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An Efficient and Accurate Building Optimization Strategy Using Singular Value Decomposition

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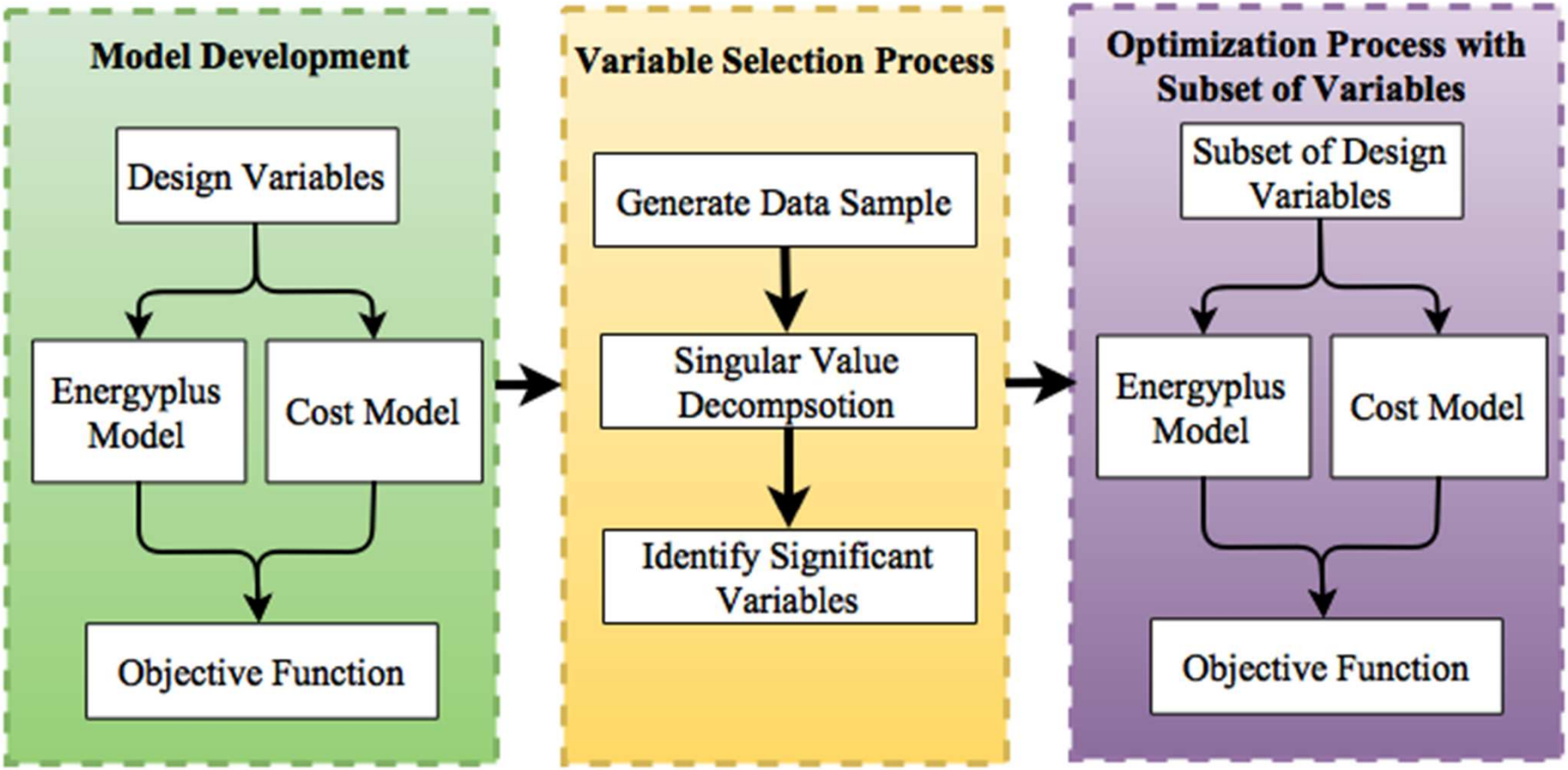
Introduction

- Optimizing the life cycle cost of a building typically involves a large number of variables due to the many options
- Large-scale optimization problems are often prohibitive because of calculation time
- To perform the optimization within an acceptable time frame, the focus of this study is on reducing the number of design variables that are considered during the optimization process

