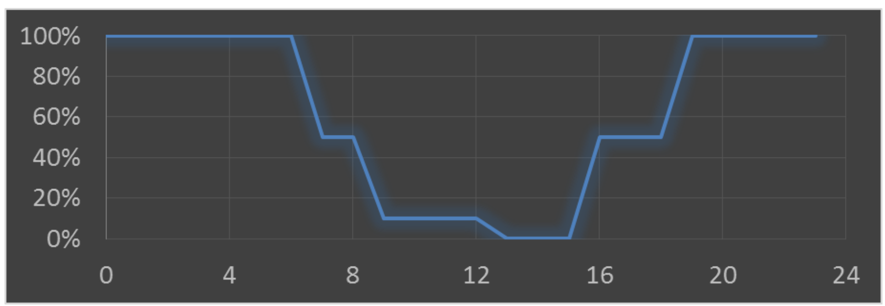
Schedules

e.g. Weekdays, bedrooms

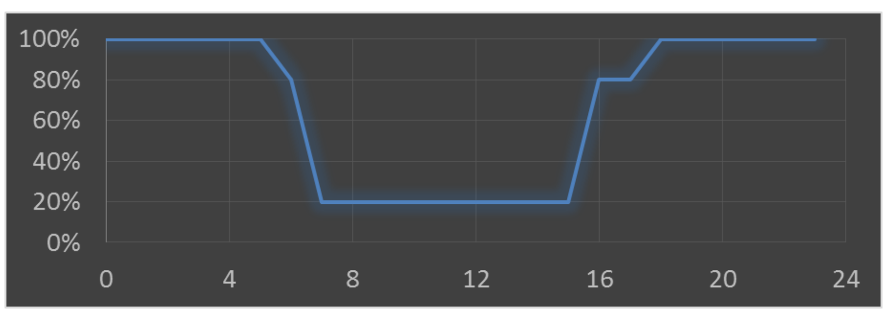
Lighting



Occupancy

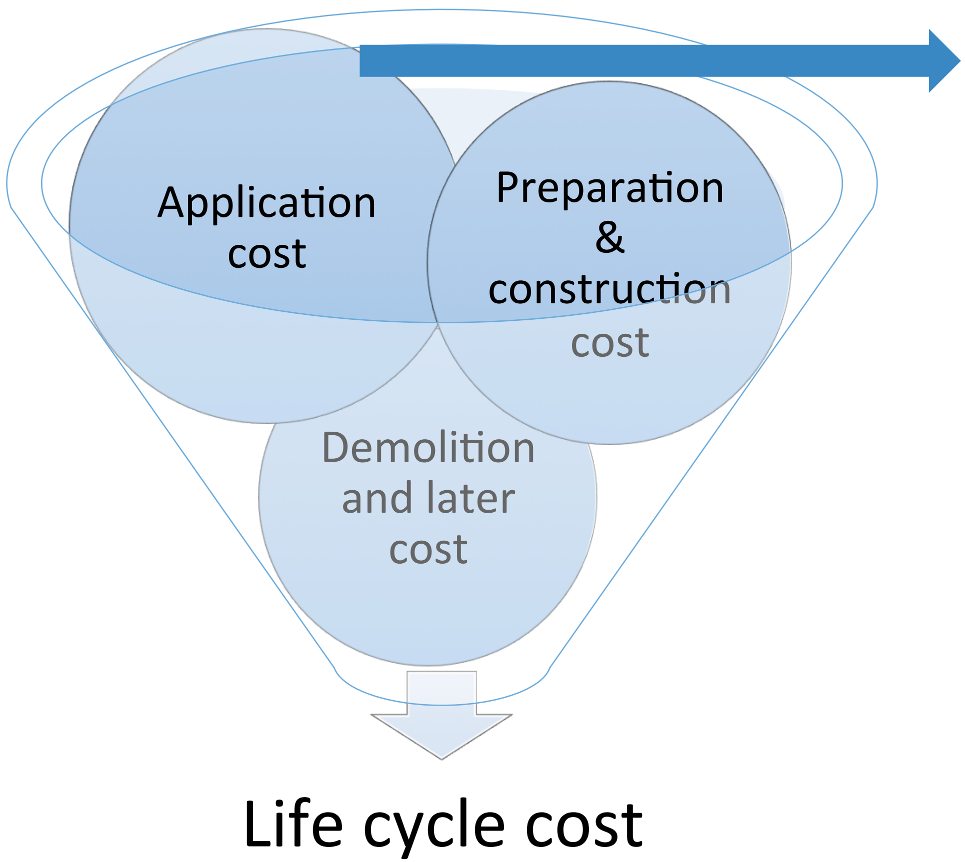


Ventilation



Objective function

- Life cycle of building



- *90% or more*
- *Initial investment*
  - *Insulation*
  - *Wall*
  - *Window*
  - *Heat pump*
  - *…*
- *Operation cost*
  - *Electricity*
  - *Gas*

Objective function

- Initial *investment*

$$F_{ini} = \sum_{j=0,25} \left[(F_{ins} + F_{wi})(1+r_e)^{-j} \right] + \sum_{k=0,17,34} \left[(F_{so} + F_{hr} + F_{hp} \right.$$

Time discount rate

Cost of insulation and window

Insulation and window are replaced twice during the building life, at initial and 25th year

$$r_e = \frac{1+i}{(1+e)(1+f)} - 1$$

r_e ——Actual interest rate

i ——Nominal interest rate, 7%

e ——Escalation rate, 1%

f —— Inflation rate, 2%

Objective function

- Operation cost

$$F_{oc} = \sum_{i=1}^{n} \left[w(E_h + E_C)(1+r_e)^{-i} \right]$$

n——Building life span, 50 years ① ;
E_h ——Annual heat energy demand per unit area;
E_C ——Annual cooling energy demand per unit area;
w——Electricity price, considering external cost of electricity generation in the coal power chain 0.88￥/KWh ②;

