Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
30	0.000	0.000	100.000						
31	0.000	0.000	100.000						
32	0.000	0.000	100.000						
33	0.000	0.000	100.000						
34	0.000	0.000	100.000						
35	0.000	0.000	100.000						
36	0.000	0.000	100.000						
37	0.000	0.000	100.000						
38	0.000	0.000	100.000						
39	0.000	0.000	100.000						
40	0.000	0.000	100.000						
41	0.000	0.000	100.000						
42	0.000	0.000	100.000						
43	0.000	0.000	100.000						
44	0.000	0.000	100.000						
45	0.000	0.000	100.000						
46	0.000	0.000	100.000						
47	0.000	0.000	100.000						
48	0.000	0.000	100.000						
49	0.000	0.000	100.000						

Table 8. Rotated Component Matrix.

Code	Component										
	1	2	3	4	5	6	7	8	9	10	11
FPT23	.810										
FC10	.800										
FPT16	.787										
FPT20	.765										
FPT19	.717										
FPT22	.702										
FPT13	.624										
FPT18	.623										
FC2	.619								-.462		
FPT21	.611	.464									
FPT17	.606				.516						
FPT3		.849									
FD15		.668									
FPT4	.431	.628				.419					
FD11		.614	.469						.410		
FPT12		.509		.503							
FPT2		.501					.417				

Code	Component										
	1	2	3	4	5	6	7	8	9	10	11
FPT14		.446		.408							
FPT7			.810								
FC7	.433		.588								
FPT1			.552					-.434			
FC5			.534	.416							
FD7				.872							
FC6	.490			.695							
FC1				.530						.507	
FC4				.550							
FC3				.463		.406					
FD16					.787						
FPT15					.755						
FPT5				.471	.670						
FPT6		.450			.603						
FPT10						.779					
FPT9						.715					
FPT11			.449			.505					
FD4							.849				
FD13			.451				.670				
FD12			.477				.639				
FD10								.883			
FD1								.729		.436	
FD3				-.408				.614			.439
FPT8					.418			-.524			
FD2									.823		
FD5									.819		
FD6									.517		
FD8										.885	
FD9										.719	
FC9											.806
FC8	.471										.601
FD14					.451						-.600

Note: Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 113 iterations.

DISCUSSIONS

The high capital cost hinders prefabrication development. Our study explored 49 factors affecting the high capital cost of prefabrication. This study found that experience as a tacit knowledge, has an important effect on project management. This result can be adopted by decision-maker to promote the prefabrication development. For experienced, OCI, COI, DAI, SI, TMI, DSI, CGI, LCI, ERM, RII, CTI, ESI, KMI were significant factors affecting the high capital cost of prefabrication. Experienced paid more attention to the practical problems, and then focused on cooperation, management, and technical innovation. However, for inexperienced, APCI, ESI, POI, COI, SI, MII, TCI, DAI, DLI, DCI and COI were also important factors affecting the high prefabrication cost. Inexperienced stressed on the 'cost risk', 'opportunity cost' and 'sunk cost'. Inexperienced were likely to consider the risks and benefits when they choose the construction method, and paid more attention to the potential risks and expenses. This study found that different manager have different opinion on prefabrication, but the high capital cost was also the most important hindrance to prefabrication development.

CONCLUSION

Our study explored 49 factors affecting the high capital cost of prefabrication. The results revealed that 49 factors were divided into groups because of the different knowledge and experience. This results suggested that the experience was a moderator for prefabrication project management. The experienced paid more attention to practical problems while the inexperienced taken potential risks and expensive into account. Similar to practical problems, i.e. organization Coordination Index (OCI)', 'Construction Organization Index (COI)', 'Design Ability Index, the potential risk also become important, i.e. Additional Physical Consumption Index (APCI)', 'Economics of Scale Index (ESI)', 'Production Organization Index (POI)' etc. Our studies suggest that the government can make measures to solve practical problem to meet the need for the prefabrication and also eliminate risk to increase enthusiasm of potential investors.

Meanwhile, the findings emphasized the effect of cooperation among participants on cost management. The new project procurement model may suit for the prefabrication to strengthen cooperation in the industrial chain, such as Engineering Procurement Construction (EPC).