Methodology



Model Development

Life cycle cost

- To assess the total cost associated with any given building construction permutation

$$LCC = C_{Construction} + C_{Utility}$$

$C_{Construction}$: Cost Model

$C_{Utility}$: Energyplus Model

Design variables

- elements that may have a high impact on house energy consumption,
- elements that may have a strong influence in the construction cost
- elements that may have energy saving or cost saving but whose influence is not strictly known beforehand

Variable Selection

- Jacobian matrix, A: Measure spatial average of magnitudes of directional derivate of objective function over design space

- Using Singular Value Decomposition, approximate a matrix to identify significant components

$$A = USV^T = U_1 S_1 V_1^T + U_2 S_2 V_2^T \approx U_1 S_1 V_1^T$$

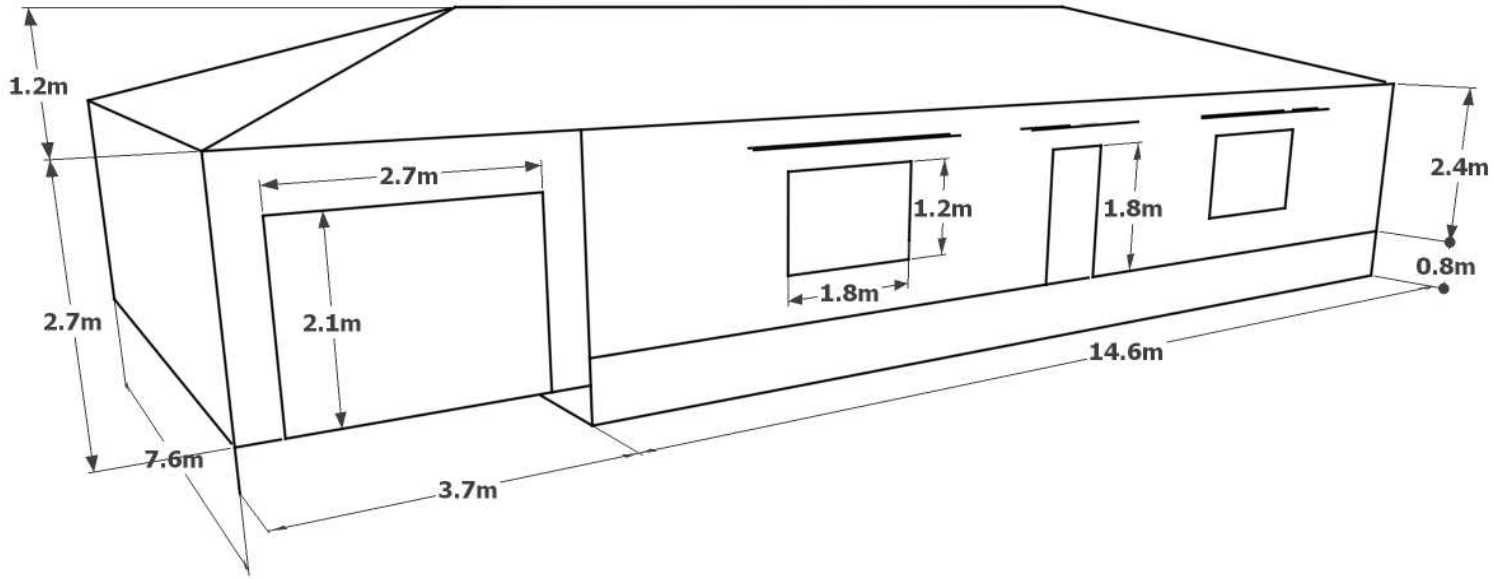
- Discard the variables that contributes less to the new variable by examining the column vectors of V_1^T

Optimization

- Optimization is performed with reduced number of original variables
- Remaining Variables can be fixed to any values
  - » cheapest material
- A discrete binary version of the particle swarm optimization methodology

Case Study

- Typical residential building
- Gross floor area of the house: 139.1m^2
- The living space (111m^2), actively conditioned
- Denver, CO, Indianapolis, IN, Minneapolis, MN, Phoenix, AZ, Seattle, WA, Tampa, FL



Design Variables

Design variables (Number of options)	
Roofing Material (3)	Under Floor Insulation (7)
Roof Eave overhang Depth (3)	Window Type (2)
Attic Insulation Material (12)	Garage Door (4)
External Wall Siding Material (4)	Heat Recovery Type (2)
Wall Core (16)	Air Conditioner Seasonal COP (6)
External Foam Board Insulation (6)	Natural Gas Furnace Efficiency (4)
Foundation Wall Insulation (9)	