① *Dong Chao, et al. Life cycle assessment for integrated building energy consumption [J]. HV&AC, 2014, 44(9):91-96*
② *Jiang Ziying. Study on the External Cost of Nuclear Power and Coal Power in China [D]. Beijing, Tsinghua University, 2008*

Economic parameters

Building materials or equipment	Unit price	Notes
EPS insulation board	650 ￥/m^3	
Active external shading device	1 500 ￥	
Fresh air total air heat recovery unit	Y = {6 600,8 000,12 276,23 800} (￥) X={0.6,0.75,0.78,0.81}	X:total heat recovery efficiency
External window	Y = 2 500 –1 000X（0.7=< X_1=<1.1）(￥/m^2)	X:external window U-value
External wall	400 ￥/m^2	
Heat pump unit	Y = 1 525 + 0.39X（X=<3 600） (￥) Y = 470 + 0.88X（X>3 600） (￥)	X:capacity of unit (W)

Range of variables

Variables	Nomenclature	Type	Range	Step size
External wall U-value	K_{ex}	Continuous	0.1~0.3 W/(m² • K)	0.05
Roof U-value	K_{roof}	Continuous	0.1~0.3 W/(m²•K)	0.05
Summer external shading coefficient	S_{out}	Continuous	0~0.5	0.1
Total heat recovery efficiency	η_{HR}	Discrete	{0.6,0.75,0.78,0.81}	-
External window U-value	K_{wi}	Discrete	0.7~1.1 W/(m²•K)	0.1
South window-wall area ratio	R_{s}	Discrete	{0.433,0.5,0.6}	-
East/west window-wall area ratio	$R_{e} \backslash R_{w}$	Discrete	{0.1,0.2,0.3}	-
North window-wall area ratio	$\boldsymbol{R_{n}}$	Discrete	{0.275,0.3,0.4}	-