Design standardization is also the key factor to economies of scale and connection problems, which is line with the previous studies (Isaac et al. 2016). Others, this study found that the effect of the pilot projects is also important for potential investors to release the worries of the potential participants. Meanwhile, the government can provide subsidy for the investors to offset the additional cost to increase the enthusiasm for practitioners. This study provides practitioners and decision makers with valuable references to reduce high capital cost. Future research plans to explore the cooperation of the participants to promote prefabrication development. Meanwhile, the effect of policies need to be further explore.

ACKNOWLEDGMENTS

This research was partly supported by Project of the National Thirteenth -Five-year Research Program of China (2016YFC0701606). The authors are grateful to people who helped in undertaking the research and making improvements to this article. We would also like to thank the editors and reviewers of International Conference on Construction and Real Estate Management for their insightful comments on this research.

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"Energy-Economic-Environment" Assessment for Energy-Efficiency Techniques of Green Buildings

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ABSTRACT

The building sector generates significant energy and environmental footprints in a society, and green building techniques are being rapidly developed in China. However, the deployment of green building techniques is primarily prioritized by their initial economic costs, and their energy and environmental benefits are usually not considered. To facilitate robust deployments of green building techniques in China, in this study, we developed an energy-economic-environment assessment framework based on the e-QUEST building energy simulation tool and the data envelopment analysis approach, and a high-rise educational building in north China was selected for the case study, and five types of green building techniques were considered: the geothermal heat pump (GHP), solar photovoltaic system (SPS), rainwater collection and storage (RCS), external thermal insulation (ETI), and energy-efficient lighting (EEL). The results of the building under consideration show that ETI, SPS, and EEL have high priority for adoption, followed by GHP, and then RCS.

INTRODUCTION

Buildings are responsible for significant material and energy consumption in material societies. They account for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest, and two-fifths of its material and energy flows (Augenbroe et al. 1998). China's building-related energy consumption reached 1.66 billion tons coal equivalent in 2013, with a stable annual growth rate of 7% since 2001. Buildings' life-cycle energy accounted for approximately 43% of China's total energy consumption (Zhang et al. 2015). According to the statistics of the Intergovernmental Panel on Climate Change (IPCC), the building sector contributed a quarter of the global total CO_2 emissions. Furthermore, global CO_2 emissions generated from buildings increased at an average of 2.7% per year from 1999 to 2004 (Metz 2007). This figure is likely to increase because of the roaring demand for new buildings during the country's rapid urbanization. The National New Urbanization Plan (2014) projected that China's national urbanization rate will reach approximately 60% in 2020. Thus, we can infer that building energy consumption and environmental footprints play critical roles in achieving sustainable development in China.

Undoubtedly, green building techniques help to advance energy-efficient and environmentally friendly developments in China. Financial incentive schemes were developed by the government, aiming for at least 30% of annually constructed buildings being green by 2020 (Ministry of Finance and Ministry of Housing and Urban-Rural Development 2012).

However, the deployment of green building techniques is primarily prioritized by their initial economic costs. Zhang et al. provided a comprehensive review of the recent studies on the economic viability of "going green," including cost-benefit analyses from the perspectives of the building life cycle and the major market participants. While "going green" is more likely to be profitable throughout the entire building life cycle, the economic viability, from the perspective of developers and occupants, remains unclear because of information, behavioral, and policy factors (Zhang et al. 2017). Vyas and Jha (2017) outlined the potential benefits of the Indian government's green buildings and found that the average increase in the initial cost of green buildings was 3.1% for those with a three-star rating and 9.4% for the five-star-rated buildings, and such green investment is worthy in terms of environmental protection. Ziogou et al. (2017) examined the economic feasibility of green roof solutions, considering both the monetary and the environmental costs, and estimated an up to €40,000 increase in the building life-cycle cost, but the environmental and the economic benefits brought about by the green endeavors are difficult to quantify.