External Wall Siding Material	Vinyl siding, Wood siding, Fiber cement siding, Brick
External Foam Board Insulation	12.7, 25.4, 38.1, 50.8, 63.5, 76.2 [mm]
Heat Recovery Type	None, Sensible heat recovery
Natural Gas Furnace Efficiency	80%, 85%, 90%, 95%

Objective Function

Life Cycle Cost

- 20-year time horizon
- Consider incremental life cycle cost

$$LCC = C_{Mat} + C_{Equip} + C_{Elec} + C_{Ng}$$

C_{Mat}: *Material cost, RSMeans*

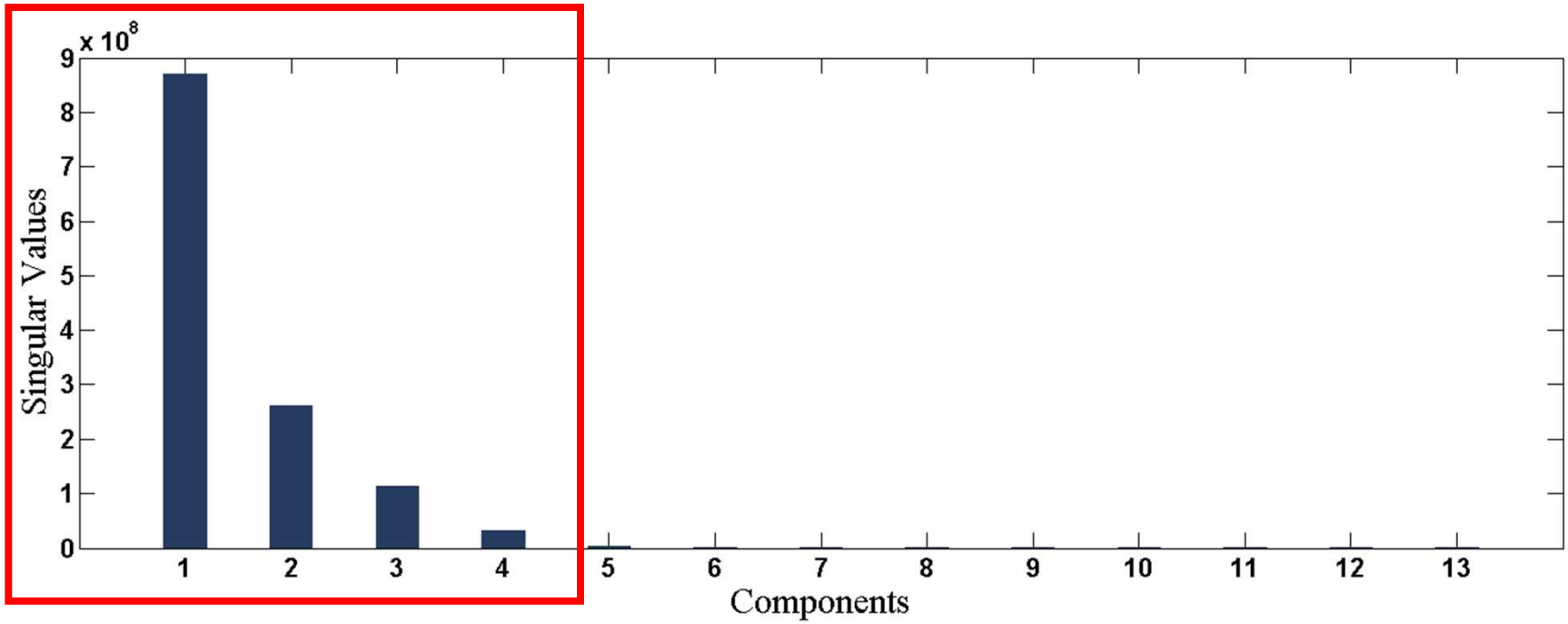
C_{Equip}: *HVAC equipment cost, online equipment suppliers*

C_{Elec}: *Electricity cost*

C_{Ng}: *Natural gas cost*

Variable Selection

- 100 data samples for each location is generated
- singular value decomposition (SVD) is applied to the data set