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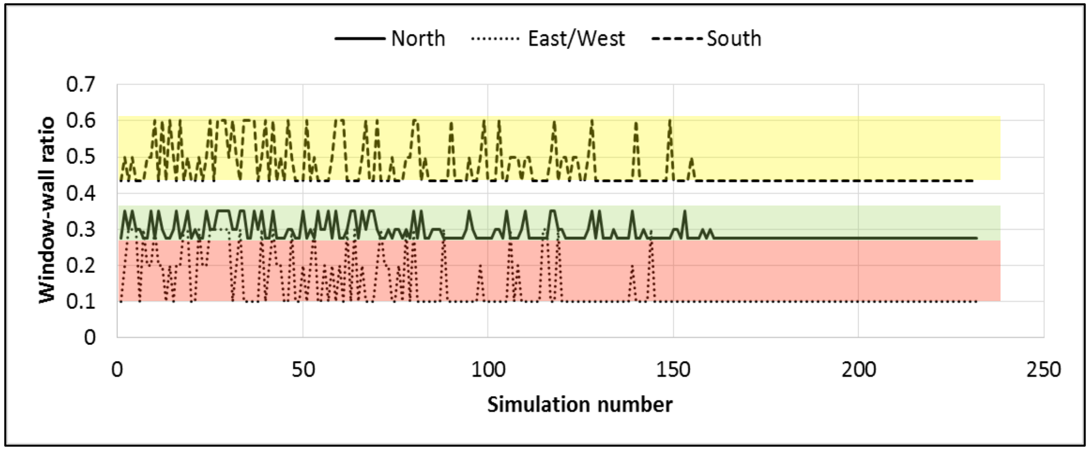
Simplification of optimization

It was found that:

- Optimal value of summer shading coefficient is always fixed at the upper bound
- Optimal value of window-wall ratios are always fixed at the lower bound



Window area is the dominating factor of life cycle cost for its high price!

Simplification of optimization

However, the window area should have a lower limit to meet the **indoor lighting need**

- According to lighting level IV of *Standard for daylighting design of buildings*:

Lighting level	Side lighting	
	Glazing to floor area ratio	Lighting effective depth(m)
I	1/3	1.8
II	1/4	2.0
III	1/5	2.5
IV	1/6	3.0
V	1/10	4.0

- The lower bound of typical building

South	North	East/West
0.433	0.275	0.1

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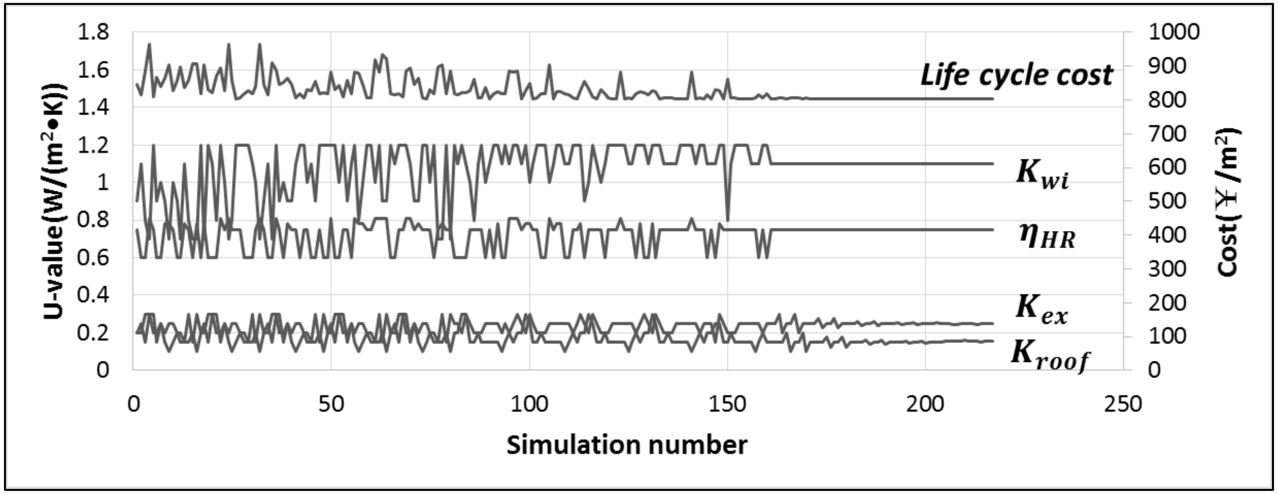
Optimization results



- *5.5 hours, 217 steps*

Variables	Optimized value	Set range
External wall U-value	0.247	0.1~0.3
External roof U-value	0.153	0.1~0.3
Heat recovery efficiency	0.75	{0.6,0.75,0.78,0.81}
External window U-value	1.1	0.7~1.1