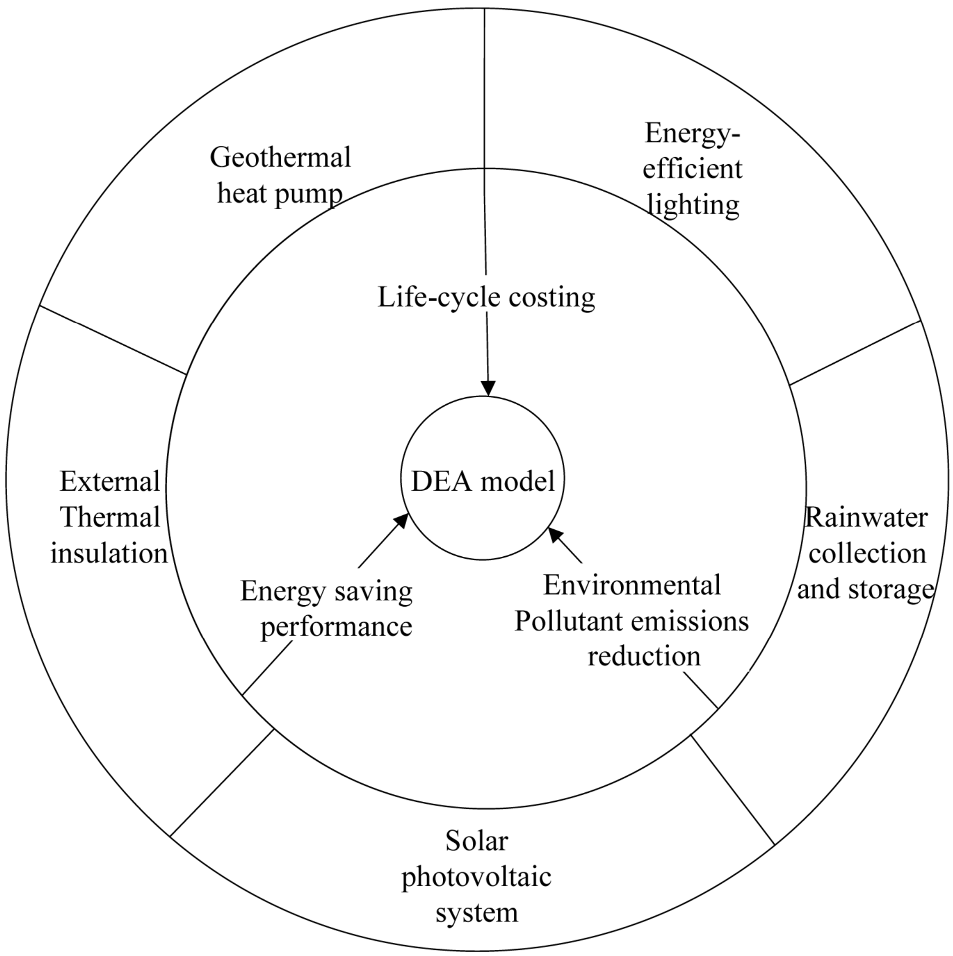

Figure 1. Study framework.

Thus, green building assessment is not new. However, considerations of energy and environmental benefits are usually lacking. To facilitate robust adoptions of the green building techniques in China, in this study, we developed an energy-economic-environment (3E) assessment framework based on the eQUEST building energy simulation tool and the data envelopment analysis (DEA) approach. A high-rise educational building in north China was selected for the case study considering five types of green building techniques: geothermal heat pump (GHP), solar photovoltaic system (SPS), rainwater collection and storage (RCS), external thermal insulation (ETI), and energy-efficient lighting (EEL). To some extent, the study results can help policymakers optimize the adoption of green building techniques through more holistic decision-making, including economics, energy, and the environment.

STUDY FRAMEWORK

To obtain the input-output efficiency of green building techniques and thus to identify the preferred order of green building technologies, we developed a hybrid DEA model to enable a comprehensive 3E assessment, as shown in Figure 1. The e-QUEST software and theoretical energy-saving calculations were used to simulate the reduction in the electricity consumption of green buildings as compared to that of conventional buildings.

For each energy-efficiency technique, the reduction of the pollutant gas emissions was represented by a greenhouse gas (with the unit of carbon dioxide equivalent). As the pollution reductions of the green technologies were mainly derived from the decrease in the electricity use during building operation, the GHG footprint of China's coal-fired electricity were referred to (approximately 980 kg CO_2e/kWh (Chang et al. 2015) because of their dominant share in the country's grid. The green techniques considered in this study were the GHP, SPS, RCS, ETI, and EEL.

The life-cycle costing (LCC) modeling approach was used to estimate the economic performance of five energy-efficiency techniques, including raw material extraction, equipment manufacturing, transportation, construction, and operation. The study period was 30 years.

The DEA method was used to measure the over efficiency of the green techniques to enable their prioritizations in adoption.