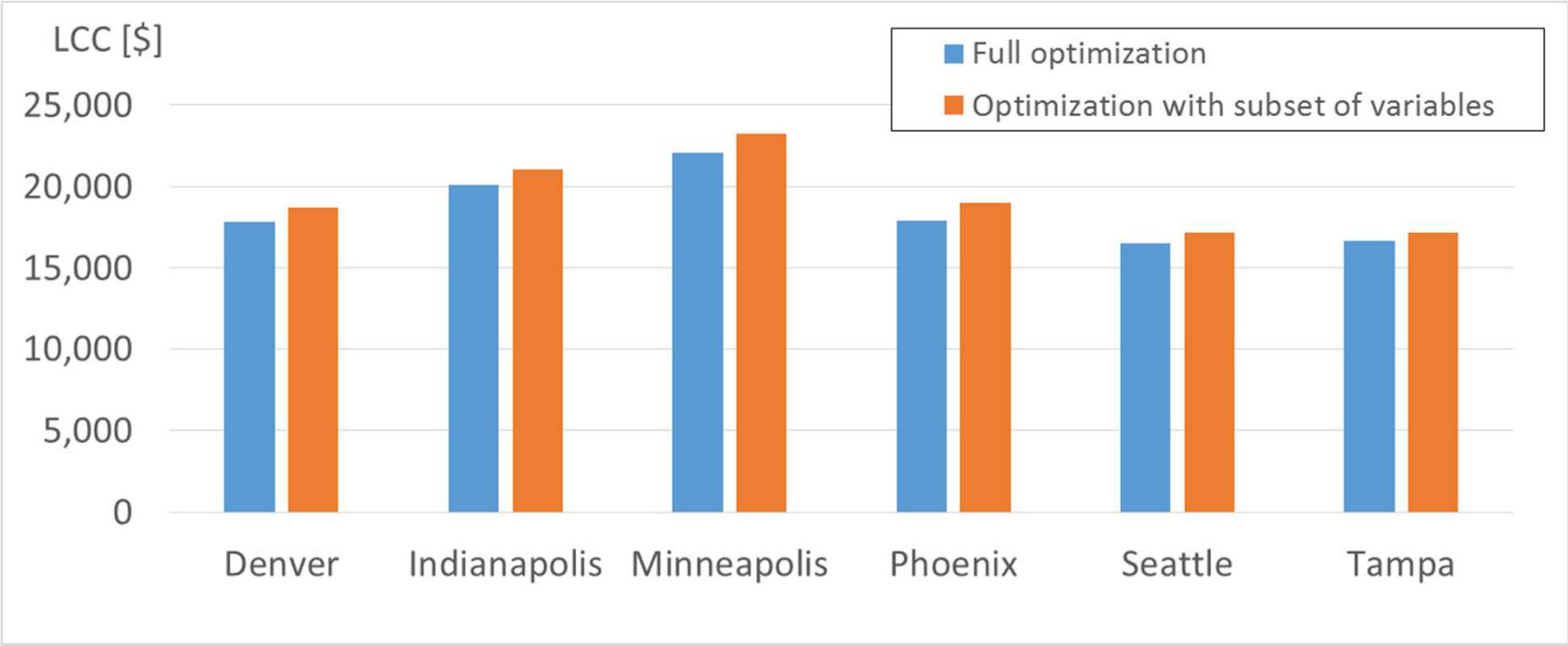
Singular Value Decomposition

	1	2	3	4
Roofing Materials	-0.009	**0.238**	0.007	0.001
Roof Eave Over Hang Depth	-0.001	0.002	-0.001	0.002
Attic Insulation Material	0.006	-0.004	0.025	0.033
External Wall Siding Material	**-0.999**	-0.033	-0.019	-0.017
External Foam Board	0.004	-0.054	-0.019	-0.011
Wall Core	-0.018	-0.032	**0.999**	-0.008
Foundation Wall Insulation	0.000	-0.021	-0.012	0.006
Under Floor Insulation	-0.018	0.003	0.007	**0.999**
Window Type	-0.029	**0.875**	0.025	-0.003
Garage Door	0.004	-0.061	-0.010	-0.002
Heat Recovery Type	0.013	**-0.401**	-0.012	0.004
Air Conditioner Seasonal COP	0.002	-0.085	-0.005	0.006
Natural Gas Furnace Efficiency	0.002	-0.020	-0.004	-0.015

Location	Denver	Indianapolis	Minneapolis
Selected design variables	Roofing Materials	Roofing Materials	Roofing Materials
	External Wall Siding Material	External Wall Siding Material	External Wall Siding Material
	Wall Core	Wall Core	Wall Core
	Under Floor Insulation	Under Floor Insulation	Under Floor Insulation
	Window Type	Window Type	Window Type
	Heat Recovery Type	Heat Recovery Type	Heat Recovery Type
	Air Conditioner Seasonal COP		