Optimization results

Other results under the optimal scheme of building parameters

Minimum life cycle cost: 804 ￥/m^2

Initial investment: 661 ￥/m^2

Initial investment: 143 ￥/m^2

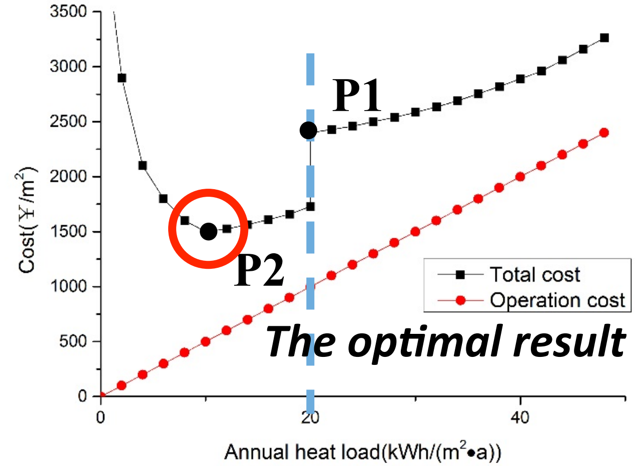
Annual heat demand: 8.03 kWh/(m^2•a)

Annual cooling demand: 17.73 kWh/(m^2•a)

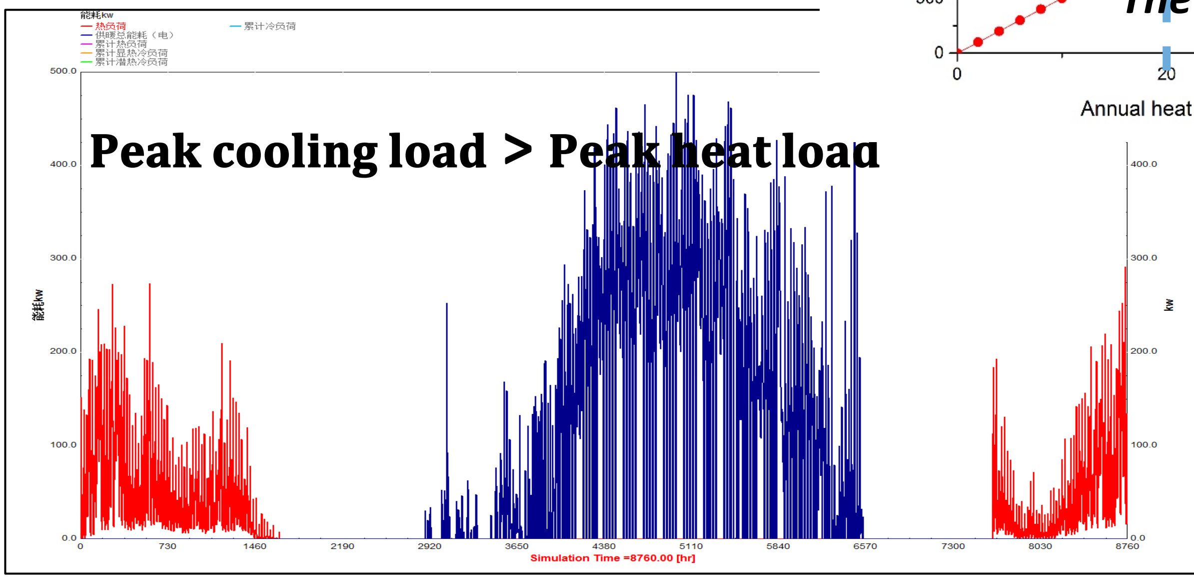
Annual electricity consumption: 10.18 kWh/(m^2•a)

Building heat and cooling system can be integrated!

Optimization results



Annual heat and cooling load



Building heat and cooling system can be integrated! This optimal scheme has crossed the threshold of jumping.

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Conclusion

- 1. Considering environmental cost of energy, the technical scheme and performance of residential buildings in the cold areas can be optimized for economic and environmental benefits.
- 2. The jump point of cost curve exist in the typical nearly zero energy residential buildings in cold areas when the heat pump can meet both the heat and cooling needs.
- 3. A multi-objective and multi-parameter optimization method and platform for NZEB is established. The method combines the energy consumption simulation tool TRNSYS and the optimization analysis tool Genopt to launch optimization.

Thank You!

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