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An optimization model for selecting the optimal green systems by considering the thermal comfort and energy consumption

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HIGHLIGHTS

- An optimization model for selecting the optimal green systems was developed.
- Thermal comfort, energy, LCC & LCA were used to select the optimal green systems.
- A total of 27 types of the green systems by roof, wall, and roof/wall were designed.
- The optimal green systems were determined from more than 51 billion possible scenarios.
- The model can be used as a decision making tool for the green systems' implementation.

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ABSTRACT

The green systems ensured a green space, improved the thermal comfort of the residents by making the seasonal indoor temperature pleasant, and saved energy in buildings. This study aimed to develop an optimization model for the optimal green systems by considering the thermal comfort in and energy consumption of an educational facility. In addition, the optimal design scenarios were analyzed considering their economic and environmental effects. The study was conducted as follows: (i) selection of the design variables and objective function; (ii) optimization of the green systems; (iii) comparative analysis of the standard and optimal designs; and (iv) economic and environmental assessment of the optimal design scenarios. In order to compare the thermal comfort of the green systems with that of the existing building, this study used the percentage of predicted dissatisfied (PPD) which is the thermal comfort index based on Fanger's model. The implementation of the green systems improved the thermal comfort by 0.18–2.18% in terms of PPD, and reduced the energy consumption by 0.02–11.00%. The economic and environmental effects of the optimal green systems also showed up to 12.62% and 18.36% reductions, respectively. Thus, the implementation of the green systems was effective in terms of thermal comfort, energy consumption, life cycle cost, and life cycle assessment. This study could help the potential green systems users establish the optimal green systems in terms of thermal comfort, energy consumption, and the economic and environmental effects.

1. Introduction

Due to the recent rise in greenhouse gas (GHG) emissions, the issues related to global warming and serious climate changes are increasing [1–3]. As such, many countries are making an effort to reduce their GHG emissions. As part of such efforts, the South Korean government is promoting an increase in green spaces in the urban areas but finds it difficult to secure land that would allow green spaces. At present, the urban parks and green spaces in Seoul amount to 4.54 m^2/person, which is considerably lower than London's 27 m^2/person, New York's 23 m^2/person, and Paris's 13 m^2/person [4,5]. Seoul is thus proactively promoting the implementation of the green systems in buildings. The green systems in a building can be either the green roof systems or the green wall systems, and have the following advantages [6–12]: (i) energy consumption reduction; (ii) urban heat island effect; (iii) air pollution mitigation; (iv) water management; (v) sound insulation and noise reduction; and (vi) ecological preservation [13–16]. To analyze such effects, various researches have been conducted on the green systems: (i) researches on the thermal comfort in and energy

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Table 1
Design variables of green systems scenarios.

Category	Scenario number	Value	Design variables (adjustable parameters)			
			Plant height (m)	Leaf area index	Stomatal resistance (s/m)	Soil thickness (m)
Green roof systems	R1	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.01	1.28	145	0.15
	R2	Standard design	0.15	2.50	180	0.15
		Range of adjustable parameters	0.01–0.15	0.001–2.50	50–300	0.1–0.30
		Optimal design	0.07	1.42	180	0.29
	R3	Standard design	1.00	3.00	180	0.30
		Range of adjustable parameters	0.01–1.00	0.001–3.0	50–300	0.20–0.50
		Optimal design	0.27	1.82	280	0.50
	R4	Standard design	1.00	3.50	180	0.45
		Range of adjustable parameters	0.01–1.00	0.001–5.0	50–300	0.30–0.70
		Optimal design	0.03	1.63	170	0.70
	R5	Standard design	1.00	5.00	180	0.50
		Range of adjustable parameters	0.10–1.00	0.001–5.00	50–300	0.50–0.70
		Optimal design	0.04	2.22	181	0.70
	R6	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.36	2.00	180	0.15
	R7	Standard design	0.15	2.50	180	0.15
		Range of adjustable parameters	0.01–0.15	0.001–2.50	50–300	0.1–0.15
		Optimal design	0.03	1.31	170	0.15
	R8	Standard design	1.00	3.00	180	0.30
		Range of adjustable parameters	0.01–1.00	0.001–3.0	50–300	0.20–0.30
		Optimal design	0.45	1.84	120	0.30
	R9	Standard design	1.00	3.50	180	0.45
		Range of adjustable parameters	0.01–1.00	0.001–5.0	50–300	0.45–0.50
		Optimal design	0.35	2.29	180	0.50
	R10	Standard design	1.00	5.00	180	0.50
		Range of adjustable parameters	0.10–1.00	0.001–5.00	50–300	0.50–0.70
		Optimal design	0.35	2.29	180	0.70
	R11	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.37	2.00	180	0.15
	R12	Standard design	0.15	2.50	180	0.15
		Range of adjustable parameters	0.01–0.15	0.001–2.50	50–300	0.1–0.30
		Optimal design	0.09	1.80	150	0.23
	R13	Standard design	1.00	3.00	180	0.30
		Range of adjustable parameters	0.01–1.00	0.001–3.0	50–300	0.20–0.50
		Optimal design	0.66	2.32	130	0.5
	R14	Standard design	1.00	3.50	180	0.45
		Range of adjustable parameters	0.01–1.00	0.001–5.0	50–300	0.45–0.70
		Optimal design	0.38	2.52	179	0.70
	R15	Standard design	1.00	5.00	180	0.50
		Range of adjustable parameters	0.01–1.00	0.001–5.00	50–300	0.50–0.70
		Optimal design	0.37	2.50	185	0.70
Green wall systems	W1	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.11	0.002	290	0.15
	W2	Standard design	0.15	2.50	180	0.15
		Range of adjustable parameters	0.01–0.15	0.001–2.50	50–300	0.1–0.30
		Optimal design	0.01	0.001	300	0.3
	W3	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.01	0.99	81	0.14
	W4	Standard design	0.15	2.50	180	0.15
		Range of adjustable parameters	0.01–0.15	0.001–2.50	50–300	0.1–0.15
		Optimal design	0.07	1.20	165	0.15
	W5	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.02	1.07	120	0.14
	W6	Standard design	0.15	2.50	180	0.15
		Range of adjustable parameters	0.01–0.15	0.001–2.50	50–300	0.1–0.30
		Optimal design	0.01	1.15	180	0.3
Green roof/wall systems	RW1	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.13	1.07	90	0.15
	RW2	Standard design	0.15	2.50	180	0.15
		Range of adjustable parameters	0.01–0.15	0.001–2.50	50–300	0.1–0.30
		Optimal design	0.01	0.001	300	0.30
	RW3	Standard design	0.10	2.00	180	0.10
		Range of adjustable parameters	0.01–1.00	0.001–2.00	50–300	0.10–0.15
		Optimal design	0.22	0.95	74	0.14

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