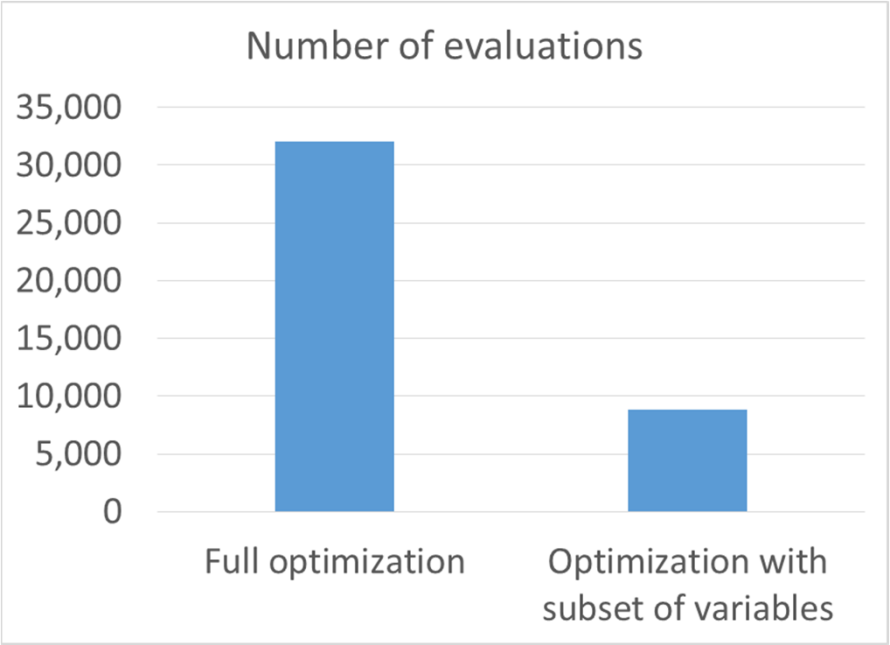
Location	Phoenix	Seattle	Tampa
Selected design variables	External Wall Siding Material	Roofing Materials	External Wall Siding Material
	Wall Core	External Wall Siding Material	Wall Core
	Under Floor Insulation	Wall Core	Under Floor Insulation
	Window Type	Under Floor Insulation	Window Type
	Heat Recovery Type	Window Type	Heat Recovery Type
	Natural Gas Furnace Efficiency	Heat Recovery Type	Natural Gas Furnace Efficiency
		Air Conditioner Seasonal COP	