CASE STUDY

Case building: The case building in this study was an educational building in northern China. The total construction area of this building was 49166 m^2. It had 19 floors above the ground and 2 floors underground. The main functional areas in this building were the classrooms and the office room. Driven by the university strategy of green campus construction, this building adopted many green techniques to enhance energy efficiency.

Table 1. Annual Electricity Consumption by eQUEST.

Type of energy consumption	Annual electricity consumption (kWh)		
	Green building	Traditional building	Difference
EEL	637900	726600	88700
Cooling system	262500	313300	50800
Heating system	177500	194100	16600

Energy-economic-environment (3E) assessment: The specific calculation process of life-cycle costing, energy consumption saving, and environmental pollutant gas emissions reduction are shown in Figure 2. For the life cycle cost calculations, the indicator of the net present value (NPV) was used. Two methods were used for quantifying the energy savings, namely the eQUEST. software and theoretical engineering calculations. To be specific, the energy use of

GHP and EEL were simulated using the software tool, which yielded the energy consumption of the air conditioning system and the lighting system for both of the green and traditional buildings, as shown in Table 1. The energy savings of SPS were derived from the onsite metering data. The electricity saving of ETI was calculated using the thermal coefficient of the building's external envelop structure. The energy saving of RCS was estimated on the basis of the annual municipal water saving and was then converted to municipal energy savings, as shown in Table 2.

The environmental assessment of these five energy-efficiency techniques was performed to quantify the reduction in the environmental pollutant emissions. Based on the energy saving results as well as the emission intensity per unit of electricity generation in China, we derived the GHG mitigations of the five techniques, as shown in Table 2.

Table 2. Electricity Consumption Saving and CO_2e Reduction.

Techniques	Electric (kWh)	CO_2e (t)
GHP	67400	66052
SPS	64000	62720
ETI	67600	66250
RCS	212	208
EEL	88700	87000