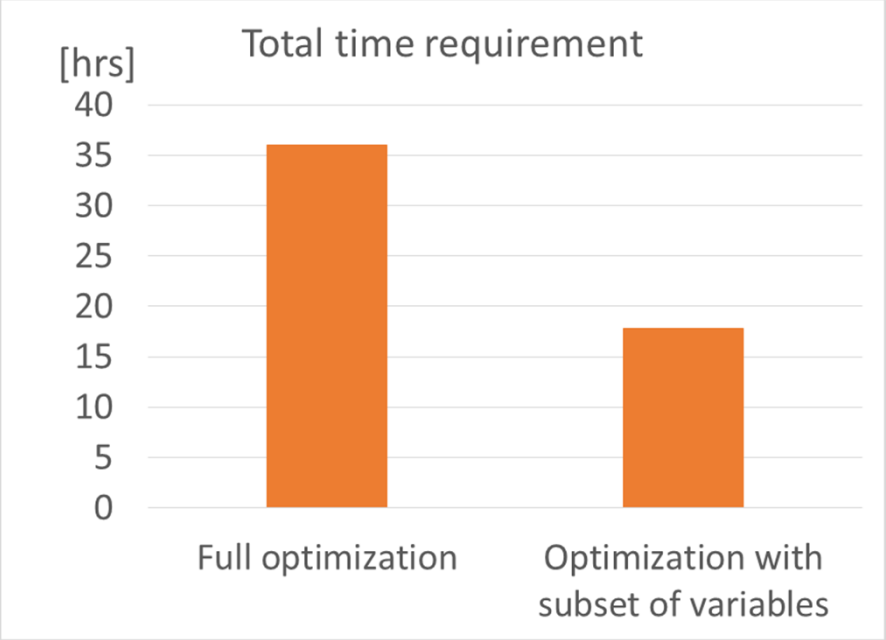
Optimization Result Comparison



Optimization Result Comparison

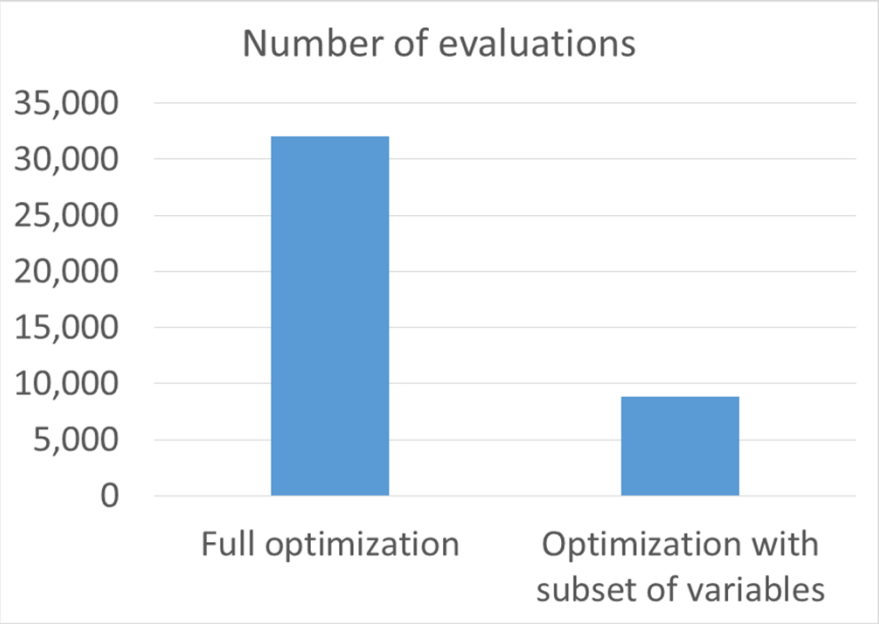
- Using a 6-core processor and 6 gigabytes of RAM
  - » Variable selection: 14.6hrs, optimization: 3.25 hrs
  - » Total: 17.85 hrs

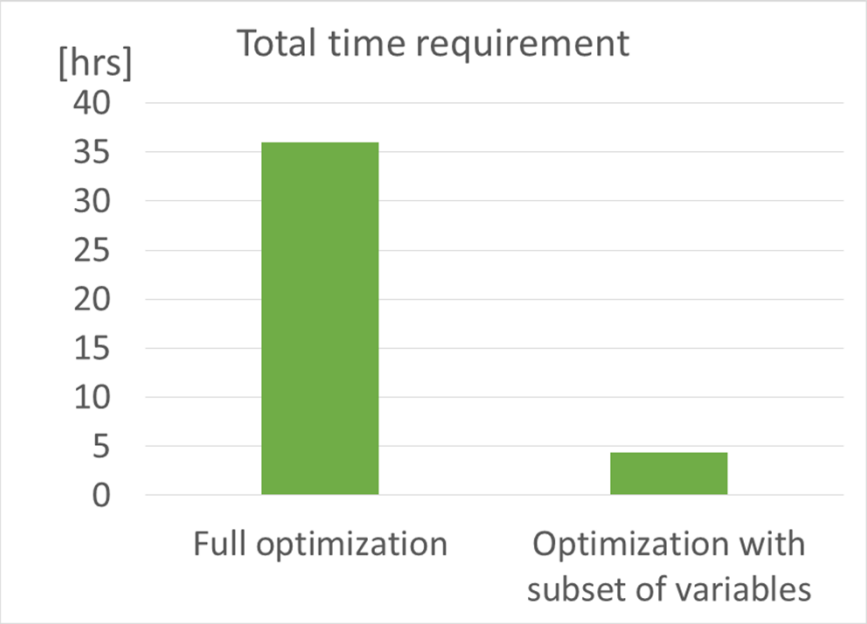




Optimization Result Comparison

- By implementing parallel computing
  - » Variable selection: 1.1 hrs, optimization: 3.25 hrs
  - » Total: 4.35 hrs





Conclusion

- Developed a methodology to perform an efficient and accurate life cycle building optimization in an acceptable time frame
- Applied the methodology to a case study of typical residential building
- Compare the results with those of the full optimization process over the entire design space
- The result shows a significantly shortened time requirement for the optimization process of 88%, while the optimized life cycle cost is close enough to the original optimum point by 3.2 to 6.2 %.