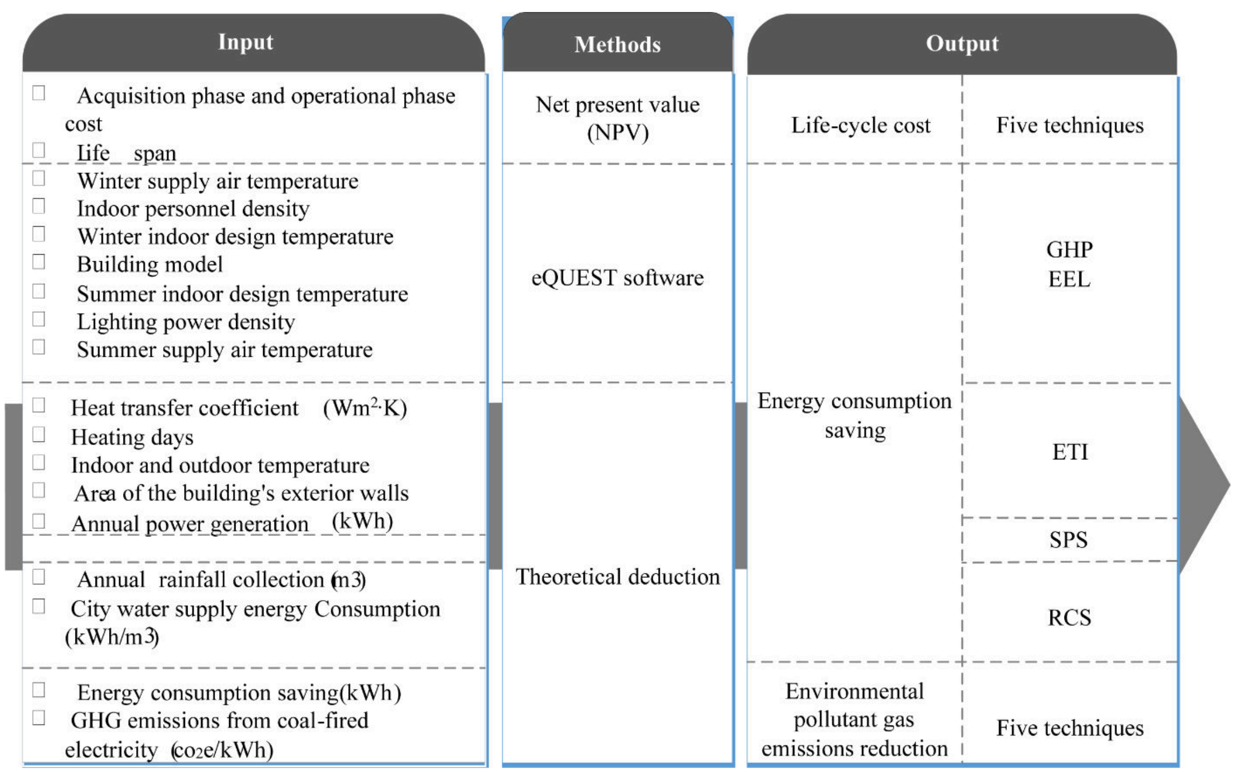

Figure 2.Calculation of technique performance in the case study.

The entire life cycle of each energy-efficiency technique was divided into three phases, namely the design, construction, and operation phases. We obtained the cost data of the green techniques from the related documents obtained from the university's owner, and calculated their net present value, as shown in Table 3. The discount rate was assumed to be 8%.

Table 3. Life-Cycle Costing of Energy-Efficiency Techniques.

Techniques	Life-cycle costing (Yuan)			
	Design phase	Construction phase	Annual operation phase	Npv
GHP	355500	14996060	526300	1615942
SPS	11850	500000	3328	7900
ETI	5925	250000	0	37251
RCS	98750	4166660	3030	20572
EEL	24100	1016760	331708	377092

Integrated assessment: DEA is a linear programming methodology to measure the efficiency of multiple decision-making units (DMU) when the production process presents a structure of multiple inputs and outputs. DEA was first proposed by Charnes et al. (1978) as the model called the constant returns to scale (CRS) model. Later, some experts changed the assumption of the constant returns to scale in the CRS model and proposed the variable returns to scale (VRS) model.

Assuming that there was data on K inputs and M outputs on each of the N firms or DMUs as they tend to be called in the DEA literature, we found that for the i-th DMU, these were represented by the vectors x_i and y_i, respectively (see Formula 1).

$$X_i = (x_{1i}, x_{2i}, \cdots x_{ki})',\ Y_i = (y_{1i}, y_{2i}, \cdots y_{pi})', i = 1, 2, \cdots, N, \quad (1)$$

where X is the K × N input matrix and Y is the P × N output matrix. Under the assumption of CRS, the relative efficiency of the i-th DMU was measured as follows (see Formula 2):

$$\max_{u,v}\left(\frac{u'y_i}{v'x_i}\right),\ \text{s.t.}\frac{u'y_i}{v'x_i} \le 1,\ j = 1, 2, 3, \cdots, N,\ u, v \ge 0 \quad (2)$$

where u and v are the output weights of the P × l order and K × 1 order input weight vectors, respectively. The array was transposed while increasing the constraint v'xi = 1, to avoid an infinite number of solutions, which provided the following (see Formula3):

$$max_{u,v}\left(u'\,y_i\right),\ \text{s.t.v'x}_\text{i} = 1, i = 1, 2, 3, \cdots, N,\ \text{u}'y_i - v'x_i \le 0,\ \text{u}, v \ge 0 \quad (3)$$

Using the duality in linear programming, we derived an equivalent envelope form of this problem (see Formula 4):

$$max_{\theta,\lambda}\theta\ ,\ \ \text{s.t.} - y_i + Y\lambda \ge 0, i = 1, 2, 3, \cdots, N,\ \ \theta_{x_i} - X\lambda \ge 0, \lambda \ge 0 \quad (4)$$

where θ is a scalar constant and λ is an N × 1 vector of constants. The linear programming problem was solved N times, once for each DMU in the sample. The value of θ was then obtained for each DMU.

However, the CRS assumption was only appropriate when all of the DMUs were operating at an optimal scale. There are still many situations that may cause a DMU to not operate at the optimal scale. To establish the VRS model, the convexity constraint $N_1^{'}\lambda = 1$ was added to (4). Thus, the CRS model was transformed into the VRS model as follows (see Formula5):

$$\begin{aligned} &max_{\theta,\lambda}\theta,\ \ \text{s.t.} - y_i + Y\lambda \ge 0,\ \ \theta_{x_i} - X\lambda \ge 0, \lambda \ge 0, \\ &N_1{'}\lambda = 1,\ N_1 \text{is an } \text{N} \times 1 \text{ order unit vector} \end{aligned} \quad (5)